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Impact of New Irrigation Technology on the Texas High Plains: 1980-2020

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ABSTRACT

Crop production on the Texas High Plains is constrained by limited and erratic rainfall, hence irrigation is important. Presently, 6 million acres, or 50% of regional cropland, are irrigated annually. Irrigation water is drawn from the Ogallala Aquifer, which has a recharge rate near zero, and is being depleted at the present rate of use.

Future crop production is dependent on technology, as well as the resources available. Because water is a major limiting resource, technologies that increase plant available water, such as advanced irrigation distribution systems and soil moisture conserving tillage methods, are of particular interest, and are the focus of this study.

Two levels of analysis were included. The first, a farm level analysis based upon representative counties showed the similarities and differences of response given particular resource endowments, technological options and price situations. Part of the analysis considers the impact of annual groundwater withdrawal constraints on discounted net present value for a forty year planning horizon. The discounted net revenue was higher for lower discount rates, better commodity prices, and more advanced technology. However, alternative discount rates, prices, and technology did not change the optimum annual withdrawal limit. Lower initial groundwater resources reduced the revenue level and the optimal annual groundwater decline limit.

The other part of the farm firm analysis covers expected costs, returns and cropping patterns for a single period. Prices have a significant influence on production, but a far greater impact on net returns.

The value of production is 64% to 85% higher for normal prices versus low prices, while net returns are from 8 to 30 times higher. The amount of available groundwater was not as important as price in the determination of production levels, but it too had a significant impact on net returns. Comparing across representative counties, with prices, technology and groundwater situations held constant, the value of production varied more than $150 per acre, but net returns changed very little. The value of production increases 17% with advanced technology, but net revenue more than doubles.

The second level of analysis, a regional analysis, addressed expected changes in cropland use, groundwater pumpage, production levels, input demand, and farm income over the next forty years, under select technology and price assumptions. Water availability and hence use, drops over time, reducing irrigated cropland, gross returns and net revenue. The demand for other inputs does not decline as quickly as water usage, indicating input substitution. Further, the decline in net revenue is greater than the reduction in gross returns or variable costs of production. The intensity of crop production declines and the mix of crops changes, reducing purchased input demand and lowering regional farm income.

Advanced technology enhances the value of the groundwater resource, increasing water use especially in the later periods of the time horizon. Nontheless, over the whole 40 years, technologies which improve dryland, as well as irrigated, crop production, such as limited tillage and crop rotations, have a greater impact than advanced irrigation technology.

While advanced technology enhances productivity and increases net returns, technology is not a substitute for irrigation. Nor does technology save groundwater resources in the large, since the increased value of the water, given advanced technology, encourages greater use, overall. Advanced technology, however, is important to the future of crop production in the region, since it increased the level of production, and net revenue. Further, the impact of technology was proportionally greater under the low commodity price scenarios than for average prices.

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CHAPTER I

INTRODUCTION

Over the last century world population has increased several fold and continued growth is projected well into the next century. Per capita income is also projected to grow, which implies that the worlds output of goods and services will increase at a rate even faster than population growth. Given the finite amount of natural resources on the earth, some attention to the future availability of these resources is required (Meadows, et al.).

Among the needs of an increasing population clearly one of the most fundamental is for the food and fibers that have been the traditional products of agriculture. These needs may be expected to increase at least as fast as population expands, since nutritional needs are constant within a narrow band. However, the more likely situation is for agricultural production to increase at a rate faster than population growth. This is because many people are presently malnourished and if there is, as projected, an increase in per capita income, then one would expect an increase in food demand that is larger than the population change.

Despite the increased demand, if production is actually to increase, resources must be available. Certain of the resources necessary for traditional agricultural production (land, water and fossil fuels) are available only in fixed, finite amounts, and another key input, solar energy, while essentially unlimited, arrives in fixed amounts per unit time. Furthermore, these resources have other, competing uses. Thus, increased production may only be possible if usage of some production inputs can be reduced, at least relative to other inputs.

If decreased use of certain inputs is to be possible, use of other inputs must increase or production efficiency must be improved. Production efficiency in static economic analysis is taken as a given. Knowledge concerning the production process is assumed to be freely available, costless to implement and used to the best advantage. It is also assumed changeless within the period of analysis. Over a longer time horizon these assumptions are no longer valid. Knowledge becomes a commodity that can be increased by research and other forms of human capital investment. Therefore, in the long run production efficiency is the result of capital formation analogous with other capital goods, and can be substituted for them or other inputs in the production process.

Thus, the broad future mandate for agriculture is to increase total production while reducing the utilization of traditional fixed inputs on a per unit output basis, and perhaps on an absolute basis if enough resources can be shifted to alternate uses. The efficiency of agriculture production processes must continue to improve, accelerating the shift toward human capital using technology.

Objectives

This study will investigate possible changes in Texas High Plains agriculture over the next twenty to forty years. Changes in the technology of crop production, the levels of input usage and the types and quantities of commodities produced will be of particular interest. Agriculture in the Texas High Plains region was chosen because the area is an important agricultural producing region of Texas, where the costs of production per unit of output are high and the production technology in use over the last twenty years cannot be sustained in the future. Groundwater resources, which have been the basis for that technology, are being depleted. Thus, it is certain that technology will change or as the groundwater is exhausted present levels of irrigation will no longer be physically, or more likely, economically feasible. Unless something is done the impact will be a dramatic reduction in agricultural output affecting producers, and the local and regional economics. The question then becomes what transformation paths are available to the region and how to choose among them. Given exogenously set input supply prices and commodity demands, certain changes will be more attractive than others. Within the set of possible transformations this study will concentrate on those that are economically optimal from the farmers viewpoint, that is, those maximizing net revenue in the short or long run.

To accomplish the general objective the following specific tasks will be set:

1. Inventory the natural resources in the region involved in agriculture. Agricultural production requires land, water and solar energy along with other variable inputs. For High Plains agriculture, land, solar energy and that part of the water requirement derived from rainfall, are fixed geographically. Besides crop agriculture, these resources have other potential uses from wilderness or hunting areas to cattle range, all the way to urban uses. On the High Plains, due to its location and climate, most of the area does not have a higher value alternative than crops, so crop agriculture need only compete with range.

The climate of the region is semi-arid, limiting natural vegetation and crop growth due to limited annual and seasonal water availability. There are no significant sources of surface water with which to supplement the limited rainfall but much of the area overlays the Ogallala aquifer. This aquifer is a major natural resource on which the present level of crop agriculture in the area depends (Black). Unfortunately the Ogallala is limited in volume, has little to no recharge and is uneven in its distribution under the area (Texas Water Development Board). Both the depth to the top of the aquifer and the saturated thickness varies significantly across the region.

The quality of the land resource also varies, with different soil depths, textures and slopes (Blakeley and Koos). This, combined with changes in latitude and rainfall, leads to multiple microclimates with significantly different production characteristics.

2. Set the price relationship for variable inputs and crop commodities. Since the High Plains is only one region in a much larger integrated national economy, those items that move in trade within the economy are priced mainly external to the region. Thus, it can be assumed that changes in production levels within the region will not have a significant impact on general price levels. The present (1982) prices for inputs in the region will be used as the base since variable input prices are much more stable than commodity prices. This is because many variable inputs have a wider market than just agriculture, their supply

is not as subject to weather and other uncertainties and any oversupply can be kept in inventory. While input price stability is generally true, it is recognized that the relative price of specific inputs, energy being the most recent example, can shift rapidly.

Commodity prices are much more volatile than input prices. Thus, average prices over a period of time may provide a better guide to expected price than current price. However, when dealing with prices over time, the impact of inflation must also be considered. Because the level of inflation varies from year to year, it is important to deflate the nominal price for any given year to obtain an average of the real value of the commodity over time.

3. Investigate the technology presently in use on farms in the region, that which is being introduced now and that which is under development at agricultural research centers.

Technology in the wide sense is defined as the science or study of the practical arts or as the pool of knowledge concerning how to accomplish some task. Technology as a concept can be used to mean the whole knowledge pool in a particular industry or it can refer to some average or most common way of doing something . At times technology is also used to refer to a particular production procedure or even to specific machinery. To avoid this confusion, this study differentiates between technique, production activity, and technology. Technique shall be used to refer to a particular process or method to accomplish a narrowly defined task such as soil preparation, crop irrigation, land improvement, etc. Crops are produced by a sequence of these operations or techniques. A production activity is defined as a unique set of techniques to produce one acre of a specified crop. From an economist's point of view, a production activity is a combination of inputs (V_1, V_2, ..., V_m) used to produce some combination of outputs (Y_1, Y_2, ..., Y_n). The combinations are called technical coeffients and define the amount of inputs used and outputs produced from a unit level of the activity. Technology shall be used to refer to the complete set of production activities available in the region and to the set chosen as optimal for a particular situation.

The particular set of farming techniques, which predominate in the region at this time will be considered the base. The innovative practices that are being tried by the better managers in the region are considered indicative of the possible technology of the near future. This broad set of techniques, with at least some field testing, will be used to define a large part of the choice set of future technology. Experiment stations and research organizations are also active in the region developing technology based on the latest results of basic research. These techniques will also be considered in the choice set, even though the technical coefficients for them are not known with complete certainty. Data from these three sources are assumed to include most of the technology that will be available for adoption and use in the region over the projected forty-year time horizon of this study.

4. Develop methodology to replicate farm production decisions shaped by limited natural resources, exogenous prices and changing technology. A combination of computer simulation and optimization techniques are used to analyze the economic ramifications of new technology and changing input and commodity prices given a defined resource situation. Fortran subroutines were developed to generate production activities for the region under different technology and price scenarios. The IBM MPSX linear programming optimization routine was then used to solve for

combinations of crop and resource use that maximize revenue minus the variable costs specified.

The Study Region

The High Plains region of Texas (Figure 1) is a nearly level to undulating semi-arid area encompassing approximately 35,000 square miles in 42 counties. The region is mainly agricultural, producing cattle, cotton, wheat and feed grains. In 1981 approximately 96% of the land area was farm and ranch land, and of that 43% was planted to crops. Over five million acres were irrigated which amounted to 68% of the irrigated land in the state and 22% of the farm and ranch land in the district. Regional crop production, by value, averaged approximately 40% of the state total for the 1972-1981 period. In 1981 High Plains crop production equaled 1.69 Billion dollars, while total agricultural cash receipts were 2.76 Billion dollars (Texas Crop and Livestock Reporting Service 1972-1981a).

The climate of the region is characterized by low and erratic precipitation, wide daily and seasonal temperature variations, moderately high wind velocities and low relative humidity. As can be seen in Figure 1, average annual precipitation declines as one travels west and south in the region. At approximately the center of the region (Amarillo) the annual rainfall ranges from 8 to 31 inches with an average of 18.7 inches. The rain comes mainly in the summer months as intense local showers (U. S. Department of Commerce). The monthly average ranges from .56 inches in November and January to 2.83 inches in May. At Amarillo temperatures have been recorded from 115 degrees F. to less than -10 degrees F. with an average monthly maximum of 91 degrees F. in July and monthly average minimum of 21 degrees F. in January. Average annual wind speed is 13.7 miles per hour with monthly averages ranging from 15.6 m.p.h. in March to 12.1 m.p.h. in August. Annual pan evaporation measured over a 30 year period at the U.S. Department of Agriculture's Southwestern Great Plains Research Center, Bushland, Texas averaged 53.25 inches indicating that potential evaporation is far greater than annual precipitation. The frost free growing period for the region varies from 165 to 224 days with an average of 193 days at Amarillo (Johnson and Davis).

The limited rainfall restricts the type and yield of crops severely unless irrigation water can be applied. With irrigation not only can humid zone crops such as corn and soybeans be grown, but the yield of dryland crops such as wheat, sorghum and cotton can be increased several fold. Average annual crop acreages and yields for crop reporting districts 1N and 1S, which coincide, by and large, with the High Plains region, are given in Table 1. As shown in Table 1, in the 1972 to 1981 period, over 3 million acres of cotton, 2.8 million acres of wheat and 2.3 million acres of sorghum were planted annually. This represented over 55% of upland cotton, 53% of wheat and 44% of grain sorghum produced in Texas. More importantly, of statewide irrigated production, the region accounted for 77% of cotton, 91% of wheat and 84% of grain sorghum. Further, the region was responsible for 77% of the state corn production, 32% of soybean and 92% of sunflowers produced. Thus, irrigation, while not absolutely essential for crop agriculture to exist in the

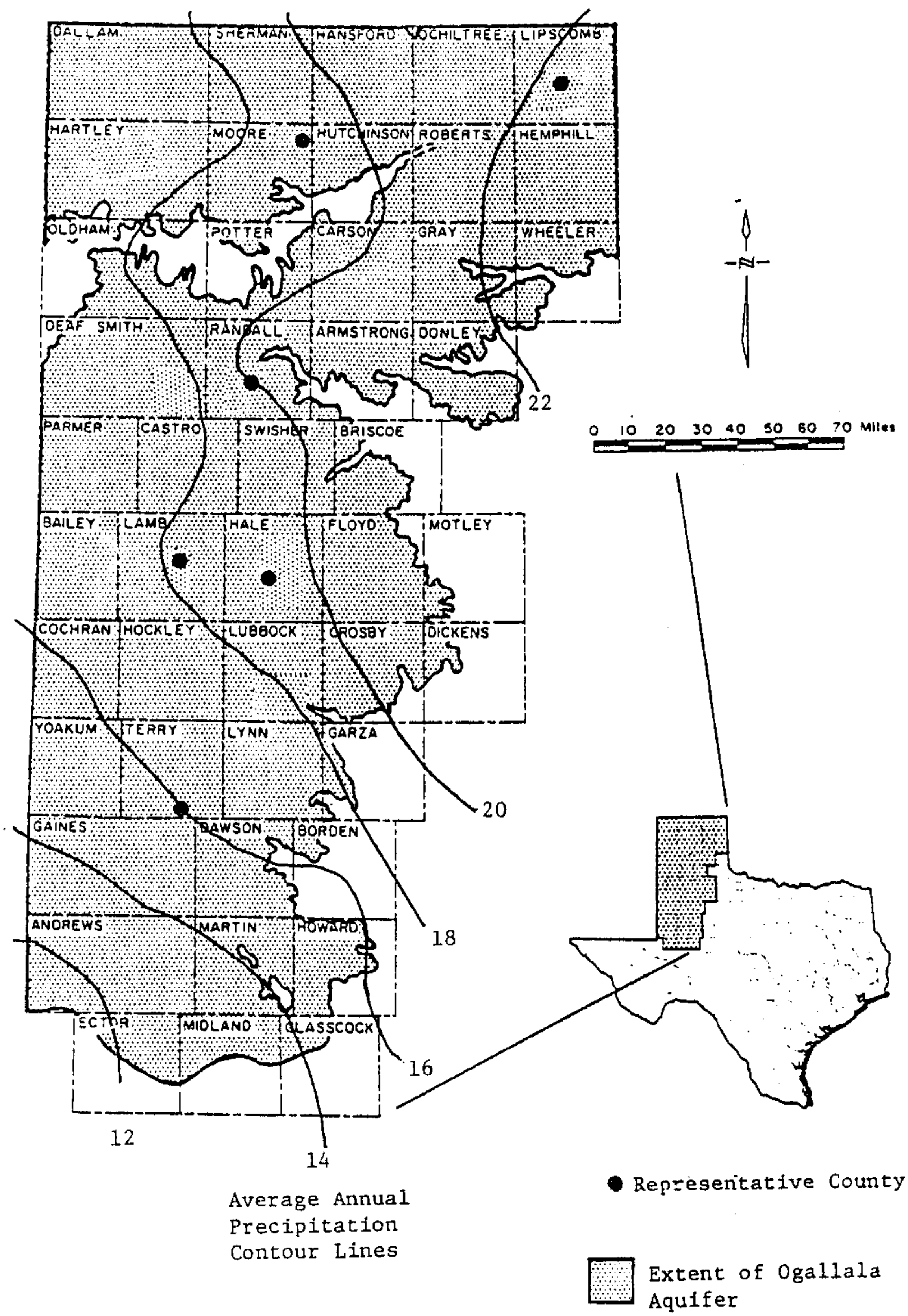


Figure 1. Map of the Study Region

Table 1. Average Annual Crop Totals (1970-1981), Texas Crop Reporting Districts 1N & 1S: Texas High Plains

Crop		Planted Ac	% of State	Yield per Planted Ac	Harvest Ac	% of State	Yield per Harvest Ac	Production	% of State
Cotton	Total	3,238,358	53.69	318.6 lb	2,933,890	53.29	351.69 lb	2,149,624 bale	55.37
	Irrigated	1,751,315	81.07	379.2 lb	1,634,260	80.28	406.34 lb	1,383,485 bale	76.80
	Dry	1,487,043		247.3 lb	1,299,630		282.96 lb	766,139 bale	
Wheat	Total	2,890,683	52.00	17.6 bu	1,985,192	51.11	25.55 bu	50,719,000 bu	53.46
	Irrigated	1,018,266	89.34	29.9 bu	816,446	89.98	37.27 bu	30,432,774 bu	90.63
	Dry	1,872,417		10.8 bu	1,168,746		17.36 bu	20,286,226 bu	
Sorghum	Total	2,268,758	34.79	3,149.4 lb	2,013,783	36.95	3,548.13 lb	71,451,683 cwt	43.69
	Irrigated	1,281,183	78.72	4,646.5 lb	1,229,925	79.93	4,840.15 lb	59,530,233 cwt	83.94
	Dry	987,575		1,207.1 lb	783,858		1,502.87 lb	11,921,450 cwt	
Corn		708,050	61.22	111.8 bu	629,200	61.27	125.76 bu	79,127,009 bu	77.49
Soybeans		114,083	23.91	30.4 bu	111,601	25.29	31.06 bu	3,466,809 bu	31.62
Sunflowers		119,600	92.00	778.1 lb	105,291	92.01	883.84 lb	93,060,900 lb	92.14

Source: Texas Crop and Livestock Reporting Service (1972-1981a).

region, allows a much greater production intensity, increasing average yields per harvested acre for cotton from 283 lb/ac to 406 lb/ac, for wheat from 17.4 bu/ac to 37.3 bu/ac, and for grain sorghum from 1,503 lb/ac to 4,840 lb/ac. With the new, high yield wheat varieties, irrigated yields in excess of 60 bu/ac are now common (Harman).

The irrigation water used on the High Plains is pumped principally from the Ogallala aquifer. The Ogallala formation (the gray shaded area, Figure 1) is an unconsolidated aquifer beneath much of the Great Plains from southern South Dakota to a few miles north of the Pecos River in Texas. The sediments that compose the formation are believed to have been eroded from the Rocky Mountains and deposited in the eroded and dissected surface of the pre-Ogallala rocks ranging in age from Permian to Cretaceous. After the gullies and folds in the base rock were filled, streams continued to shift and deposit sediment over the area until thicknesses up to several hundred feet were laid down. The result is a very extensive aquifer, but one that varies substantially in distance from the surface, saturated thickness, and coefficient of storage. The aquifer underlies more than 20 million acres of Texas and holds 340 million acre-feet of water in storage (estimated 1974, Muller and Price), of which 282 million acre-feet is considered technically recoverable. Saturated thickness ranges from less than 50 ft. in the Southern High Plains to over 400 ft. in some areas north of the Canadian River. The Canadian River has effectively separated the Ogallala into two units having little hydraulic connection. Further, there is only a narrow connection to the north at the Beaver River in the Oklahoma Panhandle. As a result both Northern and Southern High Plains are virtually hydraulically independent. This, coupled with the scarcity of rainfall has resulted in recharge rates estimated between a fraction of an inch to .8 inches, much less than present withdrawal (Wyatt, Bell and Morrison 1976a).

Irrigation on the High Plains began as early as 1911 but development of the groundwater resources progressed very slowly until 1935. Drought in the mid 1930's coupled with improved pumping equipment stimulated increased growth. After World War II, and particularly during the drought of the 1950's, irrigated acreage expanded at an unprecedented rate. Easily obtained financing, and improved pumping equipment, allowed the area to develop rapidly. Currently, development is continuing on the Northern High Plains. In other areas, particularly specific locations in the south and where the saturated thickness was thin initially, the aquifer is essentially depleted and cropping has reverted to dryland or very limited irrigation. Overall irrigation development on the High Plains reached a peak during the 1974-1977 period. To what extent, or at what rate irrigation development will change in the future depends on rainfall, energy prices, crop prices and water availability (Texas Department of Water Resources). There were 77,000 irrigation wells on the High Plains in 1976, 38% of which were powered by electricity, 59% natural gas fueled and the remainder diesel driven (Texas Crop and Livestock Reporting Service 1976).

For the Northern High Plains alone, there were 35,000 irrigation wells in 1976, 24% electric powered and 73% driven by natural gas fueled engines (New 1976). Seventy three percent of the wells produced less than 700 gallons per minute and the pump lift was greater than 125 feet for more than 98% of the wells (New 1977). By 1980 the number of operating wells had dropped to 32,500 and electric power had increased to 31% of the pumping systems (Texas Crop and Livestock Reporting Service

1981c).

Table 2. Irrigation on the High Plains: Selected Years, 1958-1980

Year	Acres Irrigated (000)	Acre-feet Applied (000)	Acre-feet Per Acre	Explanatory Variables[a] Relative Rainfall North	Relative Rainfall South	Parity Ratio
1958	4502	5133	1.14	115	91	76
1964	5039	7645	1.52	86	77	75
1969	5468	6393	1.17	112	157	73
1974	5895	8051	1.37	114	128	87
1979	5385	5707	1.06	101	110	82
1980	5547	7060	1.27	66	84	76

[a] Relative Rainfall: Percent of Yearly Norm, North = Amarillo, Texas; South = Lubbock, Texas. Parity Ratio = Texas Prices Received Index for all Crops / Prices Paid Index for Commodities, Wages, Taxes and Interest.

Sources: Texas Crop and Livestock Reporting Service (1962-1981); Texas Department of Water Resources (1981b).

Table 2 illustrates the irrigation situation for the last 20 years. Irrigated acreage and groundwater pumpage continued to expand into the early 1970's with some variation due to weather and market opportunities. Irrigated acres peaked in 1974 at 5.9 million and have been relatively steady for the last 10 years. Pumpage has been much more erratic, trending upward over the long run but varying from year to year. Though there are not enough observations to test statistically, possible explanatory variables include the amount of rainfall, and profitability of crop production. In 1964 and 1980 dry conditions resulted in large irrigation applications both per acre and as total pumpage. Irrigation is less in other, wetter years except 1974 where exceptional profitability apparently led to extra irrigation in spite of generally favorable precipitation.

Review of Literature

There are two areas of research that are of particular relevance for the present study. The first has to do with engineering and agronomic research on improving the technical aspects of crop production especially under semi-arid conditions. The second pertains to previous economic studies of the High Plains, in particular those dealing with the groundwater situation or changing technology.

Agronomic and Engineering Studies

The limiting factor for agricultural production in most semi-arid regions is water. As such, most production techniques adapted for use in these areas have as either their primary or collateral goal the technical or physical efficient use of available water. For water to be used efficiently in a technical sense, it must be available to the crop at the right time, in the right amount and without excessive waste. At the same time, economic efficiency is a direct function of the cost of water. In attempting to satify both these efficency requirements, various water conservation and irrigation application techniques have been devised.

Water conserving techniques. The purpose of water conservation techniques is to maximize crop production by minimizing the amount of water that is lost to the crop production system. To do this, as much of the water as possible that arrives on the field as precipitation or irrigation must be kept in the root zone as soil moisture. The major avenues of loss are runoff, evaporation and percolation.

Runoff can be reduced by changing the topography of the land either overall, by leveling and terrace construction or in the small by tillage practices. Young and Merrick, in an analysis of the economic value of terrace construction and use on the Southern High Plains, found that parallel terraces were profitable for nearly all moderately sloping soils, while bench terraces showed a positive return, especially with irrigation. Returns for fine textured soil were shown to be greater due to additional runoff conservation and increased irrigation field efficiency. The size of benefits accrued to terracing was found to be a function of the type of terrace, crops grown, irrigation applied, soil type and original slope. They estimated terrace rainfall conservation to range from .02 to 2.74 inches per year with an additional savings of from 2.99 to 5.02 inches of irrigation water on bench terraces.

In a 1975 study, Jones and Shipley compared the economics of conservation and contour bench terracing for dryland grain production. They found that terraces not only increased the average yield but also reduced variability and on steeper slopes (greater than 2%) reduced soil erosion. The lower construction costs of conservation bench terraces gave them an economic advantage over the level interval bench terraces studied.

A further study at the Great Plains Research Center, Bushland, Texas (Jones 1981) compared mini-bench terraces, improved furrows and conventional furrows for effectiveness in preventing runoff, controlling erosion, storing water and increasing grain sorghum yields. Over a four year period (1974-1978) improved furrows - extra wide and Orthman - increased average water use efficiency by 34% to 40% and dryland grain sorghum yields 51% to 59%. Mini-bench terraces demonstrated average water use efficiencies 51% to 71% greater than conventional graded furrow with 70% to 98% higher yields. All tested land forming systems were shown to be effective in preserving precipitation and preventing runoff. The superior performance of the mini-bench terraces were attributed to less soil water evaporation due to tillage since a smaller volume of soil was disturbed in the flat-tillage terraces than with furrow tillage.

Another landforming technique that is returning to use after being developed in the 1930's and nearly abandoned by 1950, is micro-basins or furrow dams. The original intent was to control wind erosion and save water during fallow periods but poor weed control, difficulty with dam emplacement, seed-bed preparation and tillage, and inability to demonstrate yield increases, led to their abandonment in favor of stubble-mulch tillage, terracing and other conservation practices (Clark). With present day advances in machinery, chemical weed control, and changes in usage (from fallow periods to dryland and irrigated summer crops) furrow dams have been shown to be effective in reducing runoff and increasing both soil moisture and crop yields. In dryland grain sorghum trials at Bushland, Texas (1975-1977) from .7 to 3.3 inches of additional rainfall was retained on the field, increasing yields from 25 to 40% (Clark). Dryland cotton studies have shown increases of 11% to 25% (Runkles).

A great deal of research concerning reduced and no-tillage cropping systems have been conducted in recent years. A review of conservation tillage systems (Unger and McCalla) listed the goals of these systems as: plant residue management for water and wind control, reduced energy use, and conservation of soil and water.

The value of surface residue in controlling wind and water erosion has long been recognized. The need to control soil erosion by wind particularly in the drier portions of the Great Plains during the drought of the 1930's led to development of stubble-mulch farming. Stubble-mulch tillage which is the basic tillage method in many dryland areas at the present time was an early form of limited tillage (Unger and McCalla). Johnson and Davis reported long term (25 years of data) wheat yield gains of 17% using stubble-mulch tillage compared to one-way tilled, continuous wheat.

Managing wheat residue to keep it on the surface has been shown to increase precipitation storage from 40% to 80% (Greb, Smika and Black; Unger 1972; Unger, Allen and Weise). Grain yields for subsequent crops increased 16% to 38%. In a more recent study (Unger 1978), straw mulch rates from 1 to 12 metric tons per hectare increased fallow precipitation storage from 2.7 cm to 7.5 cm, resulting in subsequent sorghum grain increases from 630 kg/ha to 2210 kg/ha.

Minimum tillage has been shown to be effective in the control of wind and water erosion (Zingg and Whitfield; Unger and McCalla) and in reducing air and water pollution (Unger and Box). Further, both labor and machinery requirements can be reduced by limiting tillage operations (Allen, Musick and Weise; Unger, Allen and Parker).

Other water conservation techniques widely practiced include rotating crops (Unger 1972; Unger 1981; Unger and Weise), closely matching cropping intensity to use all available water (Unger 1977; Stewart, Dusek and Musick) and staggering planting dates (Unger 1980; Musick and Dusek 1980).

Irrigation application techniques. Crop production is possible in the High Plains without irrigation, but irrigation allows much greater production levels. Nonetheless, because irrigation is a major user of energy, constitutes a large portion of the variable cost for irrigated crops, and is depleting a non-renewable resource (groundwater), research on improving efficiency of pumping and application continues. Statewide, on-farm irrigation water use efficiency (amount of irrigation water stored in soil for plant use versus amount of water applied) is estimated to be about 60% to 70% (Wyatt). Using advanced techniques efficiencies up to 98% have been demonstrated (Lyle and Bordovsky).

There are two main types of irrigation systems used on the High Plains; flood or furrow irrigation, installed mainly on "hardland soils", and sprinkler systems that predominate on "mixed" or "sandy" soils. Techniques designed to increase the efficiency of furrow irrigation include: alternate furrow irrigation, furrow diking, surge flow and automated furrow systems. Alternate furrow application permits reduction in irrigation size and coverage of a larger area in a timely manner. It results in greater lateral water movement in the soil and reduced deep percolation losses. Research by Musick and Dusek (1974) indicated alternate furrow irrigation had little effect on water intake and yields on Pullman silty clay loam soil but significantly reduced both intake and yields of sugar beets and grain sorghum on Pullman clay loam. Cotton yields were not signifcantly different, but water use efficiency was substantially higher in Oklahoma tests (Lyle et al. 1982).

Alternate furrow can also be used with furrow diking or row dams in the non-irrigated furrows to reduce rainfall runoff. Significant yield increases, for both cotton and grain sorghum, have been obtained by the addition of basin tillage to alternate furrow irrigation (Clark; Lyle and Dixon).

Surge flow application is designed to deliver large surges of water to the furrow on an intermittent cycle to reduce percolation losses at the upper end of the field and hence increase distribution efficiency. Automated systems operating on timers or soil moisture sensors connected to a microprocessor are also being developed in an attempt to increase distribution uniformity and application efficiency (Lyle et al. 1982).

The number of sprinkler systems has grown dramatally as the importance of application control and distribution efficiency has increased. Reducing the amount of labor required has been an important positive factor, while increased operating pressure and high investment costs, are important negative factors, to be considered. Statewide the number of sprinkler irrigated acres has increased from 668 thousand in 1958 to 2.2 million acres in 1979 (Texas Department of Water Resources). Research has focused on increasing the efficiency of sprinkler systems, and with the quadrupling of oil prices after 1972, reducing their energy requirements.

One of the most promising systems developed to meet these criteria is the low energy precision application (LEPA) system (Lyle and Bordovsky). The system operates by distributing water through drop tubes and low pressure emitters directly to the furrow as it moves through the field in either a linear or circular fashion. The system, when combined with micro-basins, is designed to maximize water application and distribution efficiency while minimizing energy costs and runoff.

In field trials of the LEPA system, measured application efficiencies averaged greater than 98% and distribution efficiency averaged 96%, while runoff, both from irrigation and rainfall, was essentially eliminated when micro-basins were included. In a two year test on soybeans at the Texas Agricultural Experiment Station, Halfway, Texas, pumping energy cost per bushel for undiked sprinkler irrigation averaged 67% more than for the LEPA system. Sprinkler irrigated soybeans combined with furrow diking still required 51% more energy than that required by LEPA (Lyle et al. 1981).

Economic Studies

There have been many economic studies investigating the High Plains region and the effects on agricultural production of a change in input cost and supply, commodity prices, or production technology. Only a sample will be reviewed here.

An input of major importance to High Plains agriculture is the groundwater from the Ogallala aquifer. The continuing decline in this aquifer is likely to have a significant impact on the regions agricultural production. Several studies have been conducted to quantify this impact. Osborn and Harris estimated that with continuing withdrawal at the mid 1960's rate, by the year 2015 production on irrigated acres would decrease by 62%. The total value of crop production by 2015 would be only 61% of the 1967 level even with an increase in dryland cropping. Another study (Hughes and Harman) covering approximately the same period (1966-2015) predicted a large shift out of cotton and grain sorghum production with a smaller increase in the amount of wheat produced. Total crop production value was estimated to decline over 70% by the end of the study period. Other studies (Casey; Harman, Hughes and Martin; Lacewell, Jones and Osborn) have also predicted a substantial decline in groundwater pumpage, irrigated acres and farm incomes particularly beyond 1990 when much of the aquifer will be dewatered at present pumpage rates.

Other inputs also affect the level of agricultural production. Adams, Lacewell and Condra (1976) investigated rising energy prices and their effect on production levels and cropping patterns in the Southern High Plains. By increasing natural gas, diesel and nitrogen fertilizer prices parametrically it was found that, given average commodity prices, crop production would begin shifting from irrigated to dryland when diesel reached $2.69 per gallon, natural gas cost more then $1.92 per mcf or nitrogen prices were higher than $.41 per lb. Similar shifts would occur if water prices were over $14.69 per acre-foot. However, the major impact of energy price increases were on net farm income rather than input use or commodity production. In a more recent study (Petty, Lacewell, Hardin and Whitson), short run increases in natural gas prices above $7.85 per mcf forced a typical High Plains farm to switch completely to dryland production even with good groundwater availability. The longer run effects were even more significant. Annual returns (above variable and fixed costs) were reduced by more than 30% and the present value of the groundwater declined by 80% when the natural gas price was increased annually by $.25 per mcf, from a base of $1.50 per mcf.

The same study also looked at operating capital constraints and land rental arrangements. Imposing credit limits on operating funds was so detrimental to net income that with extreme limits, interest rates greater than 100% could be justified to maintain credit availability. Under present tenure arrangements and increasing energy prices, annual returns for the renter-operator were from 28% to 70% lower than for owner-operators. If relative energy prices continue to increase, renter-operators will need to seek a change in rental terms, such as irrigation cost sharing, to maintain living standards.

Several Studies (Cornforth and Lacewell; Muncrief, Lacewell, Cornforth and Pena; Reneau, et al.) have included multiple soil types with changes in output yields and other inputs (usually fertilizer and harvesting costs) among the inputs restricting agricultural production. Splitting the land input into classes with different responses to specific crops and other inputs resulted in greater crop diversity, a wide range in land shadow prices and a closer match between model results and historic production in the modeled region.

Thus, there are numerous studies relating to many of the issues outlined. However, none of the studies have integrated alternate soil types, technology alternatives and multiple water resource situations in one model. Therefore, this research which provides planners, researchers and farmers some guides to potential technology, profitability and projected outlook over time, fills that gap.

CHAPTER II

MODEL AND PROCEDURES

Evaluation of new technology as it relates to crop production on the Texas High Plains requires large amounts of detailed data, as well as an analytical procedure or model. The variables in the recursive programming model developed for this study, the sources of their specification and how they interact are outlined.

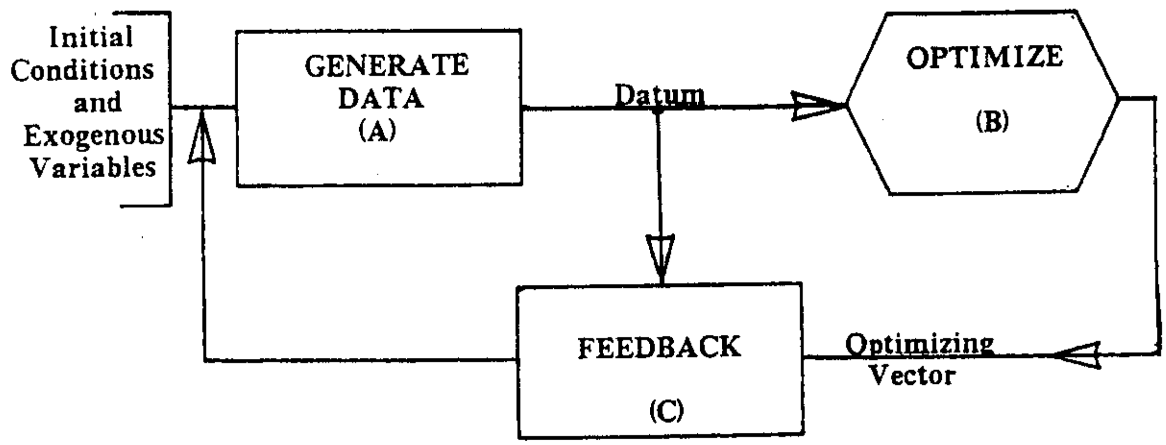
Basically, a recursive programming (RP) model is an extension and adaption of the static linear programming (LP) model to allow revision of parts of the LP model for period t+1, based upon the solution of period t, and conditions that prevail in period t+1. The revision may involve the objective function, the coefficient matrix, the level of constraints or any combination thereof.

A recursive programming model can be described schematically as a three component system (Figure 2).

> The *optimizing operator* (B) describes the dependence of certain decision or choice variables on objective constraint functions that in turn depend on various parameters or data. The *data operator* (A) defines how the data entering objective and constraint functions depend on the current state of the system as a whole. The *feedback operator* (C) specifies how the succeeding state of the system depends on the current optimal decision variables, the data and the current state. Given an initial state for the system the data for an optimization can be generated, the optimization problem formed and solved, and the next state of the system evolved through feedback. In this way, a sequence of optimizations is generated in which the parameters upon which any one optimization are based depend on past optimizations and parameters in the sequence. (Day 1976, p. 12).

The optimizing and data operators are specified to define a closed dynamic system. In principle, the data and feedback operators could be thought of as simulation and iteration loops, respectively. Because these operators may not choose globally optimal strategies with respect to the feedback operator, the system is characterized, by Day, as "suboptimization with feedback", or "suboptimal control". Detailed discussion of the theoretical foundations of recursive programming including a wide range of applications, can be found in Day (1963), and Day and Cigno.

The recursive programming model for this study was designed for flexibility, while keeping the input data required manageable, and maximizing the output of useful information. The model is divided into three sections. The first section uses input data defining a specific scenario and internally stored data to create a set of alternatives for land improvement, irrigation application and land preparation, planting and pest control. These alternatives are combined to generate production activities and a constraint set for a linear programming (LP) optimization routine which makes up section two of the model. The third section interprets the LP solution and reports the results in a convenient



Source: Day and Cigno, p. 10

Figure 2. Schematic of Information Flow in a Recursive Programming Model

format.

The internally stored data in section one is partitioned into blocks, each of which deal with a given aspect of resource management or crop production. The input that defines a particular model run indicates which parts of the internal data will be used, sets initial resource levels for groundwater and soils and gives the technology and price situation for the run. An example input data set is given in Appendix A and will be referred to, as necessary, subsequently.

Soil Classes

Since land is the basis of crop agriculture, soil units by texture, slope and yield potential for major crops and relative acreage are established first. Soil is divided into three texture classes by permeability and available water capacity. Permeability is the speed with which water enters the soil in inches per hour. The higher the permeability the less time rainfall or irrigation water stays on the soil surface, evaporating or forming runoff. Alternatively, a highly permeable soil may absorb water too fast for surface irrigation to spread properly, or lose excessive amounts of water and leach nutrients through deep percolation below the root zone.

Available water capacity is a measure of a soils ability to hold inches of plant available water per inch of soil. The higher the available water capacity the more water stored for periods of greater crop need or low precipitation. High available water soils can save more fallow season rain, go longer between irrigations, and better maintain production through drought periods. Their drawbacks include longer field drying times that can hamper field work or crop harvest, and cooler soil temperatures that may delay planting or interfere with plant germination.

Three texture classes are defined: (1) Fine, with available water capacity greater than .17 inches per inch of soil and permeability less than .8 inches per hour. The fine or hardland soils are principally clay or clay loams, such as Pullman, Mansker or Ulysses clay loam. (2) Mixed, with available water capacity between .12 to .17 inches per inch of soil and permeability between .8 to 2.5 inches per hour. The mixed soils are made up of loams or loamy sands, such as Portales, Olton or Amarillo soils. (3) Sandy, with available water capacity less than .12 inches per inch of soil and permeability greater than 2.5 inches per hour. Sandy soils, such as Brownfield or Tivoli soils, are too porous for flood or furrow irrigation techniques. If they are to be irrigated some type of sprinkler system must be used.

The High Plains, in general, is relatively level to gently sloping, but there are areas ranging from undulating to steeply sloped. Because the slopes tend to have different production characteristics than similar level soils, the amount of slope is also a defining characteristic. Slopes often have thinner, less fertile topsoils that are more prone to erosion. They also tend to be dryer, since more rainfall is lost to runoff. Slope has been broken into 4 discrete categories: relatively level, with less than .5% slope, gently sloping with inclines between .5% to 1.5% and averaging 1%, moderately sloped with an average fall of 2% and ranging from 1.5% to 3%, and slopes greater than 3%. For the latter three classes the possibility exists to apply terracing techniques to reduce runoff and soil erosion, and to improve irrigation management.

Land Improvement Techniques

From the many land modification techniques - ranging from simple contour furrows to elaborate systems of laser leveling - available to farmers in the High Plains, two have been chosen to represent the costs and benefits of topographic modification in the area. The two techniques, bench terraces and conservation bench terraces have wide applicability in the area and have been sufficiently researched (Jones 1979; Jones and Shipley; Young and Merrick) to demonstrate their efficiency at conserving water and soil, and to provide reliable data on construction and maintenance costs.

Bench terraces are constructed by cutting and filling to create a series of level benches with a raised lip or ridge to prevent runoff. The width of the bench decreases with the steepness of the slope, due to the depth of the cut and the amount of soil that must be moved as the slope increases. Thus, construction costs increase rapidly as slope increases, while the narrow benches are both harder to farm and likely to be less fertile if too much of the topsoil is removed from the cut.

Conservation bench terraces (CBT) were designed to overcome some of the difficulties encountered in conventional bench terraces, while retaining the soil and water preservation features. They are constructed by leveling only the bottom third of the terrace interval, allowing the upper two-thirds to act as a watershed. To assure retention of runoff, the terrace ridge is built higher than for conventional bench terraces, but construction costs are much lower and terrace intervals are wider for any particular slope.

Input requirements for each system, by slope class, are given in Table 3. Since terrace ridges and other areas are lost to cropping, terracing reduces the amount of cropland available per acre of farmland and the loss is both greater for bench terraces and as the slope increases.

Construction costs for each system were calculated using the average slope in each slope catagory and the cost estimates in Jones and Shipley (p. 178, Figure 2) updated to 1982 prices. Construction costs were then turned into an annualized fixed cost by calculating the equivalent infinite annuity at a 3% real rate of interest. Besides fixed costs, variable costs for repairs and maintenance were calculated using the data from Young and Merrick (p. 8, Table 4) and Jones and Shipley (p. 178, Table 1) updated to 1982 prices using the cost of production index (U. S. Department of Agriculture). The construction of terraces changes the field geometry and increases the amount of labor and machinery time to carry out necessary field operations. Since the additional requirements vary over operations and crops, a simple multiplier is used to approximate the added costs involved. This multiplier, like the dryland yield change and the irrigation multiplier, is based on the findings of the previously cited references and on the judgement of local experts. The dryland yield multiplier gives the added dryland crop yield expected due to the extra water retained on the field by the terraces. For irrigated crops, the multiplier indicates the reduction in irrigation water that would have to be applied to obtain the planned yield, as on the same land class

Table 3. Bench and Conservation Bench Terraces (CBT); Input Requirements and Effects

Item	.5 to 1.5 % Slope		1.5 to 3 % Slope		Greater Than 3 % Slope	
	Bench	CBT	Bench	CBT	Bench	CBT
Land Required[a]	1.02	1.01	1.03	1.02	1.05	1.03
Annual Fixed Cost ($)	5.10	1.74	7.80	2.88	8.94	3.84
Repair and Maintenance ($)	4.43	1.52	6.78	2.50	7.76	3.34
Labor and Machinery Multiplier[b]	1.05	1.03	1.07	1.05	1.10	1.07
Dryland Yield Multiplier[c]	1.10	1.05	1.15	1.09	1.20	1.12
Irrigation Multiplier[d]	.95	.97	.92	.96	.90	.93

[a] Acres of Farmland Needed per Acre of Cropland. Costs and multipliers are listed on a per cropland acre basis.

[b] Additional Labor and Machinery Relative to a Non-Terraced Acre of Cropland.

[c] Increase in Dryland Yield Relative to a Similar but Non-Terraced Crop Acre.

[d] Reduction in Irrigation Needed Relative to a Similar but Non-Terraced Irrigated Crop Acre.

Sources: Jones (1979); Jones and Shipley; Young and Merrick.

if left unterraced.

Yield Potential

The last set of information necessary to differentiate each land class is the relative yield potential of the main crops (cotton, grain sorghum, wheat), compared to some norm for the region as a whole. The relative yield variable is used as a proxy for local microclimate variations and those aspects of soil not included in texture and slope. The norm chosen was the average dryland harvested yield in the region in the early 1970's, since most of the area soil surveys, from which this data was derived, were published around that time. The input data for each soil, in a particular model run, contain an expected yield from the appropriate soil survey for the 3 main crops. These yields are then compared to the norms (230 lb cotton, 15 cwt grain sorghum and 15 bu wheat), to establish soil quality yield multipliers, for each crop and soil. The grain sorghum multiplier is used for corn, soybeans and sunflowers, since these are also summer crops with approximately the same growing season.

The last section of the input data (see Appendix A) gives the soil information. It includes, for each soil, an eight character alpha-numeric identification code and the associated acreage, texture, slope and expected dryland yields for cotton, wheat and grain sorghum. These data are combined with the internally stored information on soils and terracing to generate land classes. A land class, of which up to 20 can be considered in a model run, consists of a particular soil combined with a terracing option. Thus, a soil with an original slope of 2% would give rise to three land classes: (1) the soil without terracing, (2) the soil with bench terracing, and (3) the soil with conservation bench terracing.

Crop Yield and Irrigation Timing

The yield data for different intensities and timing of irrigation, developed by Hardin and Lacewell (1981), were used as the starting point for generating the irrigation requirements and expected yield for all the cropping activities. Their data were based on an extensive set of experiments conducted over the years at Texas A&M Research centers in Amarillo and Lubbock, and at the U. S. Department of Agriculture Southwestern Great Plains Research Center in Bushland, Texas. The Hardin and Lacewell data were supplemented by current research findings concerning new wheat varieties and short season grain sorghum, and expanded by adding soybeans and sunflowers to the crop choices.

Pre-plant irrigation for all the crops was assumed to apply six inches of crop usable water and post-plant irrigations, three inches. Different post-plant irrigation timings cause yields to vary, due to the amount of water stress the crop must surmount.

Irrigation application periods were defined by breaking the year into 18 uneven segments. The periods range in length from two months (Nov.-Dec., Jan.-Feb.), during times of the year when irrigation requirements are low, to ten day periods during the critical summer irrigation season (June, July, August). The watering periods were established to acknowledge the importance of timeliness of irrigation application, given the limited capacity of pumping and distribution systems, the cost of wells and pumping equipment, and limits on the rate of aquifer drawdown. However, plants can survive a certain amount of water stress with limited effect on growth and production. This allows alternative post-plant irrigation timings which, though yield is reduced by irrigating at other than the optimal period, increases irrigation flexibility and, thus, make better use of the complete set of farm inputs.

Cotton yields, irrigation levels and time periods when each post-plant irrigation is applied are given in Table 4. Cotton cultivation leads to the production of cotton seed as a joint product with the lint. As in Hardin and Lacewell (1981), cotton seed production was set at 1.67 lbs. of seed per lb. of lint.

Table 5 gives the data for corn. Both corn and soybeans are only grown with irrigation, as they are not drought tolerant and are incapable of consistently producing under dryland or limited irrigation.

Grain sorghum base yields and irrigation regimes are shown in Table 6. Short season grain sorghum which can be planted up to a month later, was added to increase the available choice set. Even though the short season varieties do not have as high yields as full season sorghum, they may be useful, since their critical irrigation periods are different and hence, more options for irrigation scheduling are obtained. Also, the short season varieties can be used after a late spring, or to take advantage of early summer precipitation. Irrigation timing and expected yield for the short season alternatives were adapted from Eck and Musick.

Sunflowers are a relatively new crop to the region, with the potential for increased production, due to drought tolerance and the ability to fit into the crop calendar, both as a dryland and irrigated crop. Sunflowers, for which base yields and irrigation timing are given in Table 7, have not been sufficiently researched to develop accurate data on yield response to irrigation timing. Nor has their use in the area been as a main crop, but rather, as either a catch crop or a supplemental crop, where flexibility in planting date may be the more important feature. Therefore, Paul Unger's Bushland research (1978a, 1980) was used to develop a range of planting dates and irrigation levels, ignoring at this point the possibilities of non-optimal irrigation timing for sunflowers.

Soybeans, like sunflowers, are a minor crop at the present time on the High Plains, but one that can be used as an irrigated crop filler if a cotton crop is lost early in the season. Soybeans do best under irrigation since, like corn, they are not drought tolerant. Soybean yields and irrigation timing are listed in Table 8.

Winter wheat is the other major crop grown on the Texas High Plains, having averaged more than 2.89 million planted acres a year over the last 10 years (Texas Crop and Livestock Reporting Service, 1981c). It is also a crop that has shown considerable yield increase as new varieties, specifically bred for the local conditions, are introduced. Thus, the yields specified in Hardin and Lacewell (1981) have been increased for this study based upon the recently introduced TAM 105 wheat variety. Four year yield trial data (Musick, 1982) were adjusted for average conditions in the area with the help of local experts, to derive the base yields by irrigation level and timing that are shown in Table 9. Wheat, like cotton, produces a joint output, in this instance grazing for beef cattle. The new varieties are not as productive for grazing as the older

Table 4. Timing of Irrigation and Related Yield for Cotton: Texas High Plains

Irrigation Level	Time of Post-Plant Irrigation			Yield Per Acre
	$June_3$ [a]	$July_2$	$Aug._1$	
				(lb)
Dryland:				230
Pre-Plant Only:				420
Pre-Plant + 1 Post-Plant:			x[b]	517
		x		470
	x			450
Pre-Plant + 2 Post-Plants:		x	x	590
	x		x	588

[a] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[b] "x" indicates a post-plant irrigation during the specifed period.

Sources: Hardin and Lacewell (1981); Jones, et al.

Table 5. Timing of Irrigation and Related Yield for Corn: Texas High Plains

Irrigation Level	Time of Post-Plant Irrigation						Yield Per Acre
	$July_1$ [a]	$July_2$	$July_3$	$Aug._1$	$Aug._3$	$Sept._1$	(bu)
Pre-Plant + 3 Post-Plants:		X[b]	X	X			116
		X	X		X		107
	X		X		X		102
Pre-Plant + 4 Post-Plants:		X	X	X		X	126
		X	X	X	X		122
	X	X	X	X			120
Pre-Plant + 5 Post-Plants:	X	X	X	X	X		146
	X	X		X	X	X	137
	X	X	X	X		X	136
Pre-Plant + 6 Post-Plants:	X	X	X	X	X	X	148

[a] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[b] "X" indicates a post-plant irrigation during the specifed period.

Sources: Hardin and Lacewell (1981); Musick (1978); Musick and Dusek (1978); Shipley and Regier (1976); Undersander.

Table 6. Timing of Irrigation and Related Yield for Grain Sorghum: Texas High Plains

Irrigation Level	Time of Post-Plant Irrigation								Yield Per Acre
	$July_1$ [a]	$July_3$	$Aug._1$	$Aug._2$	$Aug._3$	$Sept._1$	$Sept._2$	Oct.	
									(cwt)
Dryland:									15.00
Pre-Plant + 1 Post-Plant:				X[b]					45.10
Pre-Plant + 2 Post-Plants:	X	X		X					53.70
		X			X				51.90
	X			X					50.40
			X				X		47.18 SS[c]
						X	X		45.39 SS
Pre-Plant + 3 Post-Plants:			X			X	X		63.84
	X		X		X				63.00
		X		X	X				60.50
					X	X	X		59.42 SS
			X		X		X		59.33 SS
Pre-Plant + 4 Post-Plants:	X	X		X	X				69.00
			X		X	X		X	63.33 SS

[a] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[b] "X" indicates a post-plant irrigation during the specifed period.

[c] "SS" indicates a short season grain sorghum variety.

Sources: Hardin and Lacewell (1981); Shipley and Regier (1975); Musick and Dusek (1971); Eck and Musick.

Table 7. Planting Period; Timing of Irrigation and Related Yield for Sunflowers: Texas High Plains

Irrigation Level	Planting Period[a]	Time of Post-Plant Irrigation								Yield Per Acre
		$June_2$[b]	$June_3$	$July_1$	$July_2$	$July_3$	$Aug._1$	$Aug._2$	$Aug._3$	(cwt)
Dryland:										8.04
Pre-Plant + 1 Post-Plant:	APR			X[c]						15.48
	MAY				X					15.48
	JUN					X				15.48
Pre-Plant + 2 Post-Plants:	APR	X			X					17.97
	MAY		X			X				17.97
	JUN			X			X			17.97
Pre-Plant + 3 Post-Plants:	APR	X		X		X				19.60
	MAY		X		X		X			19.60
	JUN			X		X		X		19.60
Pre-Plant + 4 Post-Plants:	APR	X		X		X	X			20.78
	MAY		X		X		X	X		20.78
	JUN			X		X		X	X	20.78

[a] Planting Period: APR = last of April, MAY = mid-May, JUN = first part of June.

[b] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[c] "X" indicates a post-plant irrigation during the specifed period.

Sources: Harman, Unger and Jones; Shipley and Regier (1976b); Unger (1978); Unger (1980); Unger, Jones and Allen.

Table 8. Timing of Irrigation and Related Yield for Soybeans: Texas High Plains

Irrigation Level	Time of Post-Plant Irrigation					Yield Per Acre
	$June_2$ [a]	$July_1$	$July_2$	$Aug._1$	$Aug._2$	
						(bu)
Pre-Plant + 2 Post-Plants:			X[b]		X	32.60
			X	X		28.40
Pre-Plant + 3 Post Plants:			X	X	X	44.60
		X		X	X	39.70
	X		X		X	33.80
Pre-Plant + 4 Post-Plants:		X	X	X	X	49.00

[a] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[b] "X" indicates a post-plant irrigation during the specifed period.

Sources: Dusek, Musick and Porter; Shipley and Regier (1968); Shipley and Regier (1970).

Table 9. Timing of Irrigation and Related Yield for Wheat: Texas High Plains

Irrigation Level	Time of Post-Plant Irrigation					Yield Per Acre
	Jan/Feb	March	April	May_1 [a]	May_2	
						(bu)
Dryland:						16.20
Pre-Plant + 1 Post-Plant:			X[b]			38.00
				X		31.20
Pre-Plant + 2 Post-Plants:		X	X			56.80
		X		X		56.10
Pre-Plant + 3 Post-Plants:		X		X	X	66.00
			X	X	X	62.70
Pre-plant + 4 Post-Plants:	X		X	X	X	73.00
		X	X	X	X	72.70

[a] Subscript number refers to the 1st, 2nd, or 3rd water period in month.

[b] "X" indicates a post-plant irrigation during the specifed period.

Sources: Hardin and Lacewell (1981); Harman; Musick (1982); Schneider, Musick and Dusek.

varieties, especially at the most intense irrigation levels, thus, only two levels of grazing production were included; dryland wheat grazing at a base of $9 an acre, and irrigated wheat grazing at four times the dryland rate.

Input Requirements

All crop production activities are based upon a one acre land unit. Inputs needed in land preparation, planting and crop protection are defined per acre regardless of crop yield, as their level of use is principally dependent on the amount of land covered. Input usage varies by crop, by crop intensity (i.e., whether the crop is grown with irrigation or as a dryland crop), and by tillage management.

Tables 10 and 11 give the level of each input for the different groupings. Labor and diesel were defined in physical units, since labor is sometimes in short supply in agriculture and a constraint on its availability might be of interest for some users of the model. Diesel has suffered supply short falls in the recent past and thus, the possibility of a diesel constraint was considered in the design of the model. The irrigation efficiency and dryland yield indices are used to approximate the effect of limited tillage systems on soil moisture levels. Limited tillage is used in this study as the name for a set of advanced management practices that include minimizing tillage operations, machinery that maintains residue on the surface and chemical weed control. Since limited tillage methods reduce runoff and evaporation losses, the dryland yield index indicates the percentage increase in yield, due to the additional precipitation available for crop growth. The irrigation efficiency index specifies the relative amount of irrigation water that must be applied to obtain the expected yield with minimum tillage, as compared to conventional tillage methods. The rationale behind the two indices is that while dryland yield is dependent on soil moisture levels and cannot be directly controlled, an irrigated crop yield is chosen by the farmer, who plans his irrigation schedule to reach an optimal yield. Since limited tillage methods conserve moisture, the farmer need not apply as much irrigation water to obtain a specified yield.

The amount of other inputs (fertilizer, irrigation water and custom harvesting) required depend on expected yield. Fertilizer and harvesting equations for each crop are given in Table 12. Fertilizer application was set to maintain soil fertility levels for the majority of soils in the region for the production expected. Harvesting and hauling costs were based on local custom rates. Cotton harvest costs are set per lb of seed cotton, which contains all the material (lint, seed, leaves, burrs and trash) brought to the gin, computed at 5.5 lbs seed cotton per lb lint. Sunflower harvesting has an added hauling cost included, due to the lack of processing plants in the region that can handle sunflower seeds (Wyatte Harman, Personal Communication). Wheat harvest base cost is calculated at $12 an acre plus 12 cents a bushel over 20 bushels, with hauling at 12 cents a bushel for all wheat harvested.

Water requirements for irrigation are derived, using the application timing information in Tables 4-9, assuming a basic usable plant water delivery rate of 6 inches per pre-plant and 3 inches per post-plant

Table 10. Production Inputs per Acre with Conventional Tillage

Item	Unit	Cotton	Corn	Sorghum	Sunflowers	Soybean	Wheat	Fallow[a]
Irrigated Cropland								
Labor	Hours	6.13	4.61	5.35	5.40	4.55	3.10	
Seed	$	9.00	17.20	3.60	10.00	13.80	9.75	
Biocides	$		28.00	10.50	12.00	7.00	5.62	
Diesel	Gal	14.63	12.76	20.62	19.90	12.85	8.74	
Machinery Variable	$	9.16	6.62	7.21	5.61	7.49	6.66	
Fixed	$	37.21	36.31	23.42	22.66	21.91	26.53	
Irrigation Efficiency	Index	1.00	1.00	1.00	1.00	1.00	1.00	
Dryland Cropland[b]								
Labor	Hours	5.28		2.31	1.49		2.18	1.84
Seed	$	4.75		1.80	6.00		3.00	
Biocide	$	6.00			8.00			
Diesel	Gal	14.15		9.47	8.14		8.19	5.10
Machinery Variable	$	6.74		4.10	2.21		3.58	3.19
Fixed	$	31.16		17.37	16.20		19.63	15.63
Yield	Index	1.00		1.00	1.00		1.00	

[a] Fallow is a practice used only with dryland production.

[b] Corn and soybeans are not raised dryland.

Sources: Extention Economists-Management; Hardin and Lacewell (1981); Petty et al.

Table 11. Production Inputs per Acre with Limited Tillage

Item	Unit	Cotton	Corn	Sorghum	Sunflowers	Soybean	Wheat	Fallow[a]
Irrigated Cropland								
Labor	Hours	4.64	2.73	3.72	3.14	2.83	1.88	
Seed	$	9.00	17.20	3.60	10.00	13.80	9.75	
Biocides	$	6.00	42.00	17.00	20.00	12.00	17.00	
Diesel	Gal	10.70	9.65	14.22	14.11	8.86	6.03	
Machinery Variable	$	7.07	4.57	4.97	3.87	5.24	4.59	
Fixed	$	30.38	27.44	16.15	15.63	15.35	20.41	
Irrigation Efficiency	Index	.97	.97	.89	.91	.98	.92	
Dryland Cropland[b]								
Labor	Hours	2.92		1.39	.86		1.32	1.07
Seed	$	6.75		1.80	6.00		3.00	
Biocide	$	6.00		6.00	15.00		4.00	7.50
Diesel	Gal	8.53		5.69	5.61		5.65	2.34
Machinery Variable	$	5.12		2.41	1.28		2.47	1.81
Fixed	$	28.73		13.36	11.17		15.10	9.09
Yield	Index	1.04		1.12	1.09		1.08	

[a] Fallow is a practice used only with dryland production.

[b] Corn and soybeans are not raised dryland.

Sources: Extention Economists-Management; Hardin and Lacewell (1981); Petty et al.

Table 12. Yield Related Inputs: Fertilizer and Harvesting Equations

Crop	Crop Unit	Yield Level	Nitrogen	Phosphorus	Harvesting, Hauling
			(lb)	(lb)	($)
Cotton	lb		.0533Y	.0533Y	5.5[a] (.04Y)
Corn	bu	Y<100	1Y	.6Y	.60Y
		Y>100	100 + .8(Y-100)	60.	
Sorghum	cwt	Y<40	1.5Y	1Y	.62Y
		40<Y<60	60 + 2(Y-40)	40	
		Y>60	100 + 2(Y-60)	40 + (Y-60)	
Sunflower	cwt	Y<15	1.5Y	.5Y	12 + 2.10Y
		Y>15	3.5Y	1.16Y	
Soybeans	bu		20	.5Y	12.50 + .10Y
Wheat	bu	Y<20			12 + .12Y
		Y<40	1.5Y	.5Y	
		Y>20			14.40 + .24(Y-20)
		Y>40	60 + 2(Y-40)	20 + (Y-40)	

[a] Cotton harvest, gin, bag and tie based on seed cotton at 5.5 lbs. seed cotton per lb lint.

Sources: Extention Economists-Management; Hardin and Lacewell (1981); Unger (1980); Valentine et al.

irrigation. These base requirements are translated to water applied by consideration of terracing and tillage effects on water use and the delivery efficiency of the irrigation distribution system. Once the amount of water that must be pumped is calculated, the per acre-inch charges can be found, using the distribution costs listed in Table 13, plus the fixed and variable pumping costs.

Fixed cost for the furrow distribution system include gated aluminum pipe, hydrants, end plug, main pipeline and gate valve. Improved furrow, in addition, includes a recirculation pit and associated plumbing. Sprinkler system costs are based upon a standard center pivot with mainline, pad for pivot, control and drives. The LEPA system includes the addition of pressure regulator, drop tubes and nozzles.

Variable costs for irrigation consist of the maintenance and repair

Table 13. Inputs Per Acre-Inch, for Alternate Irrigation Systems, at Specified Pressure and Delivery Efficiency

Item	Unit	Furrow		Sprinkler	
		Standard	Improved	Standard	LEPA[a]
Annual Fixed Cost[b]	$	1.06	1.14	1.61	1.93
Annual Variable Cost[b]	$	.21	.27	.46	.59
Labor	Hr	.10	.15	.033	.043
Pumping Head	Psi	5	5	45	6
Delivery Efficiency	%	69	80	80	92

[a] LEPA is a Low Energy Precision Irrigation System as described by Lyle.

[b] Fixed and Variable Cost specified are for the distribution system only. Well, pump and fuel costs are calculated separately.

Sources: Extention Economists-Management; Kletke, Harris and Mapp; Lyle and Bordovsky; Lyle, Fenster, Ferguson and Wendt; Wyatt.

costs for the distribution system, fuel for pumping, and labor. Approximately 70% of the wells on the High Plains are fueled by natural gas ("Texas Irrigation Survey 1976, 1980", Texas Crop and Livestock Reporting Service, 1981c, pp.6-8). Further, more than 95% of the pumping energy (measured in BTU equivalent units) comes from natural gas (Texas Crop and Livestock Reporting Service, 1976). Thus, the fuel cost for pumping has been calculated using the formula for natural gas powered pumps from Kletke, Harris and Mapp,

(6) $$FUELC = (.0014539HEAD * PNGAS) / EFPUMP,$$

where FUELC is the cost to pump one acre-inch of water from the aquifer and distribute it on a field, HEAD is the total pumping lift in feet including the distribution system pressure, PNGAS is the present price of natural gas in dollars per mcf, and EFPUMP is the energy efficiency of the pump.

The price of natural gas and the pump efficiency are set at the start of each iteration of the model. The pumping head depends on the distribution system and the changes in pump lift, as the depth to the top of the aquifer increases with aquifer mining. Labor for irrigation is calculated as distribution labor (Table 13), plus 5% for pump and well maintenance.

Total fixed cost per acre-inch is derived as the sum of fixed cost for the well, the pumping unit and the distribution system. Well and pumping fixed cost equations were estimated from data for the region (Hardin and Lacewell 1981; Petty et al.). The equation for well fixed cost is

$$WELLFX = 230.3 + 4.22(PLIFT + SAT), \tag{7}$$

where WELLFX is the annual fixed cost per irrigation well, PLIFT is the pump lift from the top of the aquifer to the land surface in feet, and SAT is the aquifer saturated thickness in feet. The fixed cost for the pumping unit is derived as

$$PUMPFX = 429.5 + 4.5HEAD + 2.82GPM - .0051HEAD^2 - .002GPM^2 , \tag{8}$$

where PUMPFX is the annual cost to own a pumping unit, HEAD is the required distribution system pressure (equal to "pumping head", Table 13 plus pump lift), and GPM is the expected pumping rate from the well in gallons per minute.

Well yield or pumping rate (GPM) is a function of the saturated thickness. The equations (Pearce) to describe this relationship are:

If (SAT is less than or equal to 155 ft) then,

$$GPM = 2.264SAT + .007833SAT^2 - .0000282SAT^3 . \tag{9}$$

If (SAT is greater than 155 ft but less than 210 ft) then,

$$GPM = 800(SAT/210)^2 . \tag{10}$$

If (SAT is greater than or equal to 210 ft) then,

$$GPM = 800. \tag{11}$$

Linear Programming Matrix Generation

The discussion above has emphasized a large number of different techniques for terracing, crop tillage, irrigation application and groundwater pumping and distribution. A major part of the first section of the computer program was built to assemble these techniques into alternate crop production activities. The assemblage takes place under the direction of the given scenario, as defined by the input data. Since the production activities are generated to form an input array for a linear programming optimization routine, they must contain an identifying name and the name and coefficient values for the objective function and appropriate constraint rows. Also, since the third component of the model is a report writer, additional information not needed as part of the LP is loaded into a separate, but coordinated direct access file.

To keep the linear programming matrix as simple as possible, all the economic information concerning each production activity is stored in a direct access file for later use, and only the net return is used in the LP as the objective function coefficient. Each LP column vector (production activity) is defined for one acre of a particular crop or crop rotation grown on a specified land class, using a unique combination of irrigation distribution system, tillage method, and irrigation level and timing regime.

To generate the production activities for each run of the model, a sequence of steps are required. First the input data are read. This contains all the necessary information to define a particular scenario. An example input file, including an explanation of its main elements, is given in Appendix A.

After the input data have been read, land classes are generated and stored, as land classes do not change across iterations. Prices for each iteration are derived by updating (according to inputted data) the internally stored base prices. Internally stored prices for both inputs and commodities are given in Table 14. Prices for those inputs which are defined in physical units (natural gas, diesel, nitrogen, phosphorus and labor), were set at an average 1982 base price for the region, by using the area crop budgets (Extention Economists- Management) and local expertise (Wyatte Harman, personal communication). Commodity prices were calculated by taking 20 years of state seasonal average prices, stating them in 1982 dollars, by using the parity price index (U.S. Department of Agriculture) and then averaging. Annual nominal prices, the price index, and annual prices in 1982 dollars are given in Appendix B. Also shown in Table 14 are the alternate prices used in some situations, to test the model's sensitivity to expected price. The alternate natural gas price is the estimated deregulated price (Turhollow, Short and Heady) expressed in 1982 Dollars. The alternate commodity prices are the lowest prices in the 20 year price series, when each year is expressed in 1982 dollars (See Appendix B, Table B-2).

LP Production Activities

The program next generates the production activities, by time period, by updating terracing and irrigation costs, and looping through all possible combinations, (as set by inputted control codes) of crop, crop specific irrigation regime, irrigation distribution system, tillage method, and land class.

To demonstrate how the production activities are generated in the model, the process is enumerated for a single activity.

1) The crop irrigation regime, irrigation distribution system, tillage method and land class is specified.

Table 14. Input and Commodity Prices: Texas High Plains

Item	Unit	Expected Price[a]	Alternate Price[b]
Inputs		($)	($)
Natural Gas	mcf	3.85	8.86
Diesel	gal	1.16	
Nitrogen	lb	.28	
Phosphorus	lb	.30	
Labor	hr	5.00	
Interest on Capital	percent	10.00	
Commodities			
Cotton	lb	.74	.48
Cotton Seed	ton	151.53	104.56
Corn	bu	3.95	3.00
Grain Sorghum	cwt	5.95	4.52
Sunflowers	cwt	15.17	10.47
Soybeans	bu	8.08	5.58
Wheat	bu	4.71	3.25
Wheat Grazing			
Dryland	ac	9.00	6.84
Irrigated	ac	36.00	27.36

[a] Input Prices - 1982 average price in region, Commodity Prices - average price received 1962-1981 expressed in 1982 Dollars using the Parity Price Index.

[b] Natural Gas - expected deregulated price in 1982 Dollars, Commodities - lowest average annual price received 1962-1981 expressed in 1982 Dollars.

Sources: Extention Economists-Management; Hardin and Lacewell (1981); Texas Crop and Livestock Reporting Service (1962-1981); Turhollow, Short and Heady; U. S. Department of Agriculture.

2) Check if activity is multi-crop or dryland. If so a modified procedure is followed. Differences will be discussed after activities for the single year irrigated crop are outlined.
3) Calculate yield and return. Yield is equal to the base yield (Tables 4-9) times the soil quality multiplier times the input yield change index. Return equals the yield times commodity price. If the crop is cotton or wheat the joint product yield and return are also calculated and added.
4) Calculate the irrigation water requirement. First, the amount of water that must be pumped for each of the eighteen water periods is figured, by taking the base requirement (Tables 4-9) times the land class (Table 3), tillage system (Table 10 or 11) and irrigation distribution system delivery efficiency (Table 13) multipliers. After the individual period requirements are calculated, they are summed to derive an annual total use.
5) Calculate labor use. Labor hours, per acre of the specific production activity, are the sum of tillage plus irrigation labor multiplied by terracing and inputted labor efficiency change multipliers. Labor cost is then derived by multiplying by the wage rate.
6) Calculate machinery variable and fixed costs. Machinery costs include tillage (Tables 10 or 11), irrigation (Table 13) and terracing (Table 3) machinery multiplied by inputted machinery efficiency and price change.
7) Derive fuel use and cost. Diesel fuel use is calculated in gallons by taking the amount used for tillage and multiplying by terracing and inputted efficiency change multipliers. Total fuel cost is estimated by adding the fuel cost for irrigation to the gallons of diesel times its price plus 10% for oil and lubricants.
8) Calculate fertilizer usage and fertilizer and harvest costs. For the crop and expected yield under this production scheme, functions (Table 12) are applied with the calculated yield to derive a fertilizer use level. Fertilizer cost is then found by applying the fertilizer price. Harvest costs are similarly derived using the harvest cost function updated by present labor and machinery cost change indices.
10) Sum all variable costs; all fixed costs. All variable costs and all fixed costs as calculated above are summed into separate totals. An additional operating capital financing charge is added to the variable cost then the total is subtracted from gross returns to obtain expected return, over variable cost. Net return over variable and fixed costs is also calculated.
11) Test if net return is positive. If the activity does not generate positive net returns it is dropped from further consideration, since it is preferable to let the land lay idle than to crop it, using this production method.
12) Write activity identifier and the individual use levels and costs to a direct access file for use by the report writer (section three of the program).
13) Write to the linear programming input file. The activity identifing code and coefficients for the objective function, land of the specified type, annual water requirement and those water periods which require irrigation, are written to the LP input file. Both returns over variable, and returns over variable and fixed cost, are

written as separate objective function values. Depending on the purpose of the model run, either one or the other is actually used.

Besides the standard irrigated cropping activities, there is also the possibility of considering dryland crop production, mixed rotations (an irrigated crop followed by a dryland crop), the limited-irrigation-dryland system (LID) developed by Stewart, Dusek and Musick, and dryland rotations. For dryland crop activities, the irrigation requirements and costs are excluded, but the generation procedure is the same otherwise. For mixed and dryland rotations, the production activity is equivalent to the sum of two activities with a percentage change in the yield of the second, due to the beneficial effect of the sequence. It is an implied assumption of the model that the farmers use good management on all crops, rotating them over various fields and years for weed and insect control, field operation timeliness, and soil fertility maintenance. Thus, added yield from specific rotations is mainly attributed to additional soil moisture preservation. Mixed rotations show an increased yield for the subsequent dryland crop because the first crop is fully irrigated and when harvested leaves the soil with some residual moisture for the following crop. Dryland rotations get their added boost from the fallow period included in them.

The limited-irrigation-dryland system (LID) is a newly developed concept for managing irrigation tail water and runoff from rainfall. LID calls for the field to be divided into 3 segments, with the top half managed as fully irrigated, the next quarter as a "tail-water-runoff" section, utilizing irrigation runoff, and the last one-fourth as a "dryland" section. The "dryland" section is available to retain and utilize any rainfall and irrigation runoff that gets past the tail-water section (Stewart, Dusek and Musick). This field geometry uses irrigation water much more effectively than separate irrigated and dryland fields, but requires higher level management and more machinery field time due to the need to change planting and fertilization rates down the field. The LID plan was approximated in the model by creating production activities consisting of a fully irrigated crop plus the same crop dryland. Machinery and labor costs were increased 5% and the yield on the dryland portion was raised 55%, consistent with the limited research findings to date. Because of the newness of the concept and limited data on costs and returns only wheat and grain sorghum LID production activities were considered. The ability to remove the LID option for a specific run is also built into the model structure.

LP Constraints

A LP model is a mathematical procedure that maximizes an objective function subject to a set of constraints. In the model developed for this study, net returns are maximized subject to various resource constraints. The first set of constraints is for land by soil type, as previously discussed. The amount of acreage available by soil type is read in as part of the input data and is used directly to form the right-hand side values for each soil. These constraints remain constant over iterations for a particular model run.

The second set of constraints control the irrigation water available by irrigation period and in total. The amount of water that can be pumped in any one period depends on the average well capacity, the number of wells, the amount of time in the period and the percentage of down time required for pump repairs and maintenance. The equation to describe this relationship is

$$\text{(12)} \qquad WATPMP_i = .0528\ GPM(PDAY_i)\ P\%(WELL),$$

where $WATPMP_i$ is ac-in of water pumped in period i, .0528 converts GPM to ac-in-day, GPM (gallons of water pumped per minute per well), which is dependent on saturated thickness, has been discussed previously, $PDAY_i$ is the number of days in period i, P% is the percentage of time the pumps operate (1-downtime), and WELL is the number of wells available.

The number of days in each of the 18 pumping periods was set to conform to the critical irrigation periods for the crops in the region and is specified in the model structure. For a single static run or the first iteration of a temporal run the saturated thickness, on which the well yield depends, and the number of wells are part of the input data. The percentage of time the pumps operate is also input data and can be changed from iteration to iteration for temporal runs.

Since the recharge rate of the Ogalalla aquifer is nearly zero, pumping causes the water level in the aquifer to drop over time as the water is withdrawn. This drop manifests itself as a reduction in the saturated thickness and an increase in the average pump lift. For temporal runs, these changes and their effects must be incorporated. At the start of the first iteration, the beginning saturated thickness, pump lift, coefficient of storage, aquifer surface area and number of wells are read as input data (see Appendix A). The amount of water that can be pumped each period ($WATPMP_i$) is then calculated and used for the water constraint for that period in the LP section of the model.

After the LP is solved for the optimal crop mix a simple summation procedure is used to calculate total water pumped. Dividing water pumped by the aquifer surface area times the coefficient of storage gives the amount of aquifer decline. Since the Ogalalla is an unconfined aquifer, the decline translates directly into increased pump lift and decreased saturated thickness for the next iteration. Thus, at the start of each iteration of a temporal run, the pump lift and saturated thickness are updated. In turn, the cost of pumping increases due to increased lift, and well yield and pumping capacity per irrigation period decreases due to reduced saturated thickness.

The final constraint available in the present model design is for total water use per year. It is used to limit the feet of annual aquifer decline for certain model runs and is read, in those situations, from the input data. The economic meaning and purpose of this constraint will be discussed more fully in a later section.

The Report Writer

Once the production activities and constraints are generated for an iteration, the LP section of the model is solved. The solution, which contains the set of activities maximizing net revenue given the land and water constraints, is outputted to a file and the third section of the model is called to write a report. The purpose of the report writing section is: (1) return enough of the input data to identify the run and specify the price situation, (2) meld the LP output with the cost and returns data for the chosen production activities, (3) filter out extraneous information, and (4) report information in a standard, easy to read form. An example report is given in Appendix C. Four pages are printed for each iteration plus a four page summary if a multi-iteration temporal run is made.

Page one of the report includes the inputted title, the iteration number and years covered, as well as the current price and efficiency index values. The actual prices for the iteration (inputted index times the stored base price) are also listed for easy reference and error detection.

Page two details the groundwater and irrigation results for the iteration. This includes the starting and ending saturated thickness, pump lift and well yield, as well as, the total pumpage limit, if any, the actual amount pumped and the shadow price of the irrigation water if the limit is reached. The amount of irrigation water available, the actual usage, and shadow prices for each of the 18 irrigation periods is listed next. This makes it easier to identify the critical water periods and the marginal value of water during times of peak demand. Information on the costs associated with each irrigation distribution system and the acreage irrigated by each makes up the last table on page two.

Page three lists the costs and returns for each production activity on a per acre and total area planted basis. Use levels for the major inputs are given both to allow checking for plausibility and for comparison across crop, tillage method and soil types. After all production activities are listed, totals for the whole farm or region being modeled are reported.

Page four contains 3 tables. The first summarizes acreage, production and value of production for each of the six possible crops. The next lists the soils inputted, the acreage of each used for crop production and the shadow price on the last acre available if the soil is completely planted. The final table on page four again lists the production activities and shows the soil involved, whether terraces are employed, acreage planted, crops grown and their per acre yield.

When a multi-year temporal situation is modeled, the report writer prints a final summary. The summary is also four pages in length. The first page lists the price, efficiency and yield indices from the input data. This allows a quick check on the iteration related input, both for error detection and as a reminder of trends designed into a particular run.

The second page delineates the change in the groundwater situation over the time horizon. The decline in aquifer saturated thickness and subsequent well yield capacity is shown by iteration, along with the increasing pump lift. Acre-feet of water pumped per period is also given, as well as, the limit on total pumpage, if any. For those iterations where the total pumpage constraint is binding, the shadow price on the marginal acre foot pumped is reported.

Page three gives the annual acreage and production for each crop for each iteration. This overview of the shifts in cropping pattern and intensity of production is helpful when analyzing the response to decreasing water supplies under different scenarios. The fourth and last page of the summary repeats the production costs and return totals for each iteration. This again, facilitates comparison across time; making it easier to spot trends in input uses and net returns.

The last part of the summary deals with discounted present value of net returns. Net returns over variable costs and over all costs, excluding land, water and management, are separately summed using a standard present value formula. The formula is

$$\text{PVALUE} = \Sigma_{t=1}^{T} \ NR_t/(1 + \text{DRATE})^t \quad (13)$$

where PVALUE is the present value, NR_t equals the net returns in year t, and DRATE is the discount rate. The present value is calculated at three different discount rates; a rate that is exogenously set as part of the input data, and rates that equal one-half and one and one-half the inputted rate. Discounted present value is particularly useful when comparing the effects of different technologies or resource constraints over time periods greater than a single year.

Scenario Specification

A general model structure useful for a wide range of economic analyses was developed in this study. However, application of the model was for specific situations on the Texas High Plains. The scenarios were broken into two major categories, the first group dealing with representative counties of the region and the second the region as a whole. The representative county scenarios were devised as a multi-faceted sensitivity analysis. The object of this set was to define the difference and similarity of response for different resource endowments, technological options and price situations. The second group of scenarios compares the regional response to changes in technology and prices both at particular points in time and over a forty year time horizon.

Disaggregation of Regional Resources

The region was divided to reflect major differences in groundwater availability, soil texture and quality, and crop yield capability. The area to the north of the Canadian river is not currently suitable for cotton production, a major crop, and thus the first division was into northern and southern sections.

Groundwater classification. The variation in the aquifer depth and thickness dictated division by saturated thickness and pump lift, within each subregion. Because horizonal movement of water in the aquifer is very slow (Taylor 1979), a particular depth and thickness of aquifer can also be tied to an acreage and quality of land in a particular geographic location, at the level of disaggregation used in this study. After establishing acreages corresponding to increments of groundwater, natural breaks were used to group the cropland into low and high groundwater availability for both northern and southern sections of the study area.

The weighted average saturated thickness and pump lift was then calculated for each along with potential cropland, the number of wells and the contributing aquifer acres. The number of wells, contributing acres, saturated thickness and pump lifts were all from Texas Department of Water Resources reports on irrigation inventories and analytical studies of the Ogallala aquifer for most of the High Plains counties (see for example Bell and Morrison 1976, 1980a, 1980b, 1981; Wyatt, Bell and Morrison 1976a, 1976b). Cropland acreages are from *Texas County Statistics* (Texas Cropland Livestock Reporting Service). Table 15 lists the values

Table 15. Regional Resource Situation: Texas High Plains

Water Situation	Cropland Acres	Wells	Contributing Aquifer Acres	Saturated Thickness	Lift
	(000)		(000)	(ft)	(ft)
Southern Region					
Low	3,630.	28,988	4,630.	55.	145.
High	3,550.	34,616	4,872.	139.	281.
Total	7,180.	63,604	9,502.		
Actual (1979)	7,183.	64,460	9,340.		
% Error[a]	-.04%	-1.3%	1.7%		
Northern Region					
Low	263.	513	471.	77.	82.
High	2,671.	8,740	5,209.	207.	284.
Total	2,934.	9,253	5,680.		
Actual (1979)	2,623.	8,890	5,765.		
% Error[a]	11.85%	4.0%	-1.5%		

[a] Percent Total is different from Actual (1979).

derived for each resource situation.

Within each resource situation for the southern region, and for the northern region as a whole, two representative counties were chosen, one each mainly furrow or sprinkler irrigated. Since one of the purposes of the representative county scenarios is to investigate more closely impacts of geographic location and soil effects, the saturated thickness and lift is kept the same but the number of wells and contributing aquifer acres are derived from data for each individual county. Table 16 lists the counties chosen and the corresponding resource situation in

Table 16. Resource Situation, Representative Counties: Texas High Plains

Water Situation	Representative County	Wells[a]	Contributing Aquifer Acres[a]	Saturated Thickness (ft)	Lift (ft)
Southern Region					
Low -Furrow	Randall	8.93	1,331	55	145
-Sprinkler	Terry	7.31	1,230	55	145
High -Furrow	Hale	9.17	1,284	139	281
-Sprinkler	Lamb	10.42	1,499	139	281
Northern Region					
Furrow	Moore	3.36	1,619	196	252
Sprinkler	Lipscomb	1.92	1,574	196	252

[a] Per 1000 cropland acres.

each.

Soil classification. The cropland for each subregion was broken into classes for the regional analysis scenarios by texture, slope and yield capacity for the major crops. The classes are given in Table 17. Approximately ten categories were set up and the cropland acreage in each subregion was classified: first by texture; hardlands, mixed, or sandy soil, second by slope, and third by yield potential. The basic data for the classification process were from Soil Conservation Service's soil survey for most High Plains Counties. The crop acreage in each soil class was then divided between the low and high water situations by the relative weight of each in the total. The yield multiplier gives the weighted average potential of each soil category for production of the major crops. The sorghum multiplier is used when calculating expected yield for the other summer crops - corn, soybeans, and sunflowers.

The scenarios based on representative counties were developed

Table 17. Regional Land Disaggregation: Texas High Plains

Soil[a]	Acreage		Yield Multiplier		
	Low[b]	High[b]	Cotton	Wheat	Sorghum
	----- (000) -----				
Southern Region					
H01-1	906	886	1.036	1.064	1.058
H01-2	403	396	1.250	1.220	1.287
H13-1	195	191	.950	.982	1.017
H13-2	254	249	1.107	1.165	1.212
M01-1	412	403	.957	1.156	1.202
M01-2	149	145	1.214	1.202	1.337
M13-1	319	312	1.143	1.046	1.115
S13-1	416	406	.743	.000	.546
S13-2	573	560	1.000	1.000	1.000
Northern Region					
H01-1	69	692		.887	.647
H01-2	47	484		1.000	1.000
H01-3	3	29		1.211	1.171
H13-1	19	184		.734	.539
H13-2	17	178		1.019	.757
H13-3	13	136		1.039	.909
H13-4	11	122		.962	1.005
M01-1	27	270		.742	.745
M13-1	16	160		.746	.712
M13-2	12	112		1.256	1.177
S13-1	30	304		.708	.796

[a] Soil designation: H = hardlands, M = mixed, and S = sandy; next two numbers specify slope range; last number quality rank.

[b] Aquifer Water Situation as delineated in Table 15.

especially to take advantage of the soil survey data which is published on a county by county basis by the Soil Conservation Service. As such, the soil classes for each representative county were generated based mainly on the data in its particular soil survey. The procedure followed was to pick out the major cropland soils. Use the physical description to set the slope and texture parameters. Derive the acreage value by estimating the soils percentage of county cropland. And set the expected yield by the estimated average dryland yield given for each soil. Tables 18 and 19 list the soil classes for the furrow and sprinkler irrigated counties, respectively.

Table 18. Soil Classes: Furrow Irrigated Representative Counties

Soil	Acreage[a]	Texture[b]	Slope	Dryland Yield Cotton	Dryland Yield Wheat	Dryland Yield Sorghum
			(%)	(lb)	(bu)	(cwt)
Randall County						
Pullman Clay Loam	100.	H	1-3	204.	13.	13.8
Pullman Clay Loam	600.	H	0-1	230.	15.	15.
Lofton Clay Loam	100.	H	0-1	223.	15.4	16.
Ulysses Clay Loam	100.	H	0-1	230.	14.5	17.
Ulysses Clay Loam	100.	H	1-3	197.	12.5	12.9
Hale County						
Estacado Loam	30.	M	0-1	237.	15.	16.
Estacado Loam	30.	M	1-3	216.	13.	14.
Lofton Clay Loam	50.	H	0-1	237.	16.	15.7
Olton Loam	160.	M	0-1	240.	16.	17.
Olton Loam	80.	M	1-3	230.	14.	15.
Pullman Clay Loam	650.	H	0-1	230.	15.	15.
Moore County						
Dalhart Sandy Loam	80.	M	0-1	c	13.6	17.8
Harney Clay Loam	50.	H	0-1	c	16.3	17.8
Sherm Silty Clay	740.	H	0-1	c	15.	15.
Sunray Loam	50.	M	0-1	c	13.6	15.
Sunray Loam	80.	M	1-3	c	12.3	12.

[a] Per 1000 Cropland Acres.

[b] Soil Texture Groups: H = Hardlands, M = Mixed, and S = Sandy.

[c] Cotton is not a viable crop on the Northern Texas High Plains.

Sources: Blakely and Koos; Geiger; Jacquot, Geiger, Chance and Tripp.

Farm Level Analysis

The first set of scenarios is designed to analyze the response to various external stimuli (prices, resource constraints, technology) at the farm level. Within this set the first analysis deals with the impact of groundwater drawdown constraints. The LP optimization algorithm is a static, single period optimizer while groundwater, as an exhaustible resource, needs to be optimized over time, as well as per period. The recursive elements of the model cause water use per period to change the

Table 19. Soil Classes: Sprinkler Irrigated Representative Counties

Soil	Acreage[a]	Texture[b]	Slope	Dryland Yield		
				Cotton	Wheat	Sorghum
			(%)	(lb)	(bu)	(cwt)
Terry County						
Amarillo Loamy Sand	340.	S	0-3	232.	12.	13.5
Amarillo Sandy Loam	240.	M	0-1	240.	14.	17.
Amarillo Sandy Loam	90.	M	1-3	215.	12.	14.
Brownfield Sand	280.	S	0-1	185.	11.	13.
Portales Sandy Loam	50.	M	0-1	225.	13.	14.
Lamb County						
Amarillo Sandy Loam	350.	M	0-1	240.	16.	17.
Amarillo Sandy Loam	190.	M	1-3	215.	13.	14.
Amarillo Loam	90.	M	0-1	232.	15.	16.
Amarillo Loam	50.	M	1-3	215.	12.	13.
Amarillo Loamy Sand	70.	S	0-3	215.	14.	15.
Olton Loam	190.	M	0-1	230.	15.	15.
Portales Loam	60.	M	0-1	225.	14.	14.
Lipscomb County						
Acuff Soils	150.	M	1-3	c	16.	17.
Darouzett Loam	60.	M	0-1	c	15.	15.
Darouzett Loam	200.	M	1-3	c	13.5	14.5
Estacado Sandy Loam	150.	M	1-3	c	13.	14.
Grandfield Loam	290.	M	1-3	c	15.	17.
Mobeetie Sandy Loam	150.	M	1-3	c	15.	14.

[a] Per 1000 Cropland Acres.

[b] Soil Texture Groups: H = Hardlands, M = Mixed, and S = Sandy.

[c] Cotton is not a viable crop on the Northern Texas High Plains.

Sources: Newman; Saunders; Williams.

value and usage of water in the future but future value is not reflected back to the present period endogenously. However, this future value can be exogenously imposed by placing constraints on groundwater pumpage per period. By imposing the groundwater constraints parametrically and running the model over time for each step, a series of discounted present value of returns can be calculated. The groundwater limit, corresponding to the highest discounted present value, approximates the optimal temporal water use. The analysis covers the impact of discount rate, commodity prices, technology, and initial resource situation on the optimal water use and its corresponding present value of net returns. The temporally optimal groundwater constraint is imposed in the remaining analyses.

The second farm level analysis concerns expected costs, returns and crop mixes for a single period, given different resource situations, commodity prices and technology. The analysis is designed to explore the sensitivity of farm level production and income to a range of resource situations, prices and technologies, and to increase understanding of the importance and interaction of each.

Regional Level Analysis

The second set of scenarios looks at regional response over time, to the adoption of various technologies and changes in natural gas and commodity prices. Changes in cropland acreage, input use, and costs and returns are traced over a forty year time horizon for five different technology sets and two levels of natural gas and commodity prices. The importance of technology, prices and the resource endowment of the High Plains is analyzed to clarify the future agricultural possibilities of the region and what can be done to enhance them. The results from the farm level analysis are presented in Chapter 4. Regional level analysis results are discussed in Chapter 5.

CHAPTER III

FARM LEVEL ANALYSIS

Farm level analyses were conducted to provide insight into organization and impact of alternative production strategies for the farm firm over the next 40 years. These analyses focus on the groundwater and soil resource diversity of the region and difference and similarity of response to multiple technological opportunities and exogenous price signals. Response is measured by changes in cost, returns and net revenue, either at a point in time or as the present value of a discounted stream, and as changes in cropping intensity and crop mix.

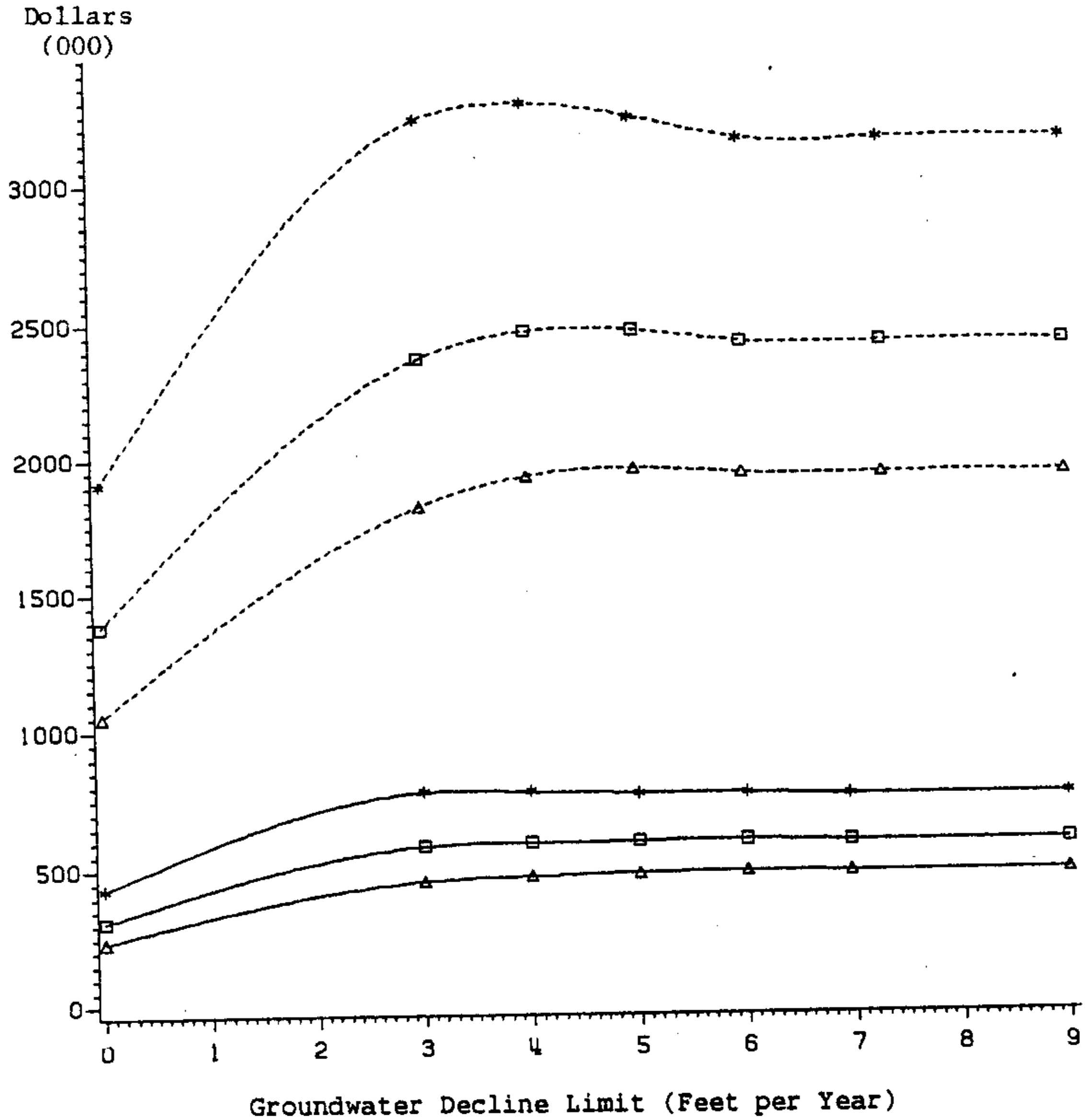
Annual Groundwater Withdrawal Limit

Due to factors external to the model including value of water for future use, weather interference with seasonal pumping, and occupational and social implications, farmers may sacrifice some present income for future income or sacrifice some expected income to maintain flexibility in the present and a larger set of future alternatives. Thus, it is important to examine the temporal economic effects of limiting annual groundwater withdrawal below that which would maximize a single years profits. Since this represents an evaluation over the long-run, revenue minus both fixed and variable cost was maximized given constraints on available land, pumping capacity for multiple periods during the year, and an overall constraint on annual water withdrawal from the aquifer. To consider how a policy of annual water withdrawal at a specific rate would impact the expected present value of its associated income stream, the analysis was applied to a planning horizon of 40 years.

Further, to test whether the discount rate used to calculate present value influences the result, three rates - 2%, 4% and 6% - were used. The operational assumptions were: Additional water should be pumped only if it contributed significantly to present value since irrigation is subject to diminishing marginal returns and stability of income is an important, if unquantified consideration. Irrigation water will only be applied if the additional return is greater than the variable cost of pumping plus the pumping fixed costs (those fixed costs associated with the pump and distribution system not the well).

Impact of Discount Rate and Price Assumptions

Illustrated in Figure 3 is the present value of discounted net revenue over a 40 year planning horizon for three discount rates at two price levels for given annual groundwater decline limits. The net revenue levels shown are for a 1000 acre farm in the southern section of the region with 139 feet of initial aquifer saturated thickness and 281



* * = 2% Discount rate
¤ ¤ = 4% Discount rate
Δ Δ = 6% Discount rate

Dashed line = Average crop prices
Solid line = Alternate low crop prices

Figure 3. Impact of Annual Groundwater Decline Limits on the Present Value of Net Revenue from 1980 to 2020. 1000 Acre Land Unit, in Hale County, Assuming Advanced Technology

feet of pump lift. This representative county (Hale) has 1.28 acres of aquifer surface per crop acre, 109 crop acres per well, and primarily hardland soils. Advanced technology - limited tillage, improved furrow irrigation, terracing and crop rotations - are also included. The plot demonstrates the importance of the chosen discount rate and expected commodity price. At a discount rate of 2% and average crop prices, discounted net returns reach a maximum of $3,289 million at a 4 foot limit while under the low price scenario the maximum of $774 million is reached at the 3 foot limit. With a higher discount rate of either 4% or 6%, the optimal withdrawal limit is 5 feet for average prices and 6 feet with low prices.

Examination of Figure 3 demonstrates that while the shape of the curves are similar, both the discount rate and expected crop prices impact the level of discounted net returns and the point of optimum temporal groundwater withdrawal limits. Also, the net revenue maximum does not change greatly within plus or minus one foot of the optimum point, and crop prices and discount rate interact. At the low discount rate the optimum annual water decline limit decreases with lower expected prices, while at higher discount rates, the optimum limit increases with lower prices.

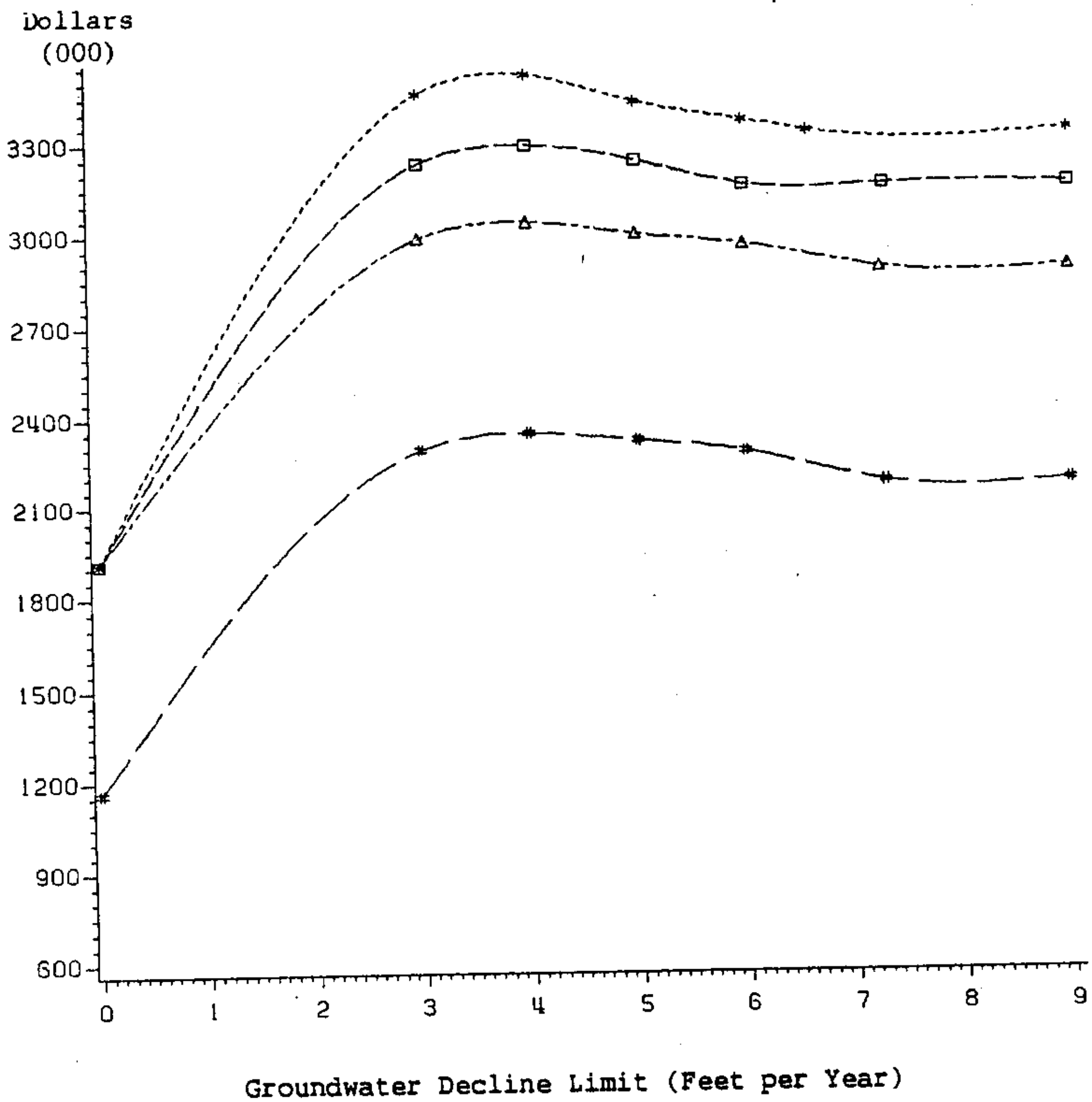
Impact of Technology

Figure 4 demonstrates the importance of the technology available to the farmer. The resource situation is the same as in Figure 3. Curves, given average prices and the 2% discount rate are shown. For the 2% discount rate the optimum annual groundwater decline limit is the same for all the technologies (4 feet), and the general shape of the curves are the same. Better technology principally inceases the net returns for each unit of water pumped. The highest incremental increase in net returns comes with the addition of limited tillage. This is because limited tillage also increases net returns on dryland crops (note the increase at the zero decline limit, i.e. all dryland). Thus, limited tillage has an impact on more acres than irrigation technologies. Though not shown, the effect of increasing the discount rate is, as previously noted, to increase the optimum decline limit to 5 feet and decease the height of the curves without changing their basic shape or relative spacing.

Impact of Initial Resource Situation

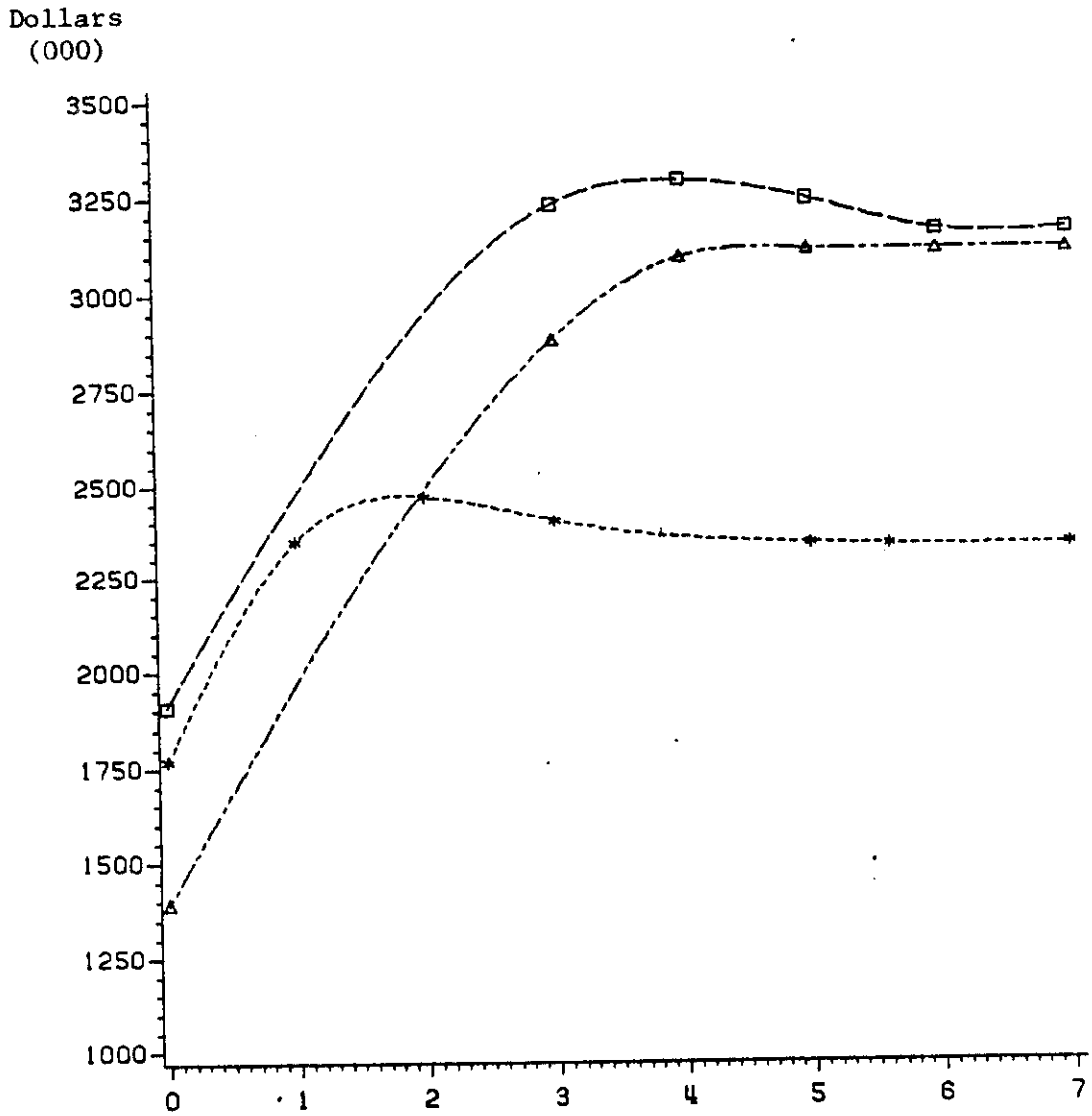
To test the importance of the initial resource situation, six representative counties were selected for analysis. The plots generated, under the assumption of average crop prices, 2% discount rate and advanced technology are shown in Figures 5 and 6. Figure 5 shows the results for the furrow irrigated, hardland soil counties and Figure 6 for the sprinkler irrigated, mixed and sandy soil counties.

The plots clearly demonstrate the value of higher initial groundwater reserves with northern and southern high initial groundwater counties (Moore, Lipscomb, Hale and Lamb) reaching maximum discounted net revenues



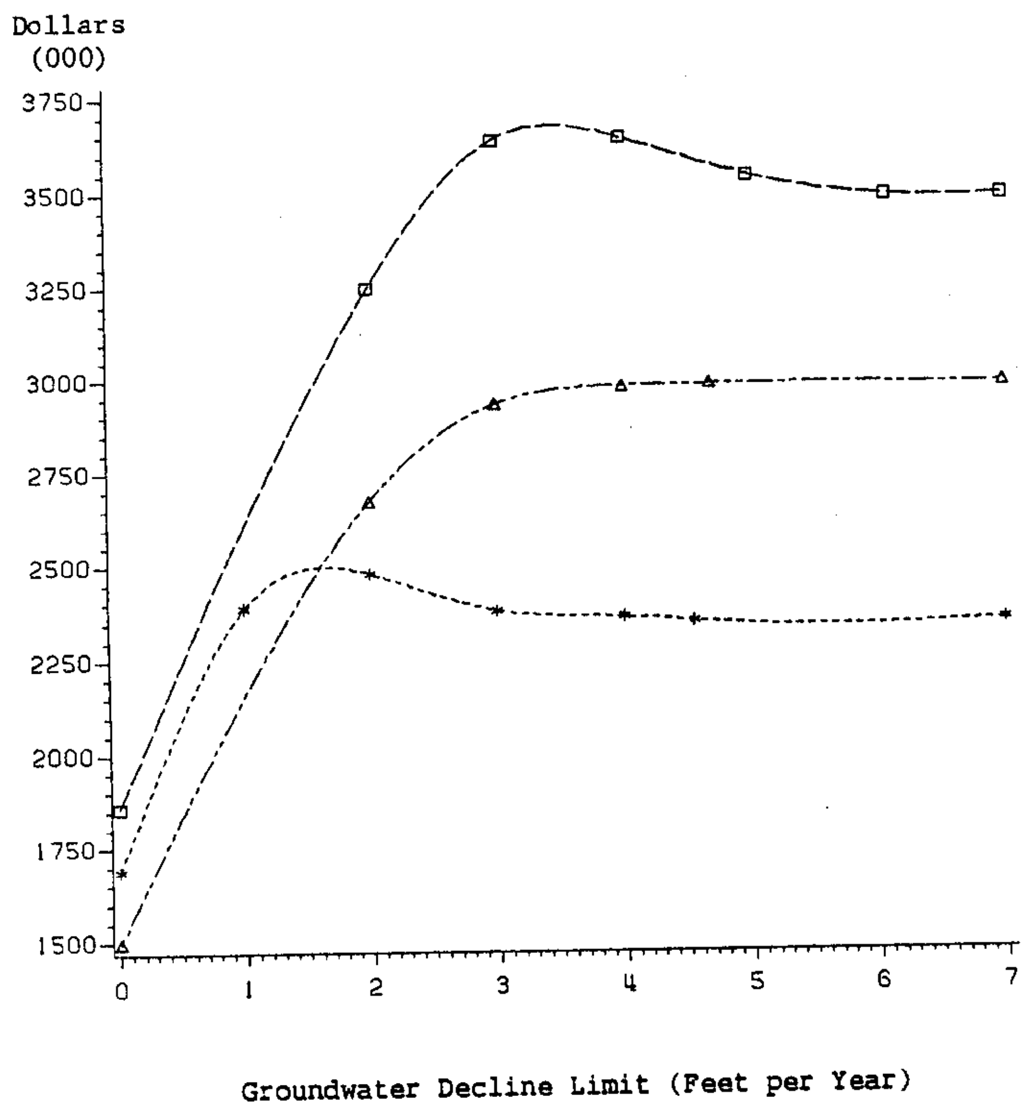
* * = Limited tillage and LEPA
¤ ¤ = Limited tillage and Improved furrow
Δ Δ = Limited tillage and Standard furrow
= Conventional tillage and Standard furrow

Figure 4. Impact of Technology and Annual Groundwater Use Limits on the Present Value of Net Revenue from 1980 to 2020. 1000 Acre Land Unit in Hale County, Assuming Average Prices and a Discount Rate of 2%



* * = Randall County
¤ ¤ = Hale County
Δ Δ = Moore County

Figure 5. Impact of Resource Situation (1)and Annual Groundwater Decline Limits on the Present Value of Net Revenue from 1980 to 2020. 1000 Acre Land Unit, Assuming Improved Furrow Irrigation, Average Crop Prices and a Discount Rate of 2%



* * = Terry County
¤ ¤ = Lamb County
△ △ = Lipscomb County

Figure 6. Impact of Resource Situation (2) and Annual Groundwater Decline Limits on the Present Value of Net Revenue from 1980 to 2020. 1000 Acre Land Unit, Assuming LEPA Irrigation, Average Crop Prices and a Discount Rate of 2%

21% to 47% greater than the low initial groundwater counties (Randall and Terry). The optimal groundwater decline limit is also a function of the initial groundwater situation with optimal annual decline limits of 2 feet for Randall and Terry, 4 feet for the deeper water southern counties of Hale and Lamb and 4.5 to 5 feet for the more favorably endowed northern counties, Moore and Lipscomb.

Other points to note include: The importance of climate - the southern counties which are suitable for cotton production have higher dryland values, and with sufficient water reach greater optimum values, than the northern subregion. The impact of soil type - the hardland soils, having higher moisture retention capacity, do slightly better than the mixed and sandy soils, under dryland conditions, in the southern region. And the importance of irrigation efficiency - the sprinkler irrigated southern counties, because they are allowed highly efficient LEPA irrigation, attain higher net revenue values at the optimum than the furrow irrigated counties, which were restricted to improved furrow systems, in this comparison.

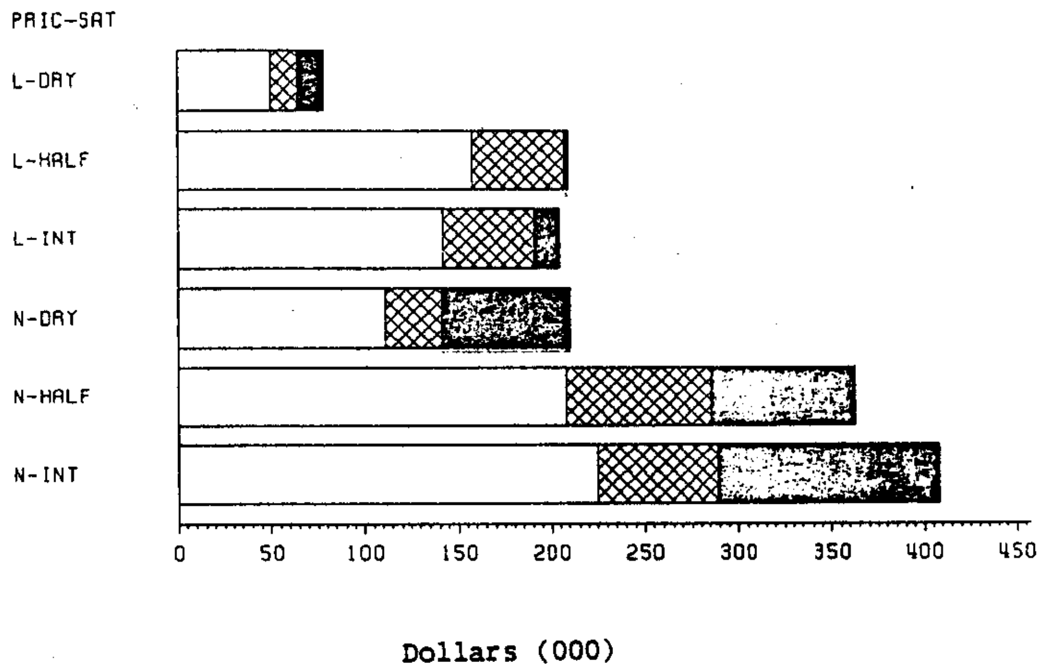
Static Resource, Price and Technology Comparisons

Within the region there is considerable variability in the resources and technology available to individual farms. Price uncertainty increases the number of decisions faced by farm managers. To better understand the importance and interaction of these variants, single period runs were made for the six representative counties under different crop price, groundwater depletion and technology sets. The impact on costs and returns and the optimal crop mix were recorded on bar charts to demonstrate the range of possible responses. Since the runs are single period, the objective for the optimization routine was the maximization of returns minus variable costs. Annual groundwater withdrawal was constrained to the long-run optimal of 2 feet per year for Terry and Randall Counties, and 4 feet per year for Hale, Lamb, Moore and Lipscomb Counties.

Impact of Price and Groundwater Availability

The first two figures in this set (7 and 8) show the change in costs and returns, and crop mix for a single representative county (Hale), under combinations of two crop price and three groundwater situations. Figure 7 emphasizes the importance of expected price to the level of production and especially to returns to land, water and management. Under normal prices, the value of production is from 64% (for dryland) to 85% (with initial groundwater availability) higher than under the low crop price expectation. Net returns, which range from $2 to $15 an acre with the low prices, increase dramatically to range between $69 and $119 with average crop prices.

Besides the change in cropping intensity, there is also a shift in optimal crop mix. As shown in Figure 8, under normal crop prices, cotton is the preferred crop for both dryland and irrigated production. Only under the more limited irrigation situation represented by the



Legend: Variable Cost   Fixed Cost

Net Revenue

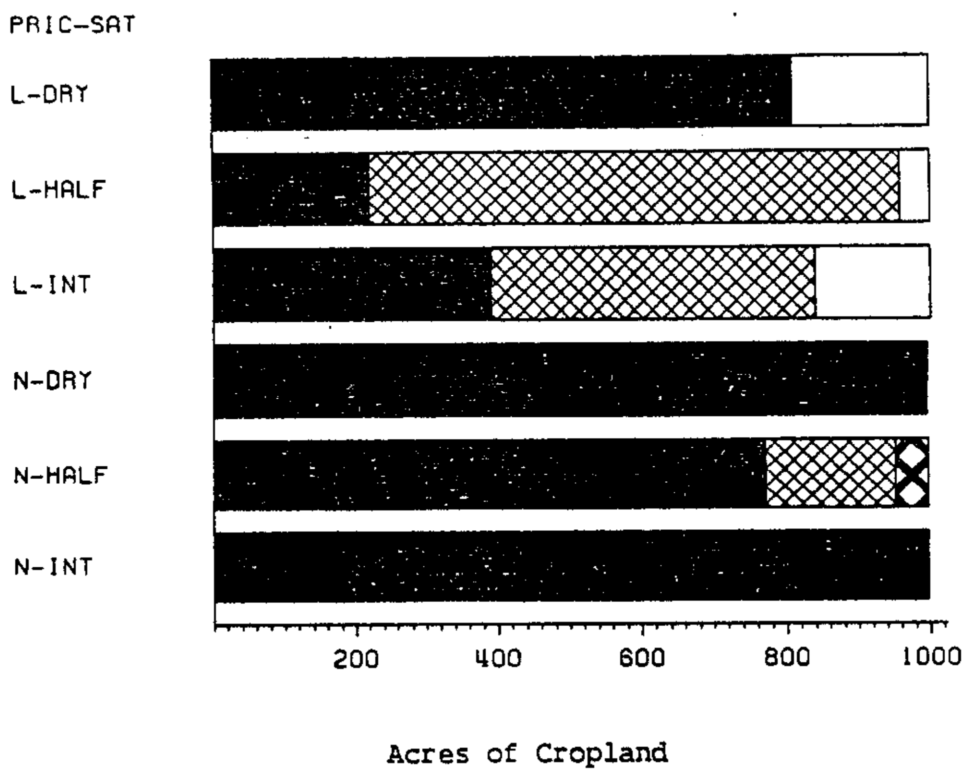
PRIC-SAT = Crop price level, Aquifer saturated thickness

L = Alternate low crop prices   DRY = Aquifer depleted

N = Normal crop prices   HALF = Aquifer half depleted

INT = Initial aquifer depth

Figure 7. Estimated Annual Variable Costs, Fixed Costs, and Net Revenue Under Alternate Crop Price and Groundwater Situations. For a 1000 Acre Land Unit, in Hale County, Assuming Advanced Technology



Legend: Cotton — Feedgrains — Oilseeds — Wheat

PRIC-SAT = Crop price level, Aquifer saturated thickness

L = Alternate low crop prices — DRY = Aquifer depleted

N = Normal crop prices — HALF = Aquifer half depleted

INT = Initial aquifer depth

Figure 8. Estimated Cropping Pattern Under Alternate Crop Price and Groundwater Situations. 1000 Acre Land Unit, in Hale County, Assuming Advanced Technology

groundwater half depleted point does significant amounts of sorghum and wheat enter the cropping pattern. However, when low prices are assumed there is a pronounced shift to feed grains under irrigation and dryland sunflowers. This is primarily due to low cotton prices being 65% of normal while low feedgrain and oil seed prices are 76% and 69% of normal prices, respectively. The relative shift in prices, in favor of feedgrains and oils, is reflected in the changed cropping pattern.

Changes Across Representative Counties

To study the impact of different soil-climate situations on costs, returns and crop mix, a single crop price-groundwater situation was run for each representative county. While this means the prices are the same for all counties, the groundwater situations are not the same but parallel, in that each has half its original groundwater endowment for these runs. Also, advanced technology is available for all, with improved furrow for the "hardlands" counties and LEPA for the sprinkler irrigated counties.

As can be seen in Figure 9, the different counties have considerably different levels of production under the stated assumptions, ranging from $253 worth of production per acre in Randall County to $406 in Lamb County. But what is particularly interesting, is that this wide range is not carried over to the profit portion of the gross returns. Indeed profits only range from $74 per acre in Terry County to $82 in Moore County, no more than plus or minus 6% of the $79 average.

Figure 10 shows the cropping patterns that exist across counties under these assumptions. In the southern counties, cotton production predominates with most of the remaining acreage in grain sorghum for the better water (Hale and Lamb Counties) and an even mix of other crops in the water scarce Randall and Terry Counties. In the north, wheat is a much more important crop. It is grown in combination with irrigated corn, sorghum, soybeans and large amounts of dryland sunflowers. Much of the sunflowers are grown in rotation with fully irrigated wheat to take advantage of the moisture remaining in the soil after the wheat is harvested.

Profit Comparison

For each of the six representative counties, six different price-groundwater situations were run. Figure 11 lists the per acre average returns over variable and fixed cost for each run. With normal prices, the net revenue ranges from $51 per acre in the northern sector under dryland farming, (N-DRY) to $129 per acre (Lamb County) with the initial amount of groundwater available (N-INT). Under dryland conditions, the ability to grow cotton increases southern net revenue approximately $15 per acre relative to the north. When groundwater is available, this difference is overshadowed by the importance of irrigation.

Under the normal price, half depleted aquifer assumption (N-HALF), the net revenue is practically the same across the High Plains, deviating less than $5 from the simple mean. Given initial groundwater levels

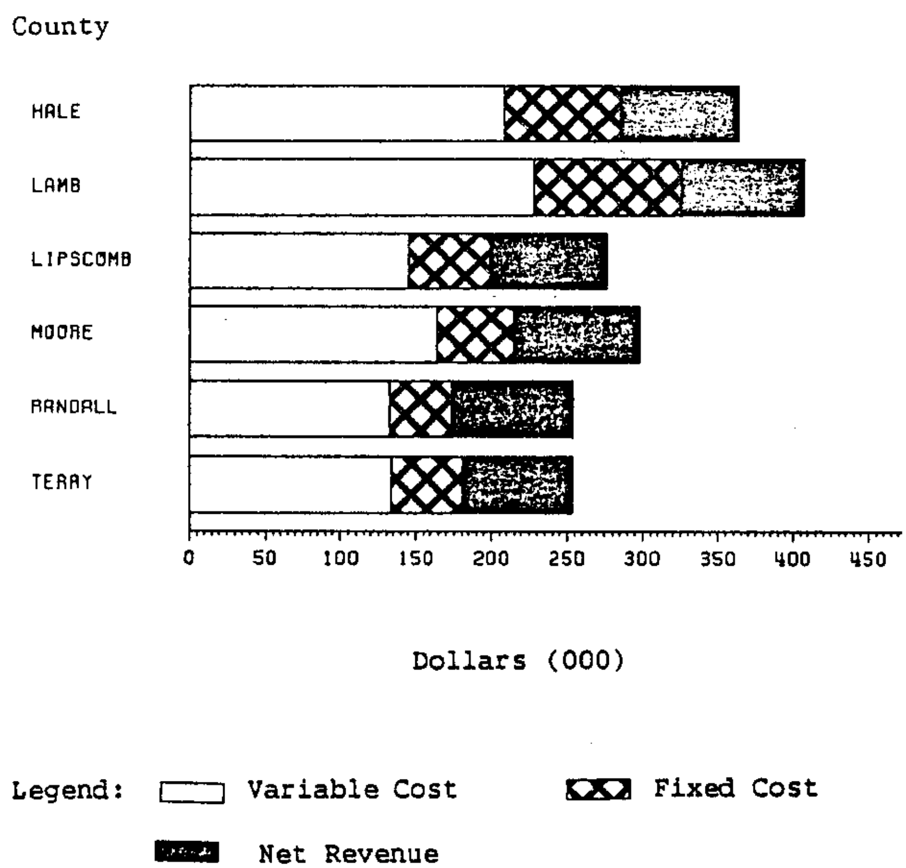


Figure 9. Estimated Annual Variable Costs, Fixed Costs, and Net Revenue for Representative Counties. Assuming Depletion of Half the Aquifer Water Supply, Advanced Technology, and Average Crop Prices, for a 1000 Acre Land Unit

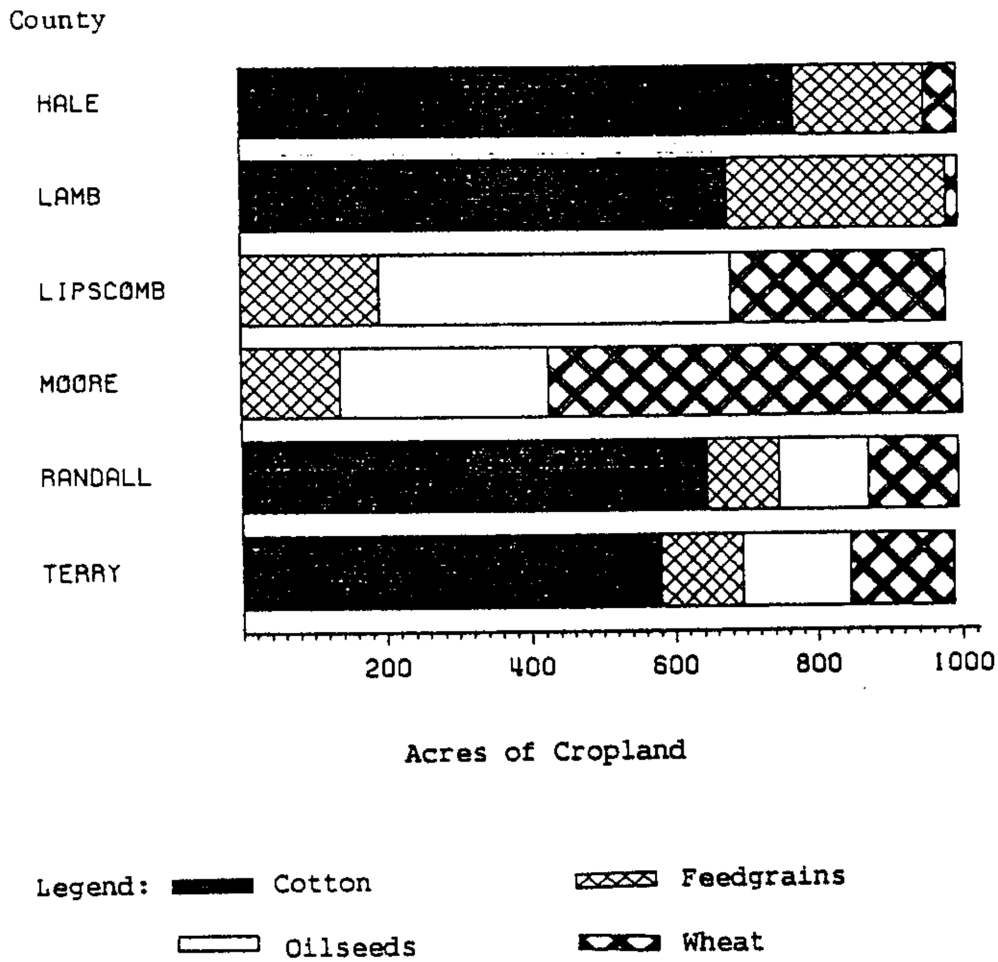
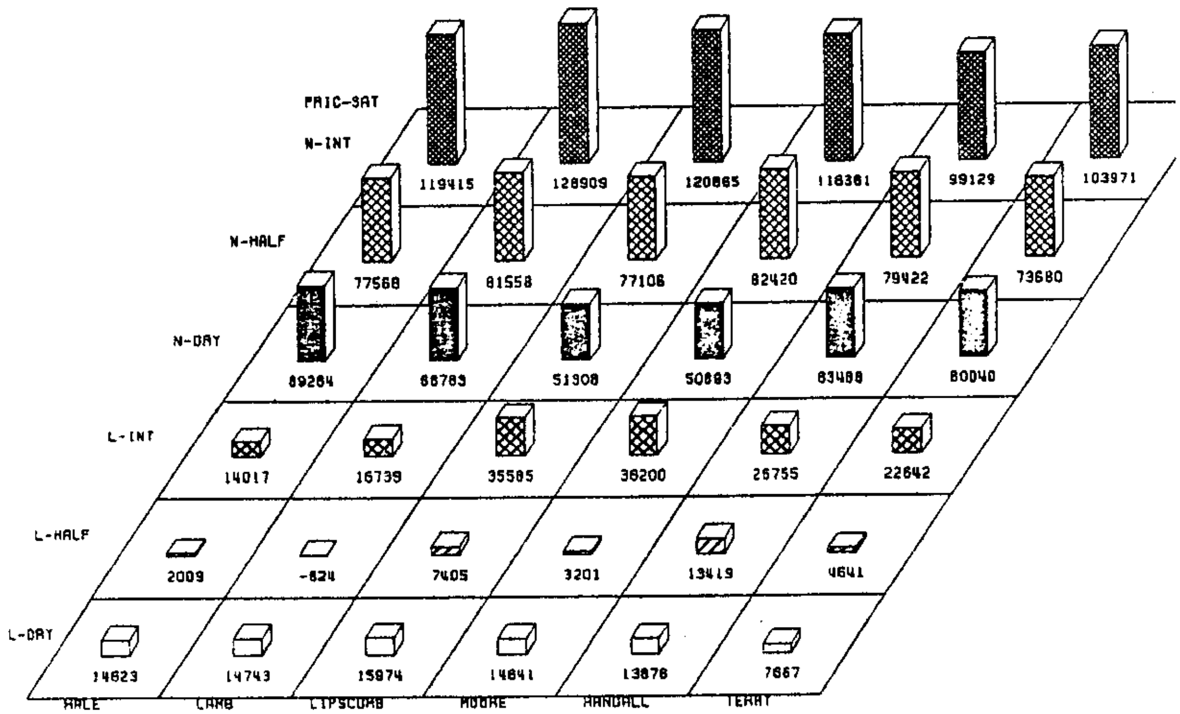


Figure 10. Estimated Cropping Pattern for Representative Counties. Assuming Depletion of Half the Aquifer Water Supply, Advanced Technology, and Average Crop Prices for a 1000 Acre Land Unit



County

PRIC-SAT = Crop price level, Aquifer saturated thickness

L = Alternate low crop prices DRY = Aquifer depleted

N = Normal crop prices HALF = Aquifer half depleted

INT = Initial aquifer depth

Figure 11. Estimated Annual Net Revenue by Selected Crop Price and Groundwater Situations Over Representative Counties. Assuming Advanced Technology and a 1000 Acre Land Unit

(N-INT) the variation in net revenue is much greater ranging from $99 in Randall to $129 in Lamb County. Further, the importance of groundwater is clear, as the southern low water counties (Randall and Terry) have net revenues $15 to $20 below the high water areas. Differences in technology are also shown. The LEPA irrigated counties, Terry, Lamb and Lipscomb, each out performs its hardland counterpart, which is restricted to less efficient, improved furrow irrigation systems. And this, in spite of the fact that the hardland soils are more productive under dryland cropping.

The net returns outlook changes dramatically under the assumption of low commodity prices. The low commodity prices combined with stable fixed and variable costs reduces net revenue to a range from less than zero to $36. Not only does the magnitude change but the relative profitability across counties and groundwater levels also shifts. These shifts are primarily caused by relative price changes and the optimization assumption used for this set of runs. The price decrease for cotton is 35%, while for feed grains, it is only 24% resulting in the southern regions losing much of their economic advantage from cotton. The optimization was performed using the maximization of returns over variable costs as the objective function. This implies that the low prices are not the long run expected price and hence, the farmer can adjust his variable expenditures but not his fixed costs. The revenue reported here is net of both variable and fixed costs and thus, the large fixed costs connected with irrigation have a significant impact.

The net returns under dryland (L-DRY) are nearly the same across the region except for Terry County, which has the largest amount of sandy and less productive soils. With initial groundwater levels (L-INT), the low groundwater counties of Randall and Terry do better than Hale and Lamb because their water is closer to the surface (initial pump lift equal to 145 feet versus 281 feet) and the lower pumping costs outweigh the limits on water availability.

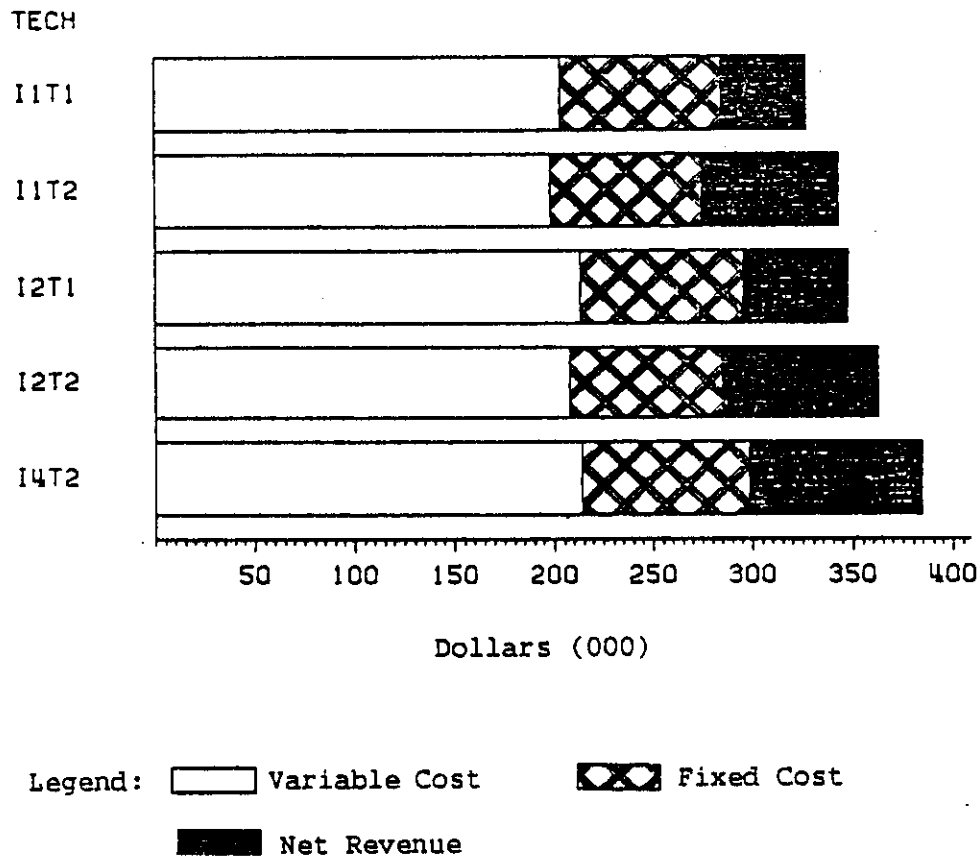
The impact of high fixed and variable pumping costs are particularly apparent with the half depleted groundwater situation (L-HALF). Here, while irrigating increases returns over variable costs compared to dryland cropping, the high fixed costs associated with irrigation actually reduces comparable net revenue and even drives it slightly negative in the case of Lamb County.

Technology Impact

Five technology sets were defined and applied to a single county (Hale), for three levels of groundwater under normal crop prices and a maximum annual groundwater drawdown of four feet. The technologies tested were:

1) Conventional tillage and furrow irrigation (I1T1).
2) Limited tillage with conventional furrow irrigation (I1T2).
3) Conventional tillage and improved furrow irrigation (I2T1).
4) Limited tillage and improved furrow irrigation (I2T2).
5) Limited tillage with LEPA irrigation (I4T2).

Figure 12 shows the costs and returns associated with each technology set for the midpoint in aquifer depletion . While the value of production increases with advanced technology, the increase is not dramatic changing



TECH = Technology set assumed

I = Irrigation system

I1 = Standard furrow

I2 = Improved furrow

I4 = LEPA

T = Tillage method

T1 = Conventional tillage

T2 = Limited tillage

Figure 12. Estimated Annual Variable Costs, Fixed Costs, and Net Revenue Given Alternate Technology Sets. Assuming Depletion of Half the Aquifer Water Supply, Average Crop Prices, and a 1000 Acre Land Unit in Hale County

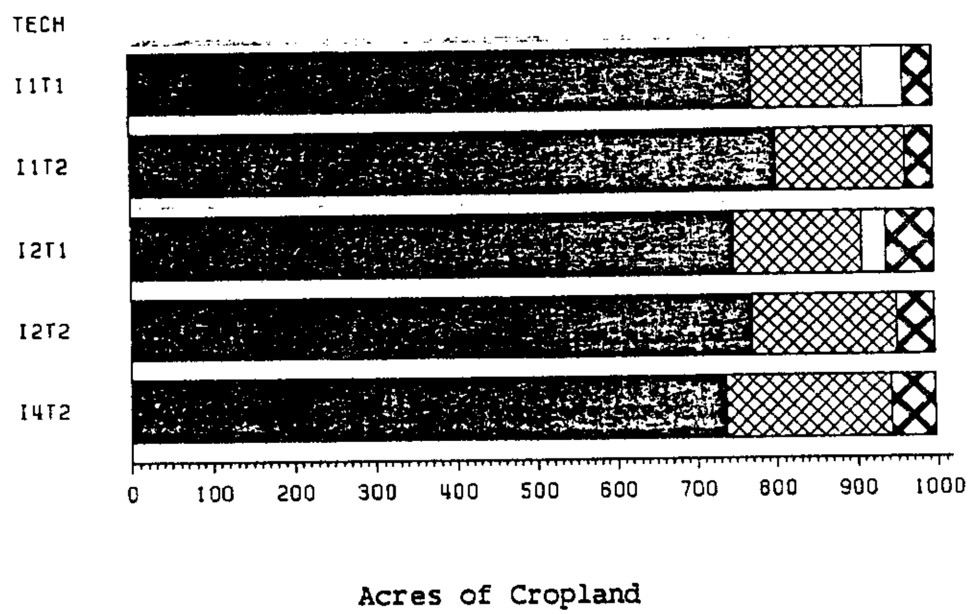
from $327 per acre for the base technology to $385 per acre for the fifth combination, a change of less than 18%. Variable and fixed costs are even more stable, with variable costs ranging from $189 for I1T2 to $214 for I4T2 and fixed costs ranging from $77 for I1T2 to $84 for I4T2. Both vary less than 9%. Net revenue however, increases a much greater percentage, going from $42 for I1T1 to $86 for I4T2, or more than 100%.

Production (gross returns) is greater for conventional tillage with improved furrow (I2T1), while net returns are greater for limited tillage with conventional furrow irrigation (I1T2). This emphasizes the point that net returns are not a fixed percentage of gross returns. Technological change has distributional effects on costs and returns, as well as an overall impact on production.

The cropping pattern for each technology set under the given assumptions is shown in Figure 13. The pattern stays relatively stable overall with some soybean acreage for conventional tillage and irrigated sorghum acreage increasing with more advanced technology. While cotton acreage predominates and is relatively stable ranging from 737 acres for I4T2 to 801 acres for I1T2, the major cropping change is in the amount of dryland acres, all of which are planted to cotton. The use of advanced techniques allow an intensificaton of crop production, permitting total irrigated acreage to increase from 628 acres to 814 acres or nearly 30%. As part of this increase, the production of cotton in physical units, increases 6%, sorghum increases 58% and wheat increases 45%. Only soybean production decreases, dropping out of the cropping pattern completely due to its relative inefficiency under limited tillage. The irrigation efficiency gain assumed for limited tillage is 11% for sorghum, 8% for wheat, 3% for cotton and 2% for soybeans. Exactly the same order in which production gains take place.

Indicated in Figure 14 are the changes in net returns for each technology set under the three groundwater situations. The greatest impact is generated by the switch to limited tillage, and the impact is greater the more severe the water limitation. Furthermore, tillage interacts very little with the irrigation technology change, increasing net returns by nearly the same amount when coupled with either conventional or improved furrow irrigation.

Comparing net revenue levels shows that improved technology can substitute, and compensate for, reduced resource endowments, but only over a certain range. Once the groundwater resource is sufficiently depleted, it is very unlikely that with present knowledge, per acre net returns can be maintained.



Legend: Cotton — Feedgrains — Oilseeds — Wheat

TECH = Technology set assumed

I = Irrigation system

I1 = Standard furrow

I2 = Improved furrow

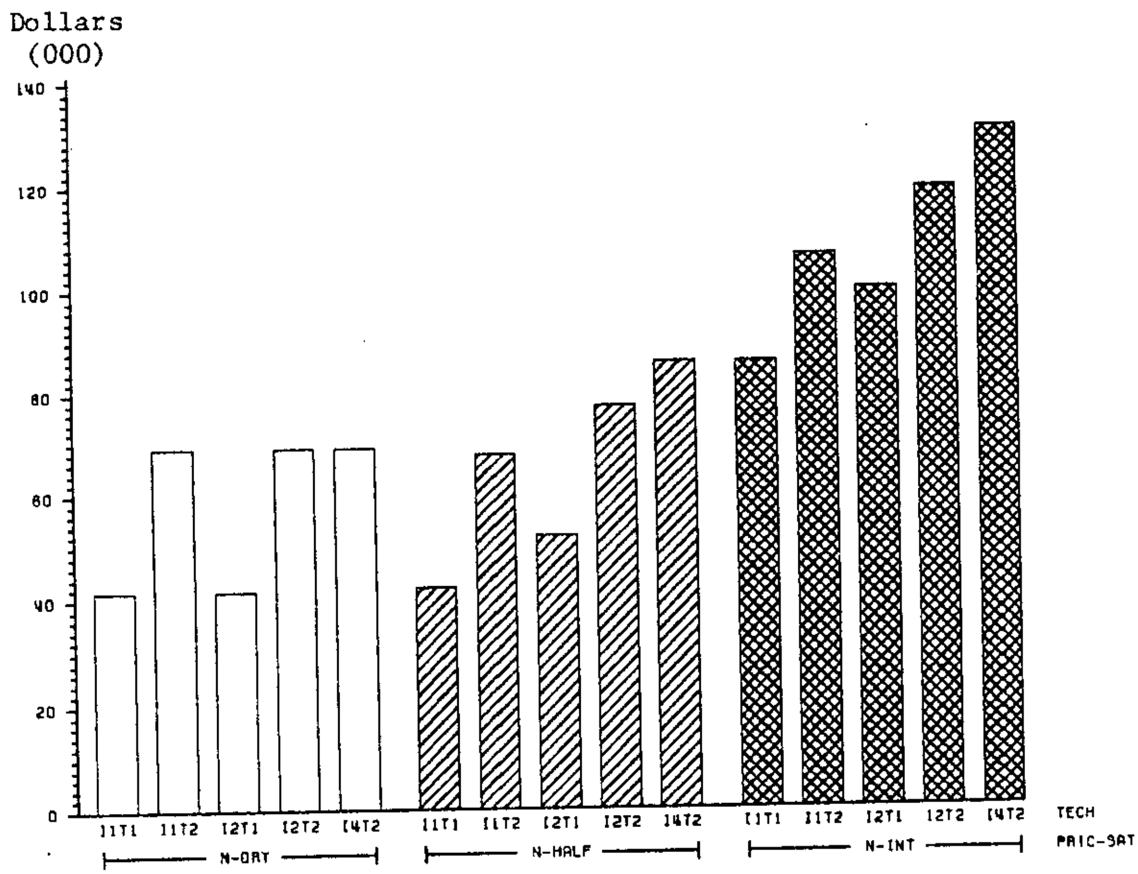
I4 = LEPA

T = Tillage method

T1 = Conventional tillage

T2 = Limited tillage

Figure 13. Estimated Cropping Pattern Given Alternate Technology Sets. Assuming Depletion of Half the Aquifer Water Supply, Average Crop Prices, and a 1000 Acre Land Unit in Hale County



TECH = Technology set assumed
- I = Irrigation system
  - I1 = Standard furrow
  - I2 = Improved furrow
  - I4 = LEPA
- T = Tillage method
  - T1 = Conventional tillage
  - T2 = Limited tillage

PRIC-SAT = Crop price level, Aquifer saturated thickness
- N = Normal crop prices
- DRY = Aquifer depleted
- HALF = Aquifer half depleted
- INT = Initial aquifer depth

Figure 14. Estimated Annual Net Revenue by Selected Average Crop Price and Groundwater Situations Over Specified Technology Sets. Assuming a 1000 Acre Land Unit in Hale County

CHAPTER IV

REGIONAL ANALYSIS

It is important to understand how the introduction of new technologies effects net revenue, and how initial resource endowment and exogenous prices, influences this. Thus, the importance of farm level analyses. However, society may be more interested in the level of production and profitability of the High Plains farm sector as a whole. What happens in the larger, regional context is more important to the other sectors of the economy, as consumers of agricultural products, suppliers of agricultural inputs, and sellers of consumer goods to the people who make their income in agriculture. Therefore, the model was applied to the total region to estimate the regional implications for farm revenue, cropping patterns and crop production.

The soils and groundwater resource situations in the High Plains were aggregated into four subregions. A series of nine scenarios were run for each of the subregions and the outputs aggregated to derive regional results. Assumptions common to all runs include: Constant input and commodity prices over time. Land quality is maintained over time. The groundwater supply and number of wells are fixed at initial levels, thus irrigation in one period reduces water availability for future years, and increases pumping cost. Groundwater decline limits of 2 feet per year for low initial groundwater and 4 feet per year for high initial groundwater are exogenously imposed. Technology is adopted instantaneously to the level of profitability. And the region acts as a profit maximizer without institutional or financial constraints on production.

Present Value of Net Returns

The nine scenarios included in the regional analysis and their discounted net returns for a forty year time horizon are given in Table 20. The first five scenarios consider the impact of technology assuming average crop prices, the last four investigate the interactive effects of alternate price assumptions with technology.

Scenario 1 is the base from which changes in discounted net revenue are compared. It assumes conventional tillage, standard furrow irrigation for hardland soils, and high pressure sprinkler irrigation on mixed or sandy soils. Terracing and crop rotation options are also unavailable. Scenarios 2 through 5 sequentially add improved technologies to the set available for crop production. For "2" limited tillage is added, for "3" the LEPA distribution system on mixed and sandy soils, for "4" improved furrow is included on hardland soils, and for "5" terracing options and rotations are added. Scenario 6 is the same as the base scenario (1) with alternate, low commodity prices assumed. Scenario 7 imposes the same low prices combined with a complete technology set (i.e. scenario 5 with low prices). Likewise, scenarios 8 and 9 are equivalent

Table 20. Present Value of Net Returns for the Period of 1980 to 2020: Texas High Plains[a]

Scenario	Discount Rate 2 %	4 %	6 %
	------Million $------		
1 Base: Conventional Technology, Average Prices	25777	19398	15229
2 Base + Limited Tillage	32290	24020	18688
Return as Percent of Base (1) Return	126	124	123
3 Base + Limited Tillage and LEPA	34039	25368	19761
Return as Percent of Base (1) Return	132	131	130
4 Base + Limited Till, LEPA and Improved Furrow	35554	26516	20667
Return as Percent of Base (1) Return	138	137	136
5 Base + Advanced Technology	36660	27181	21086
Return as Percent of Base (1) Return	142	140	138
6 Base with 20 Year Low Commodity Prices	6006	4678	3776
Return as Percent of Base (1) Return	24	24	25
7 Base + Advanced Technology and Low Prices	11675	8850	6987
Return as Percent of Base (1) Return	45	46	46
8 Base with $8.86 per mcf Natural Gas	17461	13122	10316
Return as Percent of Base (1) Return	68	68	68
9 Base + Advanced Technology with $8.86 Gas	27813	20771	16221
Return as Percent of Base (1) Return	108	107	107

[a] A total of 10,121,000 acres of cropland were included in the analysis.

to scenarios 1 and 5, including normal commodity prices but with the natural gas price increased from $3.85 to $8.86 per mcf. Natural gas fuels a majority of the irrigation pumps on the Texas High Plains and as such is a major cost item for irrigated agriculture. The value, $8.86 per mcf, is the expected 1982 price of natural gas if the natural gas market was deregulated (Turhollow, Short and Heady).

As expected, the higher discount rates reduce the net present value, having a greater absolute impact the higher the net returns per year and the further into the future they occur. Percentage change from base returns clearly show the impact of low prices, reducing discounted net returns to 24% for base technology and to 45% even with the full technology set assumed. An increased natural gas price is also quite damaging to net returns, lowering returns to 68% of base levels, but the impact can be overcome by the introduction of advanced technology. With a full technological complement, net returns equal 108% of base.

Among the various technologies tested, limited tillage is shown to be the most important to long run net present value of farm income. This is because limited tillage increases the production efficiency of both dryland and irrigated acres. However, if a large increase in the cost of chemicals were added, or the quality of management was fixed, then the value of limited tillage would be much less, since limited tillage is dependent on greater chemical use and higher levels of management.

LEPA appears to have a slightly greater impact among the irrigation techniques, increasing the present value of discounted revenue $1749 million versus $1515 million for improved furrow at the 2% discount rate. Though seemingly minor, terracing and rotation techniques increase net present value $1106 million with the 2% discount rate. This is partially due to the impact on dryland crops directly but also because mixed rotations allow irrigation to increase dryland yields.

The effect of rotations on present value is more dependent on the discount rate than is true for irrigation technology because its greatest contribution comes in the final decades of the time horizon when the aquifer is nearly depleted. Advanced irrigation technologies as well as rotations, terracing and other techniques each increase the present value of net returns up to 140% of the base when all are available.

Results by Scenario, Over Time

Each scenario was run for a forty year time horizon and annual results synthesized for the years 1980, 1990, 2000, 2010 and 2020. The divison of cropland acreage into dryland, irrigated and fallow is shown, along with usage levels of the major inputs, in physical units. The value of production (gross returns), total variable costs, fixed costs and net revenue are also listed.

Base Scenario

Table 21 gives the results of the base run (Scenario 1) for the decade years in the forty year time horizon. Irrigation is applied to 6 million acres or approximately 60% of the cropland in 1980. This is roughly equal to the 5.5 to 6 million acres irrigated on the High Plains during the past two decades (Texas Department of Water Resources). The 7.5 million acre feet of irrigation water pumped is also within the actual pumpage range documented in the 1970's. Over time, both water pumped and irrigated acres decline but not at the same rate. As the aquifer declines, the combination of increased pumping cost, and lower well yield (in gpm), increases the incentive to reduce total irrigated acres and concentrate the remaining water on more intensely irrigated crop production activities. Thus, the acre feet of water applied per irrigated acre increases from 1.23 feet per acre in 1980 to 1.68 feet per acre in 2010. Land no longer irrigated is dryland cropped; it does not revert to rangeland.

As could be expected, given economic theory, with the increased cost

Table 21. Regional Analysis: Base with Average Input and Commodity Prices, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	3838	4236	5641	8206	9910
Percent		38	42	56	81	98
Irrigated	000 ac	6098	5700	4295	1730	26
Percent		60	56	42	17	0
Fallow	000 ac	184	184	184	184	184
Percent		2	2	2	2	2
Inputs:						
Water	000 ac-ft	7523	7505	6102	2902	40
Labor	Million hr	53	53	50	44	38
Natural Gas	Million mcf	68	76	71	36	0
Diesel	Million gal	124	130	129	121	117
Nitrogen	000 ton	145	196	207	140	70
Phosphorus	000 ton	106	118	114	80	48
Gross Returns	Million $	3186	3137	2770	2160	1697
Total Variable Cost	Million $	1766	1819	1668	1327	1037
Total Fixed Cost	Million $	289	287	274	263	254
Net Revenue	Million $	1129	1034	828	569	406

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

of pumping water, input substitution occurs and the use of diesel (and hence machinery) and fertilizer increases. For any individual production activity, water and the other inputs are *technical complements* since an increase in the use of one increases the use of all. However, for the farm (or region) as a whole, it is possible to shift among different production activities. This creates an opportunity for overall economic input substitution, at least within some range. An *economic substitute* being one whose level of use increases when the *cost* of the other increases. Natural gas use also increases but that is tied to the increased pump lift as the aquifer is drawn down. The shifts within production activities enable the value of output to be maintained fairly well (less than 2% decline) for the first decade. However, as time passes, the importance of water becomes clear. Output by 2020 drops to 53% of the 1980 value. The impact on net revenue is quicker and greater, dropping by 8% in the first decade and to 36% of the 1980 estimate by 2020.

Base Plus Limited Tillage

Adding the option of limited tillage to the base scenario both increases gross returns and net revenue per period and reduces their percentage decline over time. As can be seen in Table 22, gross returns start out higher than in the base, actually increase in 1990 and then drop off more slowly, maintaining 61% of the 1980 value in 2020. Net revenue also starts higher and remains more stable, dropping 47% from 1980 to 2020. This is caused, in part, by increased crop acres since 184,000 acres move from fallow into dryland crops. Also, more water is pumped and a higher percent of cropland is irrigated in all years except 1980. The increase is slight at first but by the last period the difference is 1.3 million acre feet of water and 750,000 acres. Labor and machinery use is reduced approximately 25% in the first period, and in spite of the increased stability of production with limited tillage, the reduction is even greater in the final periods. This happens because the labor and machinery advantage of limited tillage over conventional tillage is proportionally larger for dryland crops, which cover most of the cropland acreage toward the end of the time horizon.

Base Plus Limited Tillage and Advanced Irrigation Systems

Adding LEPA irrigation for all the sprinkler irrigated mixed and sandy soils increased 1980 irrigated acreage by nearly 500,000 acres to 65% of the cropland (Table 23). Concomitantly, water pumped increases only 7,000 acre feet decreasing the average intensity of irrigation per acre. The exogenous annual groundwater decline limits keep total pumpage from expanding further in the early periods. Nonetheless, due to the LEPA increase in efficiency of water use, less water is needed per acre for the same level of production, thus allowing expansion over more acres with the same water supply.

Production increases another $108 million beyond scenario 2 in 1980 and remains higher, but only by $8 million in 2020. Net revenue is also

Table 22. Regional Analysis: Base plus Limited Tillage, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	4072	4135	5742	8176	9333
Percent		40	41	57	81	92
Irrigated	000 ac	6048	5985	4378	1944	787
Percent		60	59	43	19	8
Fallow	000 ac	0	0	0	0	0
Percent		0	0	0	0	0
Inputs:						
Water	000 ac-ft	7525	7511	6120	2946	1350
Labor	Million hr	40	40	36	29	25
Natural Gas	Million mcf	66	75	71	36	16
Diesel	Million gal	90	95	93	85	79
Nitrogen	000 ton	163	220	236	163	113
Phosphorus	000 ton	116	131	127	91	70
Gross Returns	Million $	3321	3335	2975	2328	2041
Total Variable Cost	Million $	1731	1819	1657	1277	1099
Total Fixed Cost	Million $	247	248	238	237	235
Net Revenue	Million $	1344	1267	1079	814	706

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

Table 23. Regional Analysis: Base plus Limited Tillage and LEPA, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	3534	3534	5337	7946	9296
Percent		35	35	53	79	92
Irrigated	000 ac	6586	6586	4783	2174	824
Percent		65	65	47	21	8
Fallow	000 ac	0	0	0	0	0
Percent		0	0	0	0	0
Inputs:						
Water	000 ac-ft	7530	7513	6137	3009	1345
Labor	Million hr	41	41	37	29	25
Natural Gas	Million mcf	61	69	65	36	15
Diesel	Million gal	94	99	95	84	79
Nitrogen	000 ton	177	239	247	169	114
Phosphorus	000 ton	123	139	133	93	70
Gross Returns	Million $	3429	3423	3043	2352	2049
Total Variable Cost	Million $	1756	1826	1662	1287	1100
Total Fixed Cost	Million $	250	249	240	235	235
Net Revenue	Million $	1424	1347	1140	829	713

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

higher throughout, but slightly less stable, dropping 50% from 1980 to 2020. Labor and machinery use increase in the first decades, but are nearly the same as with limited tillage alone by 2020. The initial increase is a consequence of 37,000 more acres under irrigation while water pumpage declines only 5,000 ac-ft. The increased labor and machinery associated with irrigated crops is offset by the lower distribution costs per acre.

With both LEPA for sprinkler irrigated acres and improved furrow on the hardland soils (Table 24), irrigated acreage reaches 70% of available cropland in 1980. An extra 100,000 acres are still under irrigation in 2020, with improved furrow added to the technology set. Water use is nearly the same to slightly lower, again because of the increased irrigation efficiency per acre, the binding water constraints and changes in irrigated acreage. The labor requirement increases 4 million hours in 1980 because of the increased amount of irrigated cropland and the slightly greater labor need per acre-inch with improved furrow. Gross returns are $102 million and net returns $69 million higher in 1980, with the addition of improved furrow. By 2020, the difference has decreased to $27 million for gross returns and $14 million for net revenue. Even though total fixed costs increase very little, the change in variable costs are sufficiently large that net revenue as a percent of gross revenue stays practically constant at 42% for 1980, declining to 35% by 2020. The decline in this marginal return to land, water and management reflects both the declining value of the remaining water supply and the increased costs of pumping it.

Base Plus All Available Technology

Table 25 lists the results for the five decade years, given average input and commodity prices and the complete set of technologies considered. Along with limited tillage and advanced irrigation techniques, the runs reported in this table include terracing options for sloped land and both mixed (part dryland, part irrigated) and dryland rotations. While the increase in gross returns is small in the first decades, equaling only $8 million in 1980, by 2020, the difference is $120 million, relative to scenario 4 (Table 24) values. The timing of this change is directly opposite that of advanced irrigation techniques and is due to its application on dryland as well as irrigated acreage. Net revenue increases $9 million in 1980, $1 million more than gross returns, as total variable costs remain constant and total fixed costs actually show a small decline. Fixed costs are less, since 165,000 acres shift out of irrigation; 72,000 acres to dryland and 93,000 acres to fallow.

Irrigated acreage is the most stable with this technology set, starting with 68% of the cropland irrigated and ending in 2020 with 13% still under irrigation. Water pumpage is also more stable, starting only slightly higher (due to binding aquifer drawdown constraints) but maintaining higher pumpage levels throughout the 40 year horizon. In 2010 pumpage is 2.4 million acre-feet greater than for any other scenario. These figures emphasis the importance of mixed and dryland rotations, especially as water becomes scarce. While terraces were applied to some of the more sloping soils, their high fixed cost seems to have precluded their use on much of the land. However, if soil erosion costs

Table 24. Regional Analysis: Base plus Limited Tillage, LEPA and Improved Furrow, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000ac	3066	3232	5014	7821	9190
Percent		30	32	50	77	91
Irrigated	000 ac	7054	6888	5106	2299	930
Percent		70	68	50	23	9
Fallow	000 ac	0	0	0	0	0
Percent		0	0	0	0	0
Inputs:						
Water	000 ac-ft	7529	7517	6131	2902	1363
Labor	Million hr	45	45	40	31	26
Natural Gas	Million mcf	61	69	65	34	15
Diesel	Million gal	94	99	96	86	80
Nitrogen	000 ton	178	242	259	170	121
Phosphorus	000 ton	127	143	139	94	73
Gross Returns	Million $	3531	3518	3139	2400	2076
Total Variable Cost	Million $	1787	1861	1708	1303	1113
Total Fixed Cost	Million $	252	248	239	237	235
Net Revenue	Million $	1493	1408	1189	859	727

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

Table 25. Regional Analysis: Base plus All Available Technology, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	3139	3132	4129	6431	8809
Percent		31	31	41	64	87
Irrigated	000 ac	6889	6895	5990	3678	1288
Percent		68	68	59	36	13
Fallow	000 ac	93	93	1	12	23
Percent		1	1	0	0	0
Inputs:						
Water	000 ac-ft	7591	7554	7410	5416	2062
Labor	Million hr	45	45	41	31	28
Natural Gas	Million mcf	61	69	76	65	24
Diesel	Million gal	94	98	94	78	78
Nitrogen	000 ton	182	233	296	260	142
Phosphorus	000 ton	129	141	151	123	82
Gross Returns	Million $	3539	3503	3295	2645	2196
Total Variable Cost	Million $	1787	1836	1791	1484	1199
Total Fixed Cost	Million $	250	247	232	216	244
Net Revenue	Million $	1502	1420	1273	945	752

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

had been included in the model, terracing might have been profitable on more of the steeper sloped soils.

The regional impact of imposing different technology sets, as shown in Tables 21 through 25, follow fairly closely the results from the farm level analysis. Limited tillage has the greatest impact on both production and net revenue because of its effect on dryland, as well as irrigated cropland. Irrigation technologies increase production and net revenues, but in spite of being water saving on a per unit output basis, on a regional basis, increase the total use of water. This occurs because the marginal value of water increases with the addition of each water conserving technique. For example, the 1980 value of net revenue per acre foot of water pumped increased from $150 for the base scenario (1) to $198 with the technology set assumed for scenario 5. This not only encourages water use in any one year but extends the economic life of the aquifer, increasing considerably the amount of water that can be profitably pumped in the final years.

Low Commodity Prices

Scenarios 1 through 5 were run with constant prices equal to the deflated average over the last 20 years. To test the importance of commodity prices, two scenarios were created with the lowest prices observed during that 20 year period. These scenarios, "6" for base level conventional technology, and "7" with all technology available (equivalent to scenarios 1 and 5 except for commodity prices) are assumed to define a worst case limit for expected prices.

The aggregated regional results for scenario 6 are shown in Table 26. Irrigated acreage covers only 37% of the cropland in 1980, with 26% dryland and another 37% of the cropland lying idle. Both dryland and fallow increase over time as irrigation decreases, though more cropland is still being irrigated in 2020 under the low prices than was under average prices for the same conventional technology. This is due to the water saving effect of limited profitability for irrigated crop production. Average water use per acre is initially 1.99 feet and remains above 1.8 feet for the complete time horizon using low crop prices. This is in contrast to the 1.2 to 1.7 feet average usage under normal prices. The low commodity prices can only cover the relatively high fixed and variable costs of irrigation for the more intensely irrigated production activities. Also, the relative price shift imbedded in the low price assumption biases the results away from cotton, which has strongly diminishing productivity of water, and thus favors limited irrigation in its production. Further, the very low cotton price ($.48), is partially responsible for the land shifting to fallow rather than dryland production. With average prices, the preferred irrigated and dryland crop on many southern soils is cotton. Therefore, the price bias shifts irrigated cropping toward more intensely irrigated feed grains and soybeans, covering fewer acres with the economically pumpable water, reinforcing the shift to dryland or fallow, and increasing the water use per acre.

The use of most inputs in 1980 decline appreciably, labor down 43%, diesel 41%, and fertilizer 15%, but the decline is neither proportional for all inputs nor in favor of the major non-renewable resource, water, which in 1980 declines in usage only 1%. The importance of water, even

Table 26. Regional Analysis: Base with 20 Year Low Commodity Prices, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	2668	2536	3096	4340	4570
Percent		26	25	31	43	45
Irrigated	000 ac	3736	3406	2841	1179	800
Percent		37	34	28	12	8
Fallow	000 ac	3716	4178	4183	4601	4750
Percent		37	41	41	45	47
Inputs:						
Water	000 ac-ft	7451	6412	5190	2184	1475
Labor	Million hr	30	28	26	17	14
Natural Gas	Million mcf	63	61	54	26	18
Diesel	Million gal	73	74	71	57	53
Nitrogen	000 ton	128	154	170	92	75
Phosphorus	000 ton	85	86	86	49	41
Gross Returns	Million $	1352	1281	1160	753	653
Total Variable Cost	Million $	908	913	878	568	489
Total Fixed Cost	Million $	132	124	124	101	96
Net Revenue	Million $	312	245	158	84	68

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

with poor commodity prices, is once again demonstrated.

Production or gross returns are only 42% to 38% of that achieved with normal prices. Net returns are even harder hit. As a percent of scenario 1, net returns fall to 27% for 1980, 24% for 1990, 19% for 2000, 15% for 2010 and 17% for 2020.

In Table 27 the interaction of advanced technology and low prices (scenario 7) are reviewed. Irrigated cropland increases to 51% and dryland to 36% of available cropland, leaving 1.3 million acres idle. As happens under all the scenarios, the irrigated acreage declines with time dropping to 11% in 2020. Over the same period, dryland acres increase to 70%. On average, approximately 2.5 million additional acres are cropped, in comparison with the similar price situation without advanced technology.

Water use increases only slightly, rising 27,000 acre feet in 1980 and 137,000 acre feet in 2020, above usage for the low prices base. Labor and machinery use increase a small amount but fertilizer use jumps 42%, due to the increase in planted acres. Fertilizer use is actually greater with low prices than with normal prices for similar advanced technology because the relative price shift favors feedgrains over cotton and feedgrains require more fertilizer.

Production is $487 million higher than the low prices base in 1980 decreasing to $249 million more in 2020. This increase, given the much lower base, is significantly better than that shown with normal prices, indicating that technology is relatively more important the tighter the price squeeze. Net revenue also advances, reaching $528 million in 1980, $216 million more than the $312 million registered for the low prices base, but still less than half the $1129 million for the normal prices base. Clearly, technology alone can not overcome the effects of extremely low prices.

Deregulated Natural Gas

One of the major variable inputs for irrigated crop production on the High Plains is natural gas. Since 1974, the price for this important input has risen dramatically and future increases are likely. To measure the impact of an extreme, but possible, price increase the estimated free market price was imposed for scenarios 8 and 9. Scenario 8, which is equivalent to "1" except for the $8.86 gas price, is detailed in Table 28. Compared to the base, water use in 1980 is practically the same while irrigated cropland increases 43,000 acres. However, by 1990 water use has dropped 42% and irrigated cropland 38%. The rapid decline continues for both until 2020 where it seems to be leveling. With the reduced usage in the intermediate years, more water is pumped in the final period with the high gas prices than for scenario 1.

No other fuel is allowed to substitute as irrigation pumping fuel, so input substitution is based on the shadow price of the water rather than the gas price directly. Though water use declines 42% from 1980 to 1990, labor use declines only 15%, diesel 2% and fertilizer usage 22%. Natural gas usage in physical terms declines 34%, as the average per acre-foot fuel requirement increases from 8.52 mcf in 1980, to 9.68 mcf in 1990. Thus, by 1990 fuel costs alone, for irrigation water pumping, average nearly $86 per acre foot.

Table 27. Regional Analysis: Base plus All Available Technology, 20 Year Low Commodity Prices, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	3604	3719	4028	6273	7070
Percent		36	37	40	62	70
Irrigated	000 ac	5174	4699	4193	1928	1109
Percent		51	46	41	19	11
Fallow	000 ac	1341	1702	1900	1919	1941
Percent		13	17	19	19	19
Inputs:						
Water	000 ac-ft	7[illegible]78	6783	5956	2787	1612
Labor	Million hr	32	29	28	19	16
Natural Gas	Million mcf	65	65	63	35	17
Diesel	Million gal	77	74	73	57	53
Nitrogen	000 ton	234	244	294	187	151
Phosphorus	000 ton	135	133	140	103	90
Gross Returns	Million $	1839	1742	1697	1118	902
Total Variable Cost	Million $	1176	1148	1190	781	605
Total Fixed Cost	Million $	134	128	123	117	114
Net Revenue	Million $	528	467	383	220	183

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

Table 28. Regional Analysis: Base with Alternate Natural Gas Price, Texas High Plains[a]

Item	Unit	1980	1990	2000	2010	2020
		Year				
Cropland Acreage:						
Dryland	000 ac	3795	6143	7698	8889	9284
Percent		37	61	76	88	92
Irrigated	000 ac	6141	3793	2238	1047	652
Percent		61	37	22	10	6
Fallow	000 ac	184	184	184	184	184
Percent		2	2	2	2	2
Inputs:						
Water	000 ac-ft	7513	4340	2343	1008	650
Labor	Million hr	54	46	42	40	40
Natural Gas	Million mcf	64	42	25	13	8
Diesel	Million gal	124	121	119	117	117
Nitrogen	000 ton	143	112	102	78	75
Phosphorus	000 ton	106	83	70	56	53
Gross Returns	Million $	3171	2590	2227	1954	1859
Total Variable Cost	Million $	2083	1680	1444	1245	1168
Total Fixed Cost	Million $	291	269	263	260	258
Net Revenue	Million $	797	641	521	448	433

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

Production in the first period is nearly the same as the base but variable costs increase $317 million and net revenue drops $332 million. Both gross returns and net revenue decline rapidly, dropping 18% and 20%, respectively by 1990. However, despite the continued slide, as time passes the rate of decline decreases and by 2020, both are actually above their counterparts for the base run. Due to the very high pumping costs, more of the aquifer is not physically dewatered and limited irrigation on the best soils is still possible even after 2020. Table 29 lists the results for scenario 9, which is the same as scenario 5, except for the natural gas price. Comparing Table 29 with Table 25 (scenario 5), irrigated acreage and water pumped are nearly the same for 1980 and 1990 but begin to diverge in 2000, with the high pumping cost rapidly driving the aquifer toward economic depletion. By 2020, even though the high water sector of the north has over 100 feet of saturated thickness remaining, only 25,000 acres are still under irrigation.

Production for 1980 and 1990 are also nearly the same as scenario 5, but total variable costs are $303 and $327 million higher, respectively. As a consequence, net revenue is 20% less in 1980 and 25% less in 1990. After 1990 production in scenario 9 declines relative to 5 falling to 89% in 2000, 80% in 2010 and 83% in 2020 when dryland production begins to predominate. Net revenue over the same period is down 29% for 2000, 27% in 2010 and 14% in 2020. Plainly, compared to the normal price scenario (scenario 5), high gas prices have a significant impact on production after 1990, and on net revenue throughout the forty year time horizon.

If the comparison is with scenario 8, which has the same crop prices but conventional rather than advanced technology, the implications are different. In this comparison, the advanced technology increases production from 26% (1990) to 2% (2020) and net revenue from 42% (2000) to 33% (2020). Furthermore, when the comparison is with the base run both gross returns and net revenue are greater throughout the time horizon for scenario 9. Thus, at least under the assumptions of this model, advanced technology can compensate for a large natural gas price increase.

Comparison of Scenarios by Decade

The same information which is shown in Tables 21 through 29 is resorted to make it easier to compare differences across scenarios. In Tables 21 through 29, the regional results are shown for each scenario over the forty year time horizon. In this section, each table covers all nine scenarios for a particular decade year.

Initial Resource Situation

For the initial resource situation, specified as 1980, Table 30 lists the results for the region under the assumptions of each scenario. The wide range of irrigated cropland coupled with the very narrow range of water usage is particularly noteworthy. This is especially true since the levels of gross returns and net revenue correspond more with irrigated acres than with water use. However, when the low commodity price scenarios (6 and 7) are removed much of the variation disappears. Gross

Table 29. Regional Analysis: Base plus All Available Technology, Alternate Natural Gas Price, Texas High Plains[a]

Item	Unit	Year 1980	1990	2000	2010	2020
Cropland Acreage:						
Dryland	000 ac	3124	3135	4650	8344	9463
Percent		31	31	46	82	94
Irrigated	000 ac	6903	6889	4951	1151	25
Percent		68	68	49	11	0
Fallow	000 ac	93	94	519	626	632
Percent		1	1	5	6	6
Inputs:						
Water	000 ac-ft	7590	7536	5593	1185	36
Labor	Million hr	45	45	37	26	22
Natural Gas	Million mcf	59	67	55	15	0
Diesel	Million gal	94	98	89	78	74
Nitrogen	000 ton	179	225	220	103	69
Phosphorus	000 ton	128	139	124	70	52
Gross Returns	Million $	3535	3480	2965	2116	1821
Total Variable Cost	Million $	2090	2163	1838	1193	946
Total Fixed Cost	Million $	250	246	222	231	230
Net Revenue	Million $	1195	1072	905	691	643

[a] The Base is conventional technology not including limited tillage, land modification or improved irrigation distribution systems.

Table 30. Regional Analysis Across All Scenarios for the 1980 Resource Situation, Texas High Plains

Item	Unit	Scenario[a] 1	2	3	4	5	6	7	8	9
Cropland Acreage:										
Dryland	000 ac	3838	4072	3534	3066	3139	2668	3604	3795	3124
Percent		38	40	35	30	31	26	36	37	31
Irrigated	000 ac	6098	6048	6586	7054	6889	3736	5174	6141	6903
Percent		60	60	65	70	68	37	51	61	68
Fallow	000 ac	184	0	0	0	93	3716	1341	184	93
Percent		2	0	0	0	1	37	13	2	1
Inputs:										
Water	000 ac-ft	7523	7525	7530	7529	7591	7451	7578	7513	7590
Labor	Million hr	53	40	41	45	45	30	32	54	45
Natural Gas	Million mcf	68	66	61	61	61	63	65	64	59
Diesel	Million gal	124	90	94	94	94	73	77	124	94
Nitrogen	000 ton	145	163	177	178	182	128	234	143	179
Phosphorus	000 ton	106	116	123	127	129	85	135	106	128
Gross Returns	Million $	3186	3321	3429	3531	3539	1352	1839	3171	3535
Total Variable Cost	Million $	1766	1731	1756	1787	1787	908	1176	2083	2090
Total Fixed Cost	Million $	289	247	250	252	250	132	134	291	250
Net Revenue	Million $	1129	1344	1424	1493	1502	312	528	797	1195

[a] Scenario 1 Base, Average Input and Commodity Prices; 2 Base plus Limited Tillage; 3 Base plus Limited Tillage and LEPA; 4 Base plus Limited Tillage, LEPA, and Improved Furrow; 5 Base plus All Available Technology; 6 Base with 20 Year Low Commodity Prices; 7 Base plus All Available Technology with 20 Yr Low Prices; 8 Base with Alternate Natural Gas Price; 9 Base plus All Available Technology with Alternate Natural Gas Price.

returns change only 10%, while irrigated acreage varies 14% and water use changes less than 2%. Clearly, at this point the level of water use is controlled almost completely by the exogenous annual aquifer decline constraint.

Changes in input use are different for each input. Labor use declines with limited tillage, dropping nearly 25% but increases again with the addition of the other advanced technology options, mainly due to the increase in irrigated cropland. The low crop prices reduce labor use significantly as large amounts of land go out of production. Scenario 8 has the highest labor use in spite of a reduction in gross output and water usage because the optimum calls for an extra 43,000 acres of irrigated cropland. Diesel consumption, which is a fair proxy for field machinery use responds approximately the same as labor.

Natural gas consumption decreases with limited tillage despite a 2,000 acre-foot increase in pumpage and no direct usage of natural gas in crop tillage. Nonetheless, the shifts among crops, which account for the $135 million increase in production, also change where and how the water is pumped, enough to save 2 million mcf. The biggest decline in natural gas use comes with the introduction of LEPA as a replacement for high pressure sprinklers. The lower pressure requirements save 5 million mcf. With low commodity prices, natural gas usage is less than for the equivalent normal price, conventional technology scenario, but greater than the equivalent normal price, advanced technology scenario. The reason for the greater gas use with advanced technology is not immediately clear since both irrigated acres and water pumpage are less. Apparently the cause is the shift in cropping pattern brought on by the relative price change, emphasizing that input substitution for the region as a whole, depends on commodity prices as well as input prices. High gas prices succeed in reducing natural gas usage, but only 6% for conventional technology and 3.3% with advanced technology.

The amount of fertilizer used is dependent on physical production levels and the crop mix. Since advanced technology increases production levels and fertilizer exibits diminishing marginal returns, the fertilizer usage increases faster than production, expanding 24% while gross revenue grows 11% when comparing scenario 5 with scenario 1. The importance of the cropping pattern is demonstrated by the low price, high technology scenario (7), which has the highest fertilizer usage of all the scenarios. This is due to the anti-cotton relative price change included in the low price runs that cause a shift to crops that are not nearly as fertilizer efficient as cotton. Efficiency in this case being measured as value of output per unit fertilizer input.

Differences in net revenue show the relative importance of prices and technology. Commodity price declines of 24% to 35% (low price scenarios 6 and 7) cause net revenue to drop 72% for conventional technology, and 65% with advanced technology. A 230% increase in the price of a key input, natural gas (scenarios 8 and 9) leads to net revenue declines of 29% and 20%, respectively for conventional and advanced technology.

Viewed as an enhancement of productivity, given normal prices, improved technology increases gross returns per crop acre $35 and net revenue per crop acre $37. Per labor hour, the increase in gross returns equal $18 and net returns increase $12 with the addition of all technology.

Regional Results by Scenario for 1990

The situation does not change dramatically over the first decade. As shown in Table 31, irrigated acreage, water use, and production stay nearly the same under normal prices. With low crop prices, water usage drops 1.04 million acre-feet for conventional technology, and 795,000 acre-feet with advanced technology. This is accompanied by a decline in irrigated acres of nearly 10% and gross returns of approximately 5%. The major change in irrigated acres, water usage and production comes with high gas prices and conventional technology. More than 2.3 million acres shift to dryland while irrigation water requirements decline 42% and production drops by 19%. The high gas prices coupled with conventional technology make it too expensive to irrigate the poorer soils, especially where the pump lift is high. Interestingly, at this point advanced technology is sufficient to overcome the high fixed cost handicaps, so irrigated cropland, water use and production for scenario 9 change less than 2%.

Input requirements in general change only slightly, and proportional to gross returns. Natural gas usage and variable costs increase with the greater lifts but most of the aquifer has not been depleted, so major shifts do not occur, with the exceptions noted above. Net revenue declines 5% to 9% given normal prices and 10% to 21% for the alternate price scenarios. Not only are incomes much lower under the low prices scheme, but they are less stable over the decade.

Scenario Comparison for the Year 2000

After 20 years, the water use under the various scenarios is starting to diverge significantly, even under normal prices. An inspection of Table 32 reveals that only scenario 5 is still pumping more than 6.2 million acre-feet of water and pumpage for the high gas prices, conventional technology scenario is down to 2.3 million acre-feet. Water usage at this point in the time horizon has a range greater than 5 million acre-feet, depending on the price and technology assumptions.

Considerable acreage is also shifting from irrigated to dryland crops, with only scenario 5 still irrigating more than 51% of available cropland and scenario 8 down to 22% irrigated. Most of the land moving out of irrigation shifts to dryland production, with only scenarios 7 and 9 showing increases in fallowed land. Since both 7 and 9 are advanced technology scenarios, including dryland rotations with fallow, this is to be expected. Somewhat surprising in this regard is the 92,000 acres that shifts out of fallow with scenario 5. This is the result of a northern hardland soil moving from a two year dryland, wheat-fallow rotation to wheat under a LIDS rotation.

Input usage as measured by total variable and fixed cost is down for all scenarios due to the reduction in irrigated acreage and production. For individual inputs the changes vary. In spite of the increased pump lift, as the aquifer is drawn down natural gas usage declines under all but scenario 5. The decline in total water pumped overshadows the high energy requirement per acre-foot of water. Labor and machinery requirements decline across the board due to the reduction in irrigated acres.

Table 31. Regional Analysis Across All Scenarios for the 1990 Resource Situation, Texas High Plains

Item	Unit	Scenario[a]								
		1	2	3	4	5	6	7	8	9
Cropland Acreage:										
Dryland	000 ac	4236	4135	3534	3232	3132	2536	3719	6143	3135
Percent		42	41	35	32	31	25	37	61	31
Irrigated	000 ac	5700	5985	6586	6888	6895	3406	4699	3793	6889
Percent		56	59	65	68	68	34	46	37	68
Fallow	000 ac	184	0	0	0	93	4178	1702	184	94
Percent		2	0	0	0	1	41	17	2	1
Inputs:										
Water	000 ac-ft	7505	7511	7513	7517	7554	6412	6783	4340	7536
Labor	Million hr	53	40	41	45	45	28	29	46	45
Natural Gas	Million mcf	76	75	69	69	69	61	65	42	67
Diesel	Million gal	130	95	99	99	98	74	74	121	98
Nitrogen	000 ton	196	220	239	242	233	154	244	112	225
Phosphorus	000 ton	118	131	139	143	141	86	133	83	139
Gross Returns	Million $	3137	3335	3423	3518	3503	1281	1742	2590	3480
Total Variable Cost	Million $	1819	1819	1826	1861	1836	913	1148	1680	2163
Total Fixed Cost	Million $	287	248	249	248	247	124	128	269	246
Net Revenue	Million $	1034	1267	1347	1408	1420	245	467	641	1072

[a] Scenario 1 Base, Average Input and Commodity Prices; 2 Base plus Limited Tillage; 3 Base plus Limited Tillage and LEPA; 4 Base plus Limited Tillage, LEPA, and Improved Furrow; 5 Base plus All Available Technology; 6 Base with 20 Year Low Commodity Prices; 7 Base plus All Available Technology with 20 Yr Low Prices; 8 Base with Alternate Natural Gas Price; 9 Base plus All Available Technology with Alternate Natural Gas Price.

Table 32. Regional Analysis Across All Scenarios for the 2000 Resource Situation, Texas High Plains

Item	Unit	Scenario[a] 1	2	3	4	5	6	7	8	9
Cropland Acreage:										
Dryland	000 ac	5641	5742	5337	5014	4129	3096	4028	7698	4650
Percent		56	57	53	50	41	31	40	76	46
Irrigated	000 ac	4295	4378	4783	5106	5990	2841	4193	2238	4951
Percent		42	43	47	50	59	28	41	22	49
Fallow	000 ac	184	0	0	0	1	4183	1900	184	519
Percent		2	0	0	0	0	41	19	2	5
Inputs:										
Water	000 ac-ft	6102	6120	6137	6131	7410	5190	5956	2343	5593
Labor	Million hr	50	36	37	40	41	26	28	42	37
Natural Gas	Million mcf	71	71	65	65	76	54	63	25	55
Diesel	Million gal	129	93	95	96	94	71	73	119	89
Nitrogen	000 ton	207	236	247	259	296	170	294	102	220
Phosphorus	000 ton	114	127	133	139	151	86	140	70	124
Gross Returns	Million $	2770	2975	3043	3139	3295	1160	1697	2227	2965
Total Variable Cost	Million $	1668	1657	1662	1708	1791	878	1190	1444	1838
Total Fixed Cost	Million $	274	238	240	239	232	124	123	263	222
Net Revenue	Million $	828	1079	1140	1189	1273	158	383	521	905

[a] Scenario 1 Base, Average Input and Commodity Prices; 2 Base plus Limited Tillage; 3 Base plus Limited Tillage and LEPA; 4 Base plus Limited Tillage, LEPA, and Improved Furrow; 5 Base plus All Available Technology; 6 Base with 20 Year Low Commodity Prices; 7 Base plus All Available Technology with 20 Yr Low Prices; 8 Base with Alternate Natural Gas Price; 9 Base plus All Available Technology with Alternate Natural Gas Price.

Total fertilizer use increases for all but scenarios 8 and 9, though the mix changes as nitrogen using wheat and feed grains increase their share of the cropping pattern. Thus, nitrogen use rises at a rate sufficient to counterbalance the small decrease in phosphorus use.

Net revenue continues to fall since the change in gross returns are greater than the decline in fixed and variable costs. Further, the reduction is greater in percentage terms than in 1990, ranging from 10.3% for scenario 5 to 35% for scenario 6. The conventional technology scenarios suffer steeper percentage declines under all price assumptions than their advanced technology counterparts, showing an income stabilizing effect for improved technology.

Regional Results for 2010

Table 33 lists the comparative results for the nine scenarios after 30 years. Gross returns have declined 12% (scenario 8) to 35% (scenario 6) since 2000, with the greatest declines for the low price scenarios. This reduction in output can be traced directly to the sharp decrease in water use and irrigated cropland.

By 2010, parts of the aquifer have become physically or economically depleted. Compared to 2000, water use drops more than 3 million acre-feet for all normal and low price scenarios except 5, which is down 2 million acre-feet. The high natural gas price scenarios have both the least decline, under conventional technology, and the greatest decline, for scenario 9. Scenario 8 has been the smallest consumer of water throughout the time horizon to this point, and usage is now so low that it is starting to level out. Scenario 9, which has been able to sustain high pumping levels for most of the first 20 years due to its advanced technology, has now reached a point of economic exhaustion for much of the aquifer. Thus, water usage plummets 4.4 million acre-feet and 3.8 million acres revert to dryland production.

The decline in gross returns is so large that the demand for all inputs decline, for all scenarios, compared to 2000. Net revenue declines 24% to 31% with normal prices, and 42% to 47% for low commodity prices. For both price sets, the more advanced technology scenarios do better in percentage terms than conventional technology. However, the oposite is true for the high gas price scenarios. Because irrigation has fallen so low for scenario 8, its production and net revenue values are approaching steady state conditions given the constant price assumptions of the model. Thus, its net revenue declines only 14% while scenario 9, which until now had maintained higher levels of irrigated crop production, sees net revenue drop 23.6%.

Scenario Comparison for 2020

By the end of the time horizon, large sections of the aquifer are dewatered and for certain scenarios near economic exhaustion. As shown in Table 34, water pumpage has declined to 2.1 million for the most favorable price-technology combination (scenario 5). Two scenarios, 1 and 9, are pumping less than 50,000 acre-feet per year and irrigating

Table 33. Regional Analysis Across All Scenarios for the 2010 Resource Situation, Texas High Plains

Item	Unit	Scenario[a]								
		1	2	3	4	5	6	7	8	9
Cropland Acreage:										
Dryland	000 ac	8206	8176	7946	7821	6431	4340	6273	8889	8344
Percent		81	81	79	77	64	43	62	88	82
Irrigated	000 ac	1730	1944	2174	2299	3678	1179	1928	1047	1151
Percent		17	19	21	23	36	12	19	10	11
Fallow	000 ac	184	0	0	0	12	4601	1919	184	626
Percent		2	0	0	0	0	45	19	2	6
Inputs:										
Water	000 ac-ft	2902	2946	3009	2902	5416	2184	2787	1008	1185
Labor	Million hr	44	29	29	31	31	17	19	40	26
Natural Gas	Million mcf	36	36	36	34	65	26	35	13	15
Diesel	Million gal	121	85	84	86	78	57	57	117	78
Nitrogen	000 ton	140	163	169	170	260	92	187	78	103
Phosphorus	000 ton	80	91	93	94	123	49	103	56	70
Gross Returns	Million $	2160	2328	2352	2400	2645	753	1118	1954	2116
Total Variable Cost	Million $	1327	1277	1287	1303	1484	568	781	1245	1193
Total Fixed Cost	Million $	263	237	235	237	216	101	117	260	231
Net Revenue	Million $	569	814	829	859	945	84	220	448	691

[a] Scenario 1 Base, Average Input and Commodity Prices; 2 Base plus Limited Tillage; 3 Base plus Limited Tillage and LEPA; 4 Base plus Limited Tillage, LEPA, and Improved Furrow; 5 Base plus All Available Technology; 6 Base with 20 Year Low Commodity Prices; 7 Base plus All Available Technology with 20 Yr Low Prices; 8 Base with Alternate Natural Gas Price; 9 Base plus All Available Technology with Alternate Natural Gas Price.

Table 34. Regional Analysis Across All Scenarios for the 2020 Resource Situation, Texas High Plains

Item	Unit	Scenario[a] 1	2	3	4	5	6	7	8	9
Cropland Acreage:										
Dryland	000 ac	9910	9333	9296	9190	8809	4570	7070	9284	9463
Percent		98	92	92	91	87	45	70	92	94
Irrigated	000 ac	26	787	824	930	1288	800	1109	652	25
Percent		0	8	8	9	13	8	11	6	0
Fallow	000 ac	184	0	0	0	23	4750	1941	184	632
Percent		2	0	0	0	0	47	19	2	6
Inputs:										
Water	000 ac-ft	40	1350	1345	1363	2062	1475	1612	650	36
Labor	Million hr	38	25	25	26	28	14	16	40	22
Natural Gas	Million mcf	0	16	15	15	24	18	17	8	0
Diesel	Million gal	117	79	79	80	78	53	53	117	74
Nitrogen	000 ton	70	113	114	121	142	75	151	75	69
Phosphorus	000 ton	48	70	70	73	82	41	90	53	52
Gross Returns	Million $	1697	2041	2049	2076	2196	653	902	1859	1821
Total Variable Cost	Million $	1037	1099	1100	1113	1199	489	605	1168	946
Total Fixed Cost	Million $	254	235	235	235	244	96	114	258	230
Net Revenue	Million $	406	706	713	727	752	68	183	433	643

[a] Scenario 1 Base, Average Input and Commodity Prices; 2 Base plus Limited Tillage; 3 Base plus Limited Tillage and LEPA; 4 Base plus Limited Tillage, LEPA, and Improved Furrow; 5 Base plus All Available Technology; 6 Base with 20 Year Low Commodity Prices; 7 Base plus All Available Technology with 20 Yr Low Prices; 8 Base with Alternate Natural Gas Price; 9 Base plus All Available Technology with Alternate Natural Gas Price.

fewer than 30,000 acres.

Comparing conventional technology scenarios, both low commodity prices and a high natural gas price have saved sufficient water by this time that scenarios 6 and 8 actually irrigate more acres than scenario 1. With advanced technology, the results are less consistent. Scenario 7 is second only to scenario 5 in water pumped and acres irrigated, but scenario 9 is near the point of economic depletion of the aquifer. This is a good example of the interaction between technology and prices. Their impact together may be different than the sum of their individual effects.

Most available cropland remains in production, except under low prices. Even with the low crop prices, the addition of advanced technology keeps an additional 2.8 million acres under crop production.

Gross returns, input usage and net returns in general suffer steep declines from their comparable values in 2010. Gross returns are down 12% to 21% with normal prices, 13% and 19% with low commodity prices, and 4.8% and 14% for the high gas price scenarios. Net returns follow gross returns dropping 13% to 29% for scenarios 1 to 5, and 19%, 17%, 3% and 7% under scenarios 6 through 9, respectively.

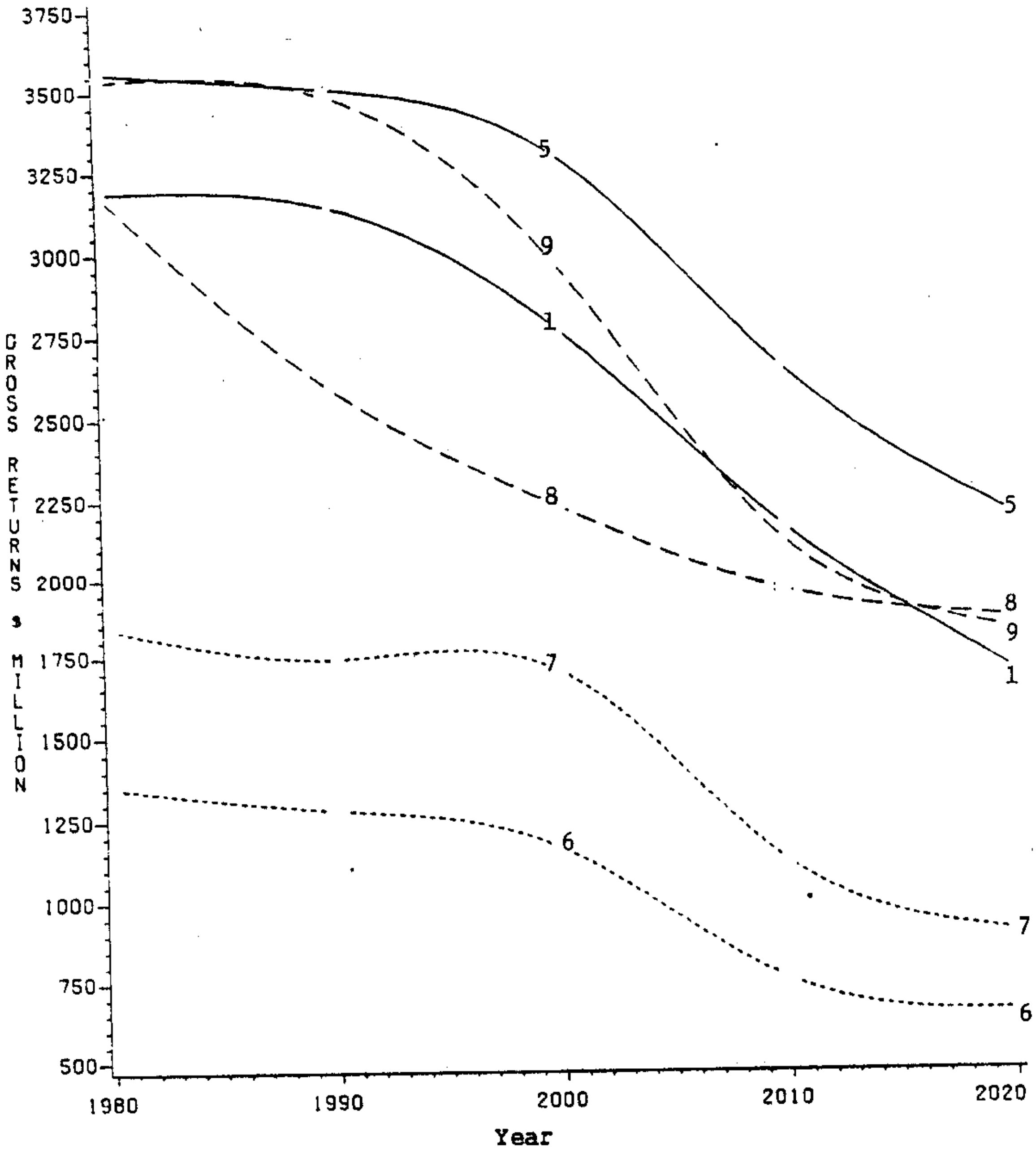
Since scenario 1 (conventional technology-normal prices) and scenario 9 (advanced technology) have practically no irrigation, a comparison of 9 with 1 approximates the impact of advanced technology on dryland crop production. With advanced technology, production is 6.8% greater while labor requirements are 42% less and machinery use 36% smaller. Nitrogen comsumption is 1,000 tons less, but 4,000 tons more phosphorus is needed. Net revenue is 58% greater.

Comparitive Change Over Time

The focus of this section of the regional analysis is on production, input use and net revenue over time. Production is measured by gross returns and input use is approximated by total variable cost. The data are taken directly from tables 30 through 34 for scenarios 1, 5, 6, 7, 8, and 9. Scenarios 1, 6 and 8 represent conventional technology; 5, 7 and 9 advanced technology. Normal prices are assumed for 1 and 5, low commodity prices for 6 and 7, and high natural gas prices for 8 and 9. Data points for all six scenarios are overlaid to aid in visualizing the relative shifts over time.

Production

Figure 15 shows the decline in gross returns over forty years for the six technology-price combinations. The normal crop price scenarios (1 and 5) start high and drop smoothly and nearly parallel. With low commodity prices (6 and 7), the initial values are much lower and the decline is not so smooth. Production stays stable through 2000, drops steeply to 2010 and then levels off over the last decade. Production under the high gas price scheme has the oddest change paths. Coupled with conventional technology, the curve is concave declining steadily, but at a diminishing rate. On the other hand, combined with advanced



1 Base: conventional technology, average input and crop prices
5 Base plus advanced technology
6 Base with alternate low crop prices
7 Base plus advanced technology with low crop prices
8 Base with alternate natural gas price
9 Base plus advanced technology with alternate gas price

Figure 15. Production, as Measured by Gross Returns, Over Time, by Scenario: Texas High Plains

technology, production rivals scenario 5 for the first decade then plunges steeply for twenty years and finally flattens out over the last decade but at a level below that of scenario 8. Both prices and technology influence the level of production, but the forces they exert are neither additive, nor proportionally the same through time.

Input Use

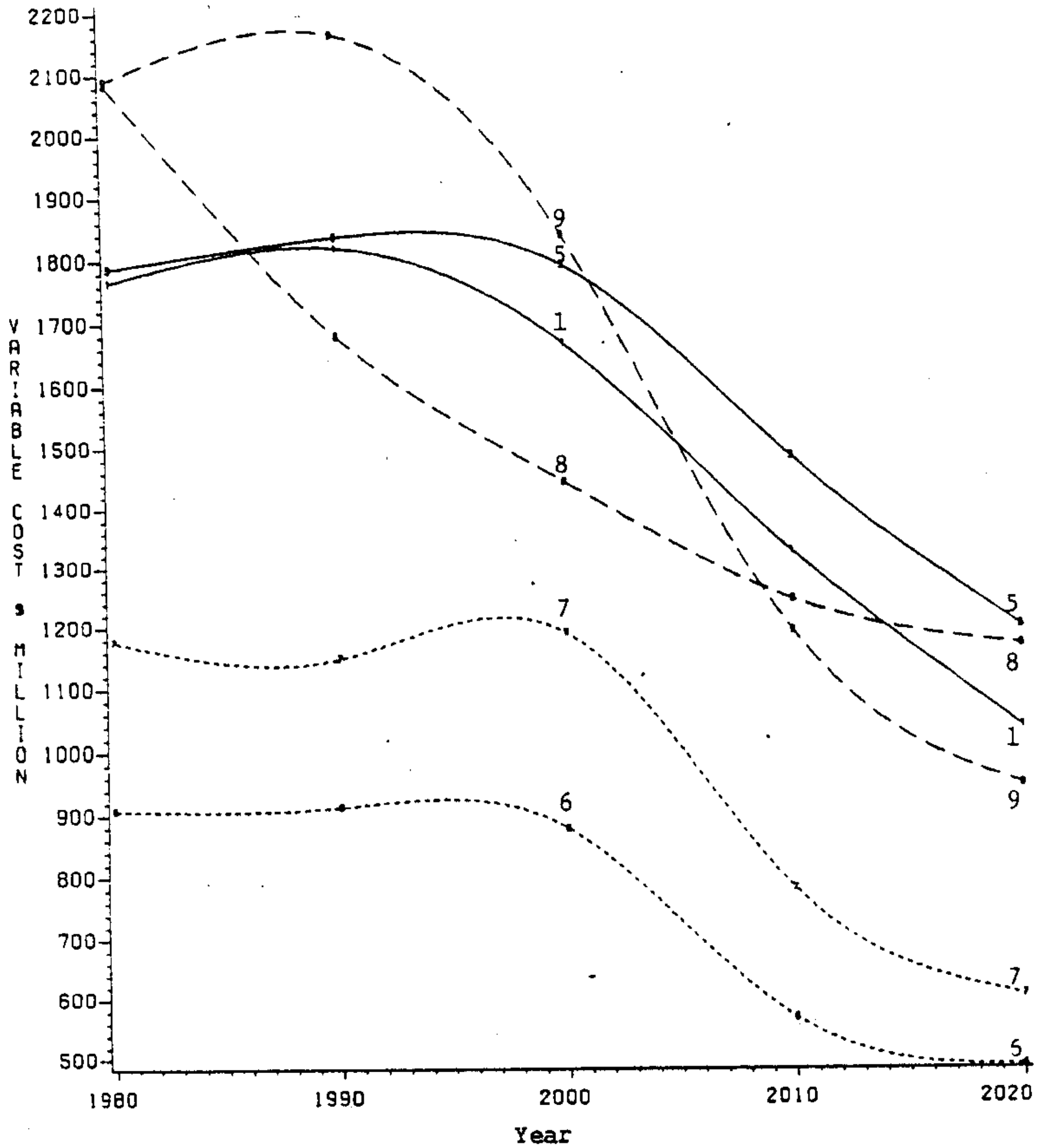
Total variable cost for each scenario across the time horizon is shown in Figure 16. The plots individually have somewhat similar shapes compared to their respective production curves, but the changes are more accentuated. Scenarios 1 and 5 rise close together for the first decade, diverge over the second decade, then continue a smooth parallel decline. Scenarios 6 and 7 start with a spread similar to their production curves, but 7 actually rises to a point above its initial value by the year 2000 before a steep decline and leveling out. Scenarios 8 and 9 start with nearly the same high variable costs. The decline is steeper, but still concave for scenario 8. For scenario 9, variable costs increase 3.5% over the first decade then decline so steeply that they drop below not only 8, but 5 and 1 also.

Variable input demand is clearly a function of production levels, but also the crop mix (note the difference between 5 and 7) and the economic availability of water. At first production is maintained despite rising variable costs, but as the supply of water becomes physically and economically limiting, both production and the demand for inputs decline.

Net Revenue

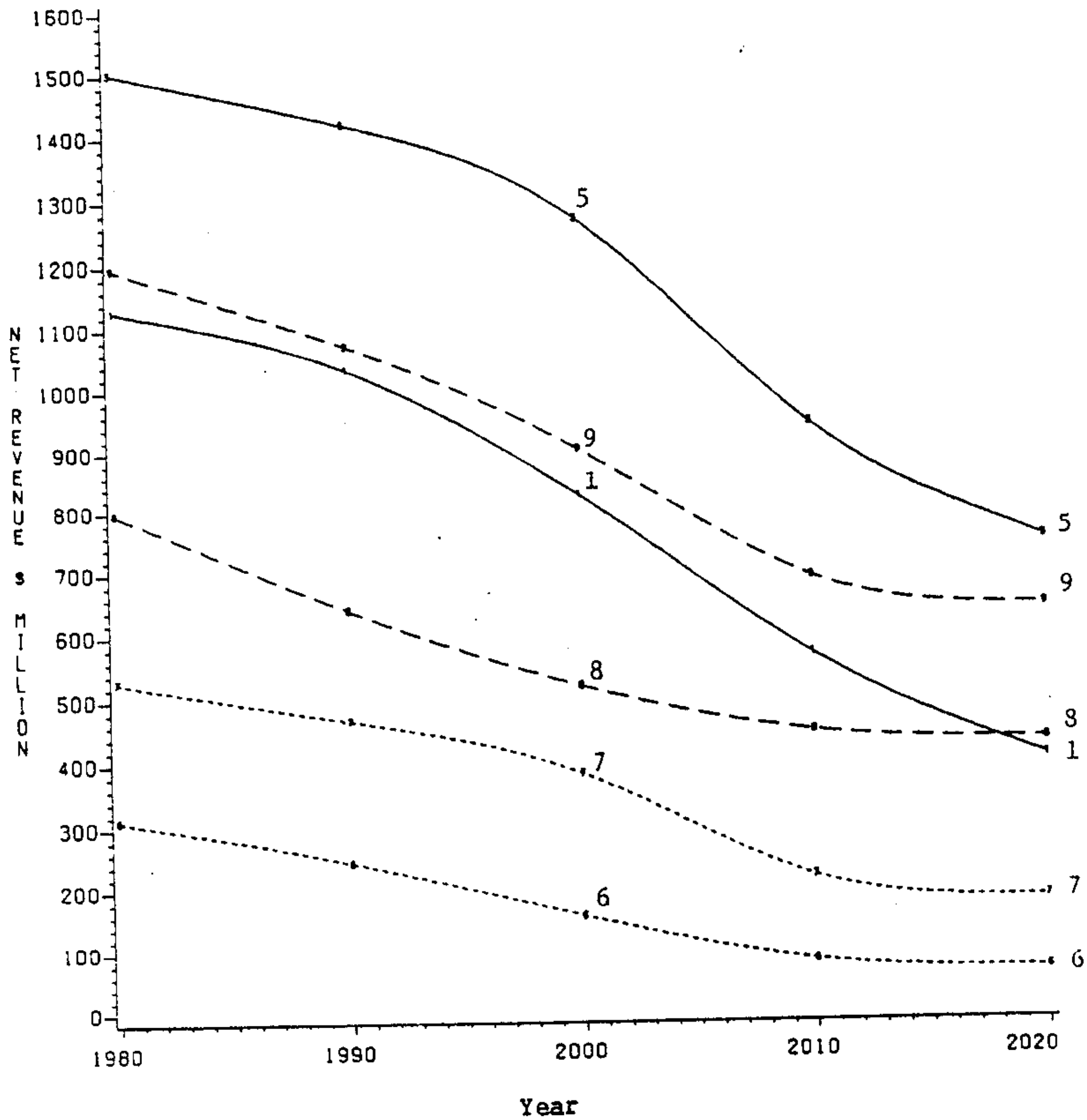
Figure 17 delineates the decline of net revenue over the time horizon by scenario. Not surprisingly, given that the model's optimization objective was to maximize net revenue, these are the smoothest, most uniform set of curves. Here the importance of both prices and technology are easiest to see as net revenue levels are ordered by price and by technology. Holding technology constant, net revenue is highest for normal prices, medium with the high natural gas price and lowest for low commodity prices. For a given price scheme, advanced technology always enjoys a significant advantage. Advanced technology also maintains stability of net revenue better for the first two decades, is less stable over the third decade and is nearly the same over the final period.

Though technology can compensate for some price changes (Scenario 9 Net Revenue is greater than that of Scenario 1 for all periods), it is not able to maintain either net returns or production in the face of the declining water resource.



1 Base: conventional technology, average input and crop prices
5 Base plus advanced technology
6 Base with alternate low crop prices
7 Base plus advanced technology with low crop prices
8 Base with alternate natural gas price
9 Base plus advanced technology with alternate gas price

Figure 16. Input Demand, as Measured by Variable Cost, Over Time, by Scenario: Texas High Plains



1 Base: conventional technology, average input and crop prices
5 Base plus advanced technology
6 Base with alternate low crop prices
7 Base plus advanced technology with low crop prices
8 Base with alternate natural gas price
9 Base plus advanced technology with alternate gas price

Figure 17. Net Revenue Over Time, by Scenario: Texas High Plains

CHAPTER V

SUMMARY AND CONCLUSIONS

In Texas, the High Plains is a major agricultural region. Over the last 10 years, the value of crop production from the region has averaged greater than 40% of the state total. In 1981, the Texas High Plains produced crops valued at more than $1.69 billion. The economy of the region is mainly agricultural, with more than 95% of the land area devoted to farms and ranches. Crop acreage presently exceeds 10 million acres. Thus, the maintainance of crop production in the region is important to the state, but even more so to the regional economy.

Crop production in the region, like agriculture everywhere, is based upon the fixed land resource, with its accompanying rainfall, solar energy and other climatic conditions. The soils across the region, though varying by texture, slope and depth, are generally fertile and suitable for field crops. However, because the rainfall is limited and erratic, crop production is severely limited by water availability. Irrigation, therefore, has become an important part of High Plains crop production.

Presently, between 5 and 6 million acres are irrigated annually, which is more than 50% of the cropland in the region. Irrigation increases cropping intensity, raising expected yields 200% to 400% for crops such as cotton, wheat and sorghum, which can be grown under dryland (nonirrigated) conditions and allows other humid zone crops such as corn and soybeans to be cultivated. It also increases farm income and input demand, contributing greatly to the entire regional economy.

Irrigation water for the region is pumped from the Ogallala aquifer, which lies beneath 30,000 square miles of the Texas High Plains and contains more than 250 million acre-feet of physically recoverable water. However, because the saturated thickness of the aquifer varies greatly, the recharge rate is nearly zero, and heavy pumping (more than 5 million acre-feet annually over the last 20 years) is occurring, the aquifer is being depleted overall, and rapidly in certain areas. As the aquifer is drawn down, the pump lift increases, raising pumping costs, and well capacity decreases, reducing the amount of water that can be pumped per given period of time. This problem is compounded by the rapid increase, since 1974, in the price of energy needed to pump and distribute the water from the aquifer.

Because of the importance of agriculture on the Texas High Plains and the state, and the heavy dependence on groundwater resources which are being depleted, changes in the future level and profitability of crop production are the focus of this study. Crop production requires the skillful blending of fixed inputs (land and water), with purchased variable inputs to produce marketable commodities. Given a declining amount, and increasing cost, of a key resource, groundwater, possible price changes for important variable inputs, such as natural gas, and uncertainty over commodity prices, the ability to produce efficiently and to change how and what is produced is essential.

Future production is dependent on the technology used, as well as the resources available. Because water is a major limiting resource, technologies that increase plant available water, such as advanced irrigation distribution systems and soil moisture conserving tillage methods, are likely to be of increasing value. Other cost reducing techniques will also be important. For this study several advanced technologies have been defined. The interrelationships between specific resource situations, technology sets and exogenous prices at the farm level are examined. Also, regional production, input demand and net revenue changes, are investigated for given technology and price assumptions over a 40 year planning horizon.

Study Procedures

Since this study was designed to be broad and cover a number of issues and a large land area, methods have to be approached systematically. Thus, there is the regional delineation and development of appropriate data. This is followed by incorporation into a model for analysis.

Regional Delineation

Variability of both the land and groundwater resources necessitated their disaggregation into more homogenous subsets. Land was divided into soil classes by texture, slope and yield capacity. The groundwater was classified by saturated thickness and pump lift. Once the individual groundwater subregions were defined, the number of wells and the ratio of cropland to aquifer surface were calculated for each. Then, specific soil classes were tied to each particular groundwater subregion to define the resource situations.

Six crops were included; cotton, wheat and sorghum, which are the major crops at present in the region, and corn, soybeans and sunflowers. Corn is highly productive under intense irrigation. Soybeans are used as an irrigated supplimental or replacement crop. And sunflowers have been recently introduced as an oil seed crop for both dryland and irrigated production.

Two crop tillage methods are defined; "conventional" tillage, which refers primarily to present practices, and "improved" tillage that uses less machinery, relies more on chemical weed control and is designed to conserve soil moisture. Per acre crop production costs for land preparation, planting, fertilization and weed control, are set at four different levels for each crop, by tillage method and for irrigated or dryland crop production.

Multiple irrigation levels and application periods were developed for each crop. Because the amount of water available is limited, particularly during critical periods in the summer, a wide choice of irrigation intensities (number and timing of post-plant irrigations) and the option to trade off some yield for greater flexibility, allows a more efficient use of the complete set of farm inputs. Experimental data from the region were used to tie irrigation application levels and timing to expected yield.

Four irrigation distribution systems were included; standard furrow and sprinkler systems representing present technology, and improved furrow and the LEPA system to represent advanced technology. Increased efficiency of water application was the major improvement for the advanced systems, although LEPA also reduces the energy required relative to present high pressure sprinklers.

Other technological improvements available for certain model runs included bench terracing and conservation bench terracing for soil classes with slopes greater than .5%, mixed (irrigated crop followed by dryland crop) and dryland rotations, and the limited-irrigation-dryland system (LIDS) developed by Stewart, Dusek and Musick.

Prices for the variable inputs and custom harvesting were set at the prevailing rates for the region for 1982. Base commodity prices were calculated by taking state seasonal average prices for the last 20 years, expressing them in 1982 dollars, and then averaging. Alternate prices (natural gas at the expected deregulated price and commodity prices at their 20 year low) were also defined for price sensitivity runs.

The Model

A flexible, recursive programming model of crop production on the Texas High Plains was developed. Besides the linear programming (LP) optimization routine and recursive feedback section, the model also includes a matrix generator and report writer to make scenario definition and output analysis faster and easier.

The production activities for each run of the model, are defined for one acre of a specific crop or crop rotation, irrigated at particular times, using a chosen irrigation distribution system and tillage method, on a given land class. The irrigation level may be zero (i.e. dryland) and the land class can include terracing when appropriate. The objective function for the LP optimization routine is the maximization of net returns (gross returns minus all variable, or variable and fixed, costs) to land, water and management. For static runs, the maximization includes net returns over variable costs only; for temporal runs, over variable and fixed costs. LP constraints include land by soil class, irrigation water availability for each of 18 irrigation periods and a total annual water use constraint.

The model can be run as either a static single period optimization or as a recursive, temporal model. When operated in the recursive mode, the model will loop through up to 20 iterations, rebuilding the LP matrix for each iteration and writing a report for each period. The feedback section of the recursive model is used to update the groundwater situation after solution of each iteration. The amount of groundwater used is summed and that usage translated into the reduction in aquifer saturated thickness, increased pump lift and reduced well yield per period. The new groundwater situation plus any inputted changes in prices, technical efficiencies or crop yields form the data, from which the production activities and constraints for the next iteration are built. At the end of the prescribed number of iterations, a summary report covering the whole time horizon is written and the discounted present value of net returns is calculated at three prescribed discount rates.

Scenarios

Two major sets of scenarios were run. The first group, a farm level analysis based upon representative counties of the region, and the second, an analysis of the region as a whole. The farm level analysis was designed to map the similarities and differences of response given particular resource endowments, technological options and price situations. There are two sections to the farm level analysis. The first concerns the impact of annual groundwater withdrawal constraints on discounted net present value for a forty year planning horizon. The importance of the discount rate, commodity prices, technology and the initial resource situation are studied. The second farm level analysis covers expected costs, returns and cropping patterns for a single period given various resource situation, commodity price and technology assumptions.

The second major scenario set, a regional analysis, concerns changes in cropland use, groundwater pumpage, production levels, input demand, and farm income over the next forty years, under select technology and price assumptions.

Results

The study considered farm level situations first. These had implications for the regional analysis, since they provided appropriate groundwater decline constraints for each of the subregions.

Farm Level Analysis-Groundwater Limits

A series of exogenous annual groundwater withdrawal limits were imposed sequentially to find the optimal temporal rate of aquifer use. Because the groundwater is a non-renewable resource, which has an opportunity cost attached to its use in any period, the maximization of long run discounted net present value of annual net revenue was used as the criteria for deriving the optimal decline limit. It was hypothesized that the discount rate, commodity prices, technology available and the initial resource situation would all have an impact on the level of maximum discounted net revenue, the consequent optimal groundwater withdrawal limit, or both.

As expected, the discounted net revenue was higher for lower discount rates, better commodity prices, more advanced technology and higher initial groundwater resource situations. The optimal withdrawal rate, however, was not so consistent. With the 2% discount rate, the optimal annual withdrawal limit decreases with lower expected prices, while at the 6% discount rate the optimum limit increases with lower prices. Technology shifts, as defined for this study, did not change the optimum withdrawal limit only the amount of net discounted revenue. Lower initial groundwater resources not only reduced the revenue level, but decreased the optimal annual groundwater decline limit. In general, the optimal groundwater withdrawal limits were fairly stable at approximately

2 feet annual withdrawal for low initial groundwater and 4 feet for the high initial groundwater. Stability in this context meaning that net discounted revenue did not change significantly for changes in the groundwater limit of plus or minus one foot.

Farm Level Analysis- Resource, Price and Technology Impacts

Production, variable and fixed costs, net returns and changes in the cropping pattern were examined: (1) for six price-groundwater situations for a given representative county, (2) for a single price-groundwater situation across all six representative counties, and (3) for a single county (Hale) and normal prices at five different technology levels. Prices have a significant influence on production, but a far greater impact on net returns. The value of production is 64% to 85% higher for normal prices versus low prices, while net returns are from 8 to 30 times higher. The amount of available groundwater was not as important as price in the determination of production levels, but it too had a significant impact on net returns. Cropping patterns were influenced more by the relative price shift (against cotton) imbedded in the low price assumption, than by the change itself. Thus, under the low price assumption land shifted out of cotton into feedgrains and oil seeds. Reduced groundwater availability also caused the cropping pattern to shift to more feedgrains under both price assumptions.

When the price situation is held constant, to compare across counties, the importance of the initial resource endowment (both land and groundwater) becomes clear. The southern High Plains counties with the better groundwater situation are the most productive, followed by the northern counties, which have good water but too cold a climate for cotton. In this case, productivity is measured by amount of agricultural crop production (gross returns). The southern counties, with a low initial groundwater endowment, are the least productive overall. Net returns however, change very little across counties, with no county more than 6% from the simple mean. The cropping pattern varies greatly with cotton predominating in the south, and wheat in the north. The high groundwater areas of the south favor feed grains as the second most important crop, whereas the low groundwater areas grow a more even mix of all other crops.

Five levels of technology were tested for Hale county, given normal prices, to examine the interaction of technology and groundwater resources. At the aquifer half depleted point, the value of production increases 17% with advanced technology, but net revenue more than doubles since costs increase less than production. The cropping pattern changes only slightly with the availability of advanced technology, though more cotton acres are irrigated as irrigation application efficiency increases.

Regional Analysis

A series of nine scenarios were run over a forty year planning horizon for each of four homogenous resource subregions and the results aggregated for the total Texas High Plains. The first five scenarios consider the impact on crop acreage, variable input demand, production and net returns of sequentially adding advanced technology to the set available for crop production in the region. Scenarios 6 through 9 examine how different price assumptions alter the results with and without advanced technology.

For any given scenario, water availability and hence use, drops over time, reducing irrigated cropland, gross returns and net revenue. The demand for other inputs does not decline as quickly as water usage, indicating that input substitution is occuring. Further, the decline in net revenue is greater than the reduction in gross returns or variable costs of production.

Advanced technology enhances the value of the groundwater resource, increasing the water use especially in the later periods of the time horizon. Technologies which improve dryland crop production as well as irrigated crop production, such as limited tillage and crop rotations, are at least as important as the advanced irrigation technology in the early decades and more important in the final decades, when most of the land is under dryland crop production.

With low commodity prices and base technology, from 37% to 47% of the cropland remains idle and only 37% is irrigated, even in the first decade. When advanced technology is added, idle land is reduced to less than 20%, and 51% of cropland acres are initially irrigated. Water use and input demand decline, but not as dramatically as the value of production and net revenue. Advanced technology increases the discounted present value of net returns 94% under the low commodity prices assumption versus 42% given normal prices.

Increasing the natural gas price to the expected free market value does not change the water pumped significantly in the first decade for either base level or advanced technology, though it does increase variable costs and decrease net revenue by nearly $300 million. However, as the pump lift increases with aquifer depletion, the decline in water use and irrigated acreage is much more rapid and economic depletion of sections of the aquifer occur much earlier. Advanced technology allows greater pumpage in the early decades, increasing discounted net present value 59%, compared with base technology and the same natural gas prices. When compared to base technology and normal prices, the increase in discounted net returns is 8%.

Conclusions

Several important themes have emerged from the analyses undertaken. The importance of the groundwater resource to crop agriculture in the Texas High Plains has, once again, been highlighted. While advanced technology can enhance the productivity of dryland crops and increase their net returns, technology is not a substitute (given the crops and technologies assumed for this study) for irrigation.

Also, technology does not save the groundwater resource, in the large. Because advanced techniques make better use of the water pumped, they lower its per unit cost and provide effectively more water during critical periods. Both effects encourage greater use of the limited supply. If saving groundwater is the goal, increasing the pumping costs is the most effective, non-regulatory method, followed by drastically reducing commodity prices.

Advanced technology however, is important to the future of crop production in the region. For any given combination of resources and prices, advanced technology increased the level of production, and especially net revenue. Further, the impact of technology was proportionally greater under the low commodity price scenario than for average prices.

Since technology did not emerge (at least in this study) as either a method for saving crucial groundwater resources, or replacing them, crop production, input demand and farm income all decline as the aquifer is depleted. While most cropland reverts to dryland production as the aquifer is depleted, the intensity of crop production declines and the mix of crops change, reducing purchased input demand and lowering regional farm income. Clearly this will force a change in the number and types of farms in the region and will adversely impact other sectors of the region's economy, which depend on agriculture or the patronage of farm families.

Limitations and Further Research

The shortcomings of the present study are partially intentional (to keep it doable), partially due to lack of data, and partially the result of human failing. Without attempting to justify the present specification, the following areas could be improved.

The first area is in the definition, number and aggregation of the basic production unit. The Ogallala aquifer is far more complex than presently modeled. Increasing the number of groundwater situations, accounting for changes in the coefficient of storage, well depth, size and location, and including the possibility of recharge, could all increase the accuracy of water availability. Likewise, further disaggregation of land by increasing the number of soil classes, considering other agriculural related attributes, such as depth, stoniness and susceptibility to erosion, and matching each more closely with the groundwater under it, would enhance resource specification.

The production inputs could be expanded to include seasonal labor requirements, machinery complements, alternate chemicals, and fertilizer types or formulations. Farm financial and tax considerations could also be included. Further increasing the number or variety of crops and adding linkages to livestock, particularly cattle, would increase options and more closely portray the true situation confronting agriculture on the Texas High Plains.

A major part of this study involves the introduction of new or advanced production technology. A larger, more detailed set of technologies would be advantageous. Considerable plant breeding research is underway, developing varieties with increased drought tolerance, disease resistance, higher yield potential and other features. There is also completely new crops or crops new to the region being researched.

Research institutes in the region are working on technical advances in crop machinery as well as pumps and irrigation equipment. Several types of limited tillage are under study along with a variety of irrigation application schemes. The addition of some or all of these techniques would increase the choice set significantly.

The recursive programming model chosen for this study is a fairly simple analytical tool. While simplicity has its virtues, a more sophisticated model could be formulated. A non-linear dynamic optimization model would, in theory, give a better answer to the optimal groundwater use problem. Replacing the LP solution algorithm with a quadratic or goal programming optimization module, within the recursive model, would allow a more realistic specification of the farmers objective function, including risk, maximization of wealth, or other plausible goals.

Finally, the analysis itself can be expanded in several ways. Prices have been shown to be of great importance. Therefore, more work on price sensitivity and how prices interact with resources and technology should be carried out. The importance of relative price shifts, hinted at by the impact on cotton production of the low commodities price scenario, should be explored further.

The analyses of the impact of advanced technology and price shifts presented in this study were for instantaneous changes. Analyses, where rates of technology adoption or incremental price changes are introduced, should give a clearer picture of their actual impact. Accounting for the higher level management that many of these techniques require, and the research and extension costs involved, would also strengthen the social welfare aspects of the study.

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APPENDIX A

EXAMPLE INPUT DATA

Input Data

Line

A 1000000001 HALE CO, AVE PRICE, GWL= 3FT, FIX 9/2/83

B CROP123456DSYS1200TILL12IRREG071014130609ITERATIONS08PVR% 4.0

C 139. 281. .15 1284. 9.17 578.

D	1980	1985	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
E	1980	1985	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	1985	1990	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	1985	1990	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	1990	1995	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	1990	1995	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	1995	2000	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	1995	2000	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	2000	2005	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2000	2005	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	2005	2010	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2005	2010	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	2010	2015	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2010	2015	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.
	2015	2020	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2015	2020	.55	.8	1.	1.	1.	1.	1.	1.	1.	1.

F	ESTOL01	30.	2.	.7	237.	15.	16.
	ESTOL13	30.	2.	1.5	216.	13.	14.
	LOFCL01	50.	1.	.3	237.	16.	15.7
	OLTNL01	160.	2.	.4	240.	16.	17.
	OLTNL13	80.	2.	1.5	230.	14.	15.
	PULCL01	650.	1.	.4	230.	15.	15.

Explanation of Data

Line A contains 10 control codes and a 40 character title. The control codes allow internal files to be printed for debugging or data checks, generated or solution files to be printed and certain options to be removed. If control code I is set to 1 then for I=:

1) Print input data, land class information
2) Hold saturated thickness, pumplift at initial values (for static, parametric analysis)
3) Print internal data matrices for checking
4) Print economic data for all production activities generated
5) Print LP solution output, corresponding file 1 records (file 1 contains economic data for each production activity)
6) Delete mixed rotations from the run
7) Delete LIDS rotations from the run
8) Delete dryland rotations from the run
9) Delete terracing options from the run
10) Delete activities with revenue - total cost ≤ 0 (Use for long planning horizon runs)

Line B contains control codes for specifying which crops, irrigation distribution systems, tillage methods, and irrigation regimes will be available for the run. The number of iterations, and the midpoint discount rate for calculating present value are also entered on this line.

The next line (C) defines the groundwater situation, listing initial saturated thickness, pump lift, coefficient of storage, aquifer surface area, number of wells and annual groundwater withdrawal limit.

The next group of input data lines (D and E) define the number of years in each iteration and a relative change index for select input prices and efficiencies, and commodity prices and yields for that iteration. Price indices are specified for (by order in line D), Natural Gas, Diesel, Labor, Machinery, Chemicals, Interest rate on capital, Wheat, Cotton, Feedgrains, and Oilseed prices. Line E sets efficiency indices for: Pump energy use, Percent of time pumps operate, Labor, and Machinery, as well as yield change indices for Cotton, Corn, Grain Sorghum, Sunflowers, Soybeans, and Wheat. The change is relative to the prices, yields and efficiencies stored as part of the internal data.

The last set of information (F) identifies the soils to be considered and their associated acreage, texture, slope, and expected dryland cotton, wheat and sorghum yields.

APPENDIX B

COMMODITY PRICE DATA

Table B-1. Average Prices Received By Texas Farmers; Parity Price Index

Year	Cotton Lint	Cotton Seed	Corn	Grain Sorghum	Sunflower	Soybean	Wheat	Price Index[a]
	$/cwt	$/ton	$/bu	$/cwt	$/cwt	$/bu	$/bu	
1962	31.48	47.70	1.17	1.86	5.50	2.16	2.08	307
1963	31.22	52.62	1.28	1.77	4.35	2.48	1.92	312
1964	28.65	47.34	1.26	1.86	4.12	2.45	1.53	313
1965	27.10	46.86	1.27	1.75	4.87	2.24	1.34	321
1966	17.64	67.41	1.43	1.79	5.63	2.60	1.66	335
1967	20.36	55.80	1.32	1.80	4.82	2.36	1.46	341
1968	20.22	50.50	1.15	1.70	4.30	2.33	1.26	349
1969	19.27	41.80	1.29	1.96	4.59	2.18	1.25	366
1970	20.56	55.00	1.42	2.02	4.91	2.61	1.30	382
1971	26.57	56.50	1.34	2.04	5.09	2.95	1.45	399
1972	23.00	48.60	1.53	2.39	4.86	4.12	1.56	424
1973	46.00	93.50	2.57	3.73	8.52	5.23	3.04	490
1974	34.90	119.00	3.09	4.89	15.90	6.61	3.87	557
1975	45.80	89.90	2.66	4.29	10.80	4.31	3.38	612
1976	61.60	98.00	2.33	3.89	11.00	6.10	3.04	652
1977	49.10	65.50	2.16	3.48	10.20	5.35	2.15	687
1978	54.60	110.00	2.45	3.82	10.70	6.30	2.93	746
1979	55.50	117.00	2.80	4.60	8.83	6.00	3.90	849
1980	69.70	119.00	3.50	5.60	10.60	7.60	3.75	950
1981	48.00	89.50	3.00	4.60	10.40	5.65	3.65	1031

[a] Index of Prices Paid by Farmers for Commodities and Services, Interest, Taxes, and Wage Rates Expressed on the 1910-1914 = 100 Base (Also Known as the Parity Index).

Sources: Texas Crop and Livestock Reporting Service 1962-1981; U. S. Department of Agriculture.

Table B-2. Prices Received (1962-1981), Expressed in 1982 Dollars

Year	Cotton Lint	Cotton Seed	Corn	Grain Sorghum	Sunflower	Soybean	Wheat
	$/cwt	$/ton	$/bu	$/cwt	$/cwt	$/bu	$/bu
1962	105.72	160.19	3.93	6.25	18.47	7.25	6.99
1963	103.17	173.88	4.23	5.85	14.37	8.20	6.34
1964	94.37	155.93	4.15	6.13	13.57	8.07	5.04
1965	87.04	150.51	4.08	5.62	15.64	7.19	4.30
1966	54.29	207.46	4.40	5.51	17.33	8.00	5.11
1967	61.56	168.71	3.99	5.44	14.57	7.14	4.41
1968	59.73	149.18	3.40	5.02	12.70	6.88	3.72
1969	54.28	117.75	3.63	5.52	12.93	6.14	3.52
1970	55.49	148.44	3.83	5.45	13.25	7.04	3.51
1971	68.66	145.99	3.46	5.27	13.15	7.62	3.75
1972	55.93	118.18	3.72	5.81	11.82	10.02	3.79
1973	96.79	196.73	5.41	7.85	17.93	11.00	6.40
1974	64.60	220.27	5.72	9.05	29.43	12.24	7.16
1975	77.16	151.45	4.48	7.23	18.19	7.26	5.69
1976	97.41	154.97	3.68	6.15	17.39	9.65	4.81
1977	73.69	98.30	3.24	5.22	15.31	8.03	3.23
1978	75.46	152.02	3.39	5.28	14.79	8.71	4.05
1979	67.40	142.08	3.40	5.59	10.72	7.29	4.74
1980	75.64	129.15	3.80	6.08	11.50	8.25	4.07
1981	48.00	89.50	3.00	4.60	10.40	5.65	3.65

Table B-3. Statistics Related to Prices Received (1982 Dollars)

Variable	Unit	Mean	Standard Deviation	Minimum Value	Maximum Value	Std Error Of Mean
Cotton Lint	$/cwt	73.82	18.01	48.00	105.72	4.03
Cotton Seed	$/ton	151.53	32.74	89.50	220.27	7.32
Corn	$/bu	3.95	0.68	3.00	5.72	0.15
Sorghum	$/cwt	5.95	1.03	4.60	9.05	0.23
Sunflower	$/cwt	15.17	4.17	10.40	29.43	0.93
Soybeans	$/bu	8.08	1.60	5.65	12.24	0.36
Wheat	$/bu	4.71	1.21	3.23	7.16	0.27

APPENDIX C

EXAMPLE OUTPUT REPORT

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 ITERATION 6 YEARS 2005 TO 2010

PRICE CHANGE			CURRENT PRICE			EFFICIENCY & YIELD		
NGAS	INDEX	1.000	ELEC	KWH	0.04	P-EF	INDEX	0.550
DESL	INDEX	1.000	NGAS	MCF	3.85	P-%	INDEX	0.800
LAB	INDEX	1.000	DESL	GAL	1.16	LAB	INDEX	1.000
MACH	INDEX	1.000	NIT	LB	0.28	MACH	INDEX	1.000
CHEM	INDEX	1.000	PHOS	LBS	0.30	Y-CT	INDEX	1.000
CAPL	INDEX	1.000	LAB	HRS	5.00	Y-CO	INDEX	1.000
WHET	INDEX	1.000	CAPL	DEC	0.10	Y-GS	INDEX	1.000
COTN	INDEX	1.000	BIOC	IDEX	1.00	Y-SU	INDEX	1.000
FEED	INDEX	1.000	MACH	IDEX	1.00	Y-SO	INDEX	1.000
OILS	INDEX	1.000	HARV	IDEX	1.00	Y-WT	INDEX	1.000
			COTN	LBS	0.74			
			CORN	BU.	3.95			
			SORG	CWT	5.95			
			SUNF	CWT	13.27			
			SOYB	BU.	8.08			
			WHET	BU.	4.71			
			COTS	TON	151.53			
			WGRZ	AUM	9.00			
			-	-	0.0			
			-	-	0.0			

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 ITERATION 6 YEARS 2005 TO 2010

GROUND WATER SITUATION

	SATURATED THICKNESS	PUMP LIFT	CAPACITY (GPM)	ANNUAL AC-FT	
START	39.05	380.95	98.68	AVAIL	770.00
END	19.06	400.94	45.81	PUMPED	770.00
CHANGE	-19.99	19.99	-52.87	S. PRICE	11.24

WATER USE PER PERIOD (AC-IN)

	WJN-FB	WMAR	WAPR	WMAY1	WMAY2	WJUN1	WJUN2	WJUN3	WJLY1
WATER AVAIL	2255.	1185.	1147.	573.	612.	382.	382.	382.	382.
WATER USED	382.	1185.	1147.	573.	382.	0.	382.	382.	96.
SHADOW PRICE	0.0	6.29	7.05	4.98	0.0	0.0	1.17	5.00	0.0

WATER USE PER PERIOD (AC-IN)

	WJLY2	WJLY3	WAUG1	WAUG2	WAUG3	WSEP1	WSEP2	WOCT	WNO-DC
WATER AVAIL	420.	382.	382.	420.	382.	573.	573.	1185.	2332.
WATER USED	382.	96.	382.	96.	382.	573.	573.	764.	0.
SHADOW PRICE	0.0	0.0	14.74	0.0	2.01	0.0	0.0	0.0	0.0

IRRIGATION PUMPING & DISTRIBUTION

PER ACIN	FURROW	IMP FURROW	SPRINKLER	IMP SPRINKLER
ANN FIX C	7378.70	7378.70	7386.54	7437.32
ANN VAR C	4.13	4.19	5.57	4.67
LABOR HRS	0.105	0.157	0.035	0.045
IRR EFFIC	0.690	0.800	0.800	0.920
NGAS COST	3.897	3.897	5.068	4.019
ACRES	0.	0.	0.	747.
WATER USED	0.	0.	0.	9240.

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 ITERATION 6 YEAPS 2005 TO 2010

CROP COSTS AND PRODUCTION

ACT CODE	RETURN	T.WAT	LAB	DSL	NIT	PHOS	FUEL$	VMACH$	HARV$	T VAR$	NETV$	FMACH$	NETF$
CTDY--LD													
PER AC	193.47	0.0	2.9	8.5	12.0	12.0	10.88	5.17	49.42	104.76	88.71	28.78	59.93
TOTAL	5804.10	0.0	87.0	255.0	360.0	360.0	326.40	155.10	1482.60	3142.80	2661.30	863.40	1797.90
CTDY--LI													
PER AC	206.00	0.0	2.9	8.5	12.7	12.7	10.88	5.17	52.62	108.59	97.41	28.78	68.63
TOTAL	2949.56	0.0	41.5	121.7	181.8	181.8	155.78	74.03	753.43	1554.82	1394.74	412.08	982.66
CTOA-ZLL													
PER AC	361.71	6.3	4.9	10.7	22.4	22.4	39.08	10.80	92.40	204.64	157.07	42.59	114.48
TOTAL	67750.94	1180.0	917.8	2004.2	4195.7	4195.7	7319.97	2022.92	17307.21	38330.59	29420.38	7977.42	21442.95
CT1B-ZLT													
PER AC	404.77	9.5	6.1	10.7	25.1	25.1	51.79	12.72	103.40	233.92	170.85	48.74	122.11
TOTAL	26585.99	624.0	335.0	702.8	1648.6	1648.6	3401.66	835.47	6791.49	15364.27	11221.72	3201.33	8020.39
CT1B-ZLL													
PER AC	404.77	9.5	5.1	10.7	25.1	25.1	51.79	12.67	103.40	233.87	170.90	48.69	122.21
TOTAL	10099.37	237.0	127.2	267.0	626.3	626.3	1292.21	316.13	2579.92	5835.26	4264.11	1214.86	3049.25
CT2B-ZLL													
PER AC	508.12	12.7	5.2	10.7	31.4	31.4	64.51	14.53	129.80	281.55	226.58	54.80	171.78
TOTAL	15358.68	383.9	157.2	323.4	949.1	949.1	1949.91	439.19	3923.40	8510.27	6848.71	1656.41	5192.30
GS3C-ZLA													
PER AC	377.12	12.6	4.3	14.2	106.8	43.4	68.69	12.44	38.03	214.32	162.80	40.47	122.33
TOTAL	11313.60	378.0	129.0	426.0	3204.0	1302.0	2060.70	373.20	1140.90	6429.59	4884.00	1214.10	3669.90
GS3C-ZLG													
PER AC	370.05	12.6	4.3	14.2	104.4	42.2	68.69	12.39	37.32	212.44	157.61	40.42	117.18
TOTAL	14979.19	510.0	174.1	574.8	4226.0	1708.2	2780.49	501.53	1510.67	8599.32	6379.87	1636.15	4743.31
GS3C-ZLH													
PER AC	400.69	12.6	4.3	14.2	114.7	47.3	68.69	12.39	40.41	220.34	180.35	40.42	139.93
TOTAL	11334.74	356.4	121.6	401.7	3244.6	1338.0	1943.11	350.49	1143.12	6232.99	5101.75	1143.40	3958.35
GS3D-ZLH													
PER AC	430.49	12.6	4.3	14.2	124.7	52.4	68.69	12.39	43.41	228.01	202.48	40.42	162.06
TOTAL	42518.17	1244.5	424.7	1402.5	12316.2	5175.4	6784.30	1223.72	4287.47	22519.84	19998.32	3992.16	16006.16
GS4A-ZLH													
PER AC	465.29	17.4	4.5	14.2	136.4	58.2	88.14	15.24	46.92	261.54	203.75	49.76	154.00
TOTAL	15328.98	573.2	148.3	467.8	4493.7	1917.4	2903.77	502.08	1545.78	8616.43	6712.54	1639.34	5073.53
WT4BSZLG													
PER AC	269.54	9.0	1.8	5.8	75.6	31.6	43.60	8.24	21.17	143.21	126.33	33.16	93.17
TOTAL	2566.33	85.7	17.1	55.2	719.8	299.9	415.12	78.45	201.56	1363.52	1202.81	315.72	887.09
WT4BCZLL													
PER AC	308.37	9.0	2.8	7.3	70.3	33.8	45.47	10.16	43.82	171.23	137.14	41.94	95.20
TOTAL	61877.03	1805.9	561.8	1464.8	14106.3	6782.2	9123.93	2038.69	8792.85	34358.72	27518.28	8415.61	19102.67
WT4BSZLL													
PER AC	255.04	9.0	1.8	5.8	70.4	29.0	43.60	8.24	20.54	140.21	114.83	33.16	81.67
TOTAL	52756.76	1861.7	372.3	1199.8	14562.7	5998.8	9018.96	1704.50	4248.84	29003.39	23753.37	6859.37	16894.00
FARM TOTAL	341223.	9240.	3615.	9667.	64836.	32484.	49476.	10615.	55709.	189862.	151362.	40541.	110820.

SHP, HALE, P=20PA, GWL=4 , FIX, LEPA , 3/20/83 ITERATION 6 YEARS 2005 TO 2010

CROP PRODUCTION AND VALUE

	COTTON	CORN	SORGHUM	SUNFLOWER	SOYBEANS	WHEAT
ACREAGE	452.81	0.0	230.48	108.19	0.0	208.52
PRODUCTION	176862.62	0.0	16045.78	1064.61	0.0	15244.96
VALUE	152318.25	0.0	95472.31	14127.31	0.0	79310.31

LAND USE

SOIL	ACRES	SHADOW PRICE
ESTOLO1	30.00	85.38
ESTOL13	30.00	58.83
LOFCLO1	50.00	80.23
OLTNLO1	160.00	102.98
OLTNL13	80.00	68.63
PULCLO1	650.00	68.73

ACTIVITY	SOIL	TERRACE	ACRES	CROP1	YIELD	CROP2	YIELD
CTDY--LD	ESTOL13	-	30.00	CT	224.64	-	0.0
CTDY--LI	OLTNL13	-	14.32	CT	239.20	-	0.0
CTOA-ZLL	PULCLO1	-	187.31	CT	420.00	-	0.0
CT1B-ZLI	OLTNL13	-	65.68	CT	470.00	-	0.0
CT1B-ZLL	PULCLO1	-	24.95	CT	470.00	-	0.0
CT2B-ZLL	PULCLO1	-	30.23	CT	590.00	-	0.0
GS3C-ZLA	ESTOLO1	-	30.00	GS	63.38	-	0.0
GS3C-ZLG	LOFCLO1	-	40.40	GS	62.19	-	0.0
GS3C-ZLH	OLTNLO1	-	28.29	GS	67.34	-	0.0
GS3D-ZLH	OLTNLO1	-	98.77	GS	72.35	-	0.0
GS4A-ZLH	OLTNLO1	-	32.94	GS	78.20	-	0.0
WT4BSZLG	LOFCLO1	-	9.52	WT	38.93	S	5.14
WT4BCZLL	PULCLO1	-	200.66	WT	36.50	C	137.54

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 SUMMARY

PRICE AND YIELD INDEX CHANGES

	PRICES										EFFICIENCY & YIELD									
PERIOD	NGAS	DESL	LAB	MACH	CHEM	CAPL	WHET	COTN	FEED	OILS	P-EF	P-%	LAB	MACH	Y-CT	Y-CO	Y-GS	Y-SU	Y-SO	Y-WT
1980-1985	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1985-1990	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1990-1995	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995-2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000-2005	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2005-2010	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2010-2015	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015-2020	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.55	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 SUMMARY

GROUND WATER SITUATION

PERIOD	SATURATED THICKNESS FT	PUMP LIFT FT	CAPACITY GPM		TOTAL WATER (ACFT) PUMPED	AVAIL	S. PRICE
1980-1985	139.00	281.00	390.30		3850.	3850.	87.07
1985-1990	119.01	300.99	332.85		3850.	3850.	44.47
1990-1995	99.02	320.98	273.61		3850.	3850.	53.51
1995-2000	79.03	340.97	213.93		3850.	3850.	40.10
2000-2005	59.04	360.96	155.17		3850.	3850.	31.84
2005-2010	39.05	380.95	98.68		3850.	3850.	11.24
2010-2015	19.06	400.94	45.81		3741.	3850.	0.0
2015-2020	0.0	420.36	0.0		0.	3850.	0.0
END	0.0	420.36	0.0	TOTAL	26841.		

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 SUMMARY

ANNUAL CROP PRODUCTION AND VALUE

	COTTON		CORN		SORGHUM		SUNFLOWER		SOYBEAN		WHEAT	
	ACRE	PROD 000LB	ACRE	PROD 000BU	ACRE	PROD TON	ACRE	PROD TON	ACRE	PROD 000BU	ACRE	PROD 000BU
1980-1985	1000.	503.06	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
1985-1990	948.	462.12	0.	0.0	0.	0.0	0.	0.0	52.	2.87	0.	0.0
1990-1995	890.	434.40	0.	0.0	110.	369.86	0.	0.0	0.	0.0	0.	0.0
1995-2000	829.	387.01	0.	0.0	171.	606.39	0.	0.0	0.	0.0	0.	0.0
2000-2005	717.	304.41	0.	0.0	207.	743.92	0.	0.0	0.	0.0	76.	5.65
2005-2010	453.	176.86	0.	0.0	230.	802.29	108.	53.23	0.	0.0	209.	15.24
2010-2015	139.	46.29	14.	2.32	138.	483.91	355.	175.11	0.	0.0	355.	26.05
2015-2020	1000.	241.01	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0

SHP,HALE,P=20PA,GWL=4 ,FIX,LEPA ,3/20/83 SUMMARY

ANNUAL CROP COSTS AND PRODUCTION

PERIOD	RETURN $000	I.WAT AC-FT	LAB HRS	DSL GAL	NIT TON	PHOS TON	FUELS $000	VAR MA $000	HARVT $000	TOT VAR $000	REV-VAR $000	FX MA $000	REV-TOT $000
1980-1985	433.24	770.7	5008.	10661.	13.40	13.40	20.67	12.49	110.67	231.16	202.08	48.19	153.89
1985-1990	421.20	770.1	4945.	10607.	12.83	13.03	21.57	12.43	102.60	224.24	186.96	47.44	149.52
1990-1995	418.13	770.3	4942.	11084.	17.88	14.17	22.82	12.29	100.01	227.70	190.43	46.65	143.78
1995-2000	405.46	770.0	4844.	11232.	20.74	14.67	23.86	12.11	92.42	223.42	182.04	45.73	136.31
2000-2005	380.79	770.0	4349.	10693.	25.93	15.60	24.45	11.56	78.06	210.82	169.87	44.22	125.65
2005-2010	341.22	770.0	3615.	9667.	32.42	16.24	24.74	10.62	55.71	189.86	151.36	40.54	110.82
2010-2015	288.53	748.1	2474.	7544.	35.74	15.48	23.78	8.88	32.05	160.35	128.18	35.25	92.93
2015-2020	207.56	0.0	2800.	8500.	6.40	6.40	5.44	5.13	53.02	109.02	98.54	28.74	69.80

1980 PRESENT VALUE OF RETURNS OVER VARIABLE COST UPTO 2020 AT A DISCOUNT RATE OF 2.00 = $ 4706761.
4.00 = $ 3528065.
6.00 = $ 2758818.

OVER VARIABLE AND FIXED COST (EXCLUDING LAND, WATER AND MANAGEMENT) AT A RATE OF 2.00 = $ 3520304.
4.00 = $ 2648216.
6.00 = $ 2076889.