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ABSTRACT

The chief sources of groundwater for the Texas Winter Garden are the Carrizo (Dimmit, Zavala, Frio, and LaSalle Counties) and Edwards (Uvalde County) Aquifers. The major user of groundwater in the region is irrigation. However, insufficient aquifer recharge relative to groundwater use has stimulated interest in alternatives to ease adjustments to diminished groundwater supplies.

The impact on net revenue, groundwater utilization, and land use of new crops (guar, guayule, and short-season irrigated cotton), row damming, and conversion of range to cropland was evaluated using a regional linear programming model. Temporal analysis, 1981-2001, incorporated changes in groundwater availability, static groundwater levels, and corresponding fixed and variable costs.

Introduction of guar and short-season irrigated cotton (base solution) was associated with increased groundwater pumpage from the Carrizo Aquifer, increased net revenue, and increased irrigated acreages. Edwards Aquifer pumpage remained constant at an upper limit. When guayule entered the base solution, net revenue rose by four million dollars and groundwater pumpage and irrigated acreages declined only in the Carrizo Aquifer.

Land clearing without guayule added 17, 25.2, and 26.3 million dollars to net revenue for light; light and medium; and light, medium, and heavy brush clearing; respectively. Under light brush clearing about 480,000 acres were added to cropland and groundwater pumpage remained steady. Pumpage increased under the other land clearing activities. Land clearing with guayule almost doubled net revenue compared to land clearing without guayule.

Row damming was the most effective alternative in reducing dependence on groundwater. Row damming in dryland grain sorghum and dryland cotton decreased groundwater pumpage and increased net returns above the base by 6.7 million dollars without land clearing and 18.6, 30.3, and 32.9 million dollars with the respective land clearing alternatives. Carrizo Aquifer groundwater pumpage was significantly reduced in each of the four alternatives and Edwards pumpage was reduced in all but the heavy brush clearing alternative.

Under temporal and static analysis for projected (forecast) groundwater pumpage, net revenue, groundwater pumpage, and irrigated acres exceeded those of solutions with restricted (forced conservation) groundwater. Carrizo Aquifer groundwater pumpage was greater under restricted than in the projected groundwater scenarios.

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Winter Garden well drilling and irrigation sales and service firms described irrigation hardware and provided data to estimate 1981 irrigation costs. A special thanks goes to Jim Ballard, Able Irrigation; Fred Miller, Zavala Pump and Engine Company; J.A. Letsinger, Sonora Drilling Company; Kelly Pepper, Pepper Irrigation; Sharon Wilson, Wilson Drilling Company; and Jon Biddick, Gensco. We are greatly indebted to those mentioned here as well as many others that contributed to increasing the quality of the study. However, any errors are solely the responsibility of the authors.

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CHAPTER I

INTRODUCTION

The Winter Garden Region of Texas is an important agricultural region with both livestock and crop production. Although crop production without irrigation (dryland) is practiced on much of the cropland, irrigation enhances per acre yields substantially. Irrigation is predominately from groundwater. Irrigation from surface supplies utilized 40,474 acre feet in 1979 (Texas Department of Water Resources, 1981).

The Edwards Aquifer and Carrizo Aquifer are the major sources of groundwater for the Winter Garden. In 1979, total groundwater pumpage in the Winter Garden was estimated at about 317,000 acre feet. Irrigation in the Winter Garden accounted for the use of 293,000 acre feet of groundwater of which 76,000 and 217,000 were from the Edwards and Carrizo Aquifers, respectively (Texas Department of Water Resources, 1981). Other uses of water such as livestock, municipal, manufacturing, and mining, totaled 15,000 and 9,000 acre feet for the Carrizo and Edwards Aquifers, respectively (William Moltz, personal communication).

The annual recharge rate for the Winter Garden is approximately 68,000 acre feet for the Edwards in Uvalde County (Tommy Knowles, personal communication), and 44,500 acre feet for the Carrizo including 9,500 acre feet per year leakage from other water bearing formations through well casings (Klemt, Duffin, and Elder, p.8). Given an effective recharge in the neighborhood of 110,000 acre feet and a discharge of about 300,000 acre feet, together these aquifers are experiencing overdrafting of about 190,000 acre feet of groundwater annually. Continued groundwater mining has contributed to declines of over 200 feet in Carrizo water levels over the period 1930-1970 for some areas (Klemt, Duffin, and Elder).

Water limitations are even more striking when irrigated land is compared with estimated irrigable acres. In 1979, 220,824 acres were irrigated. Some 188,915, 21,165, and 10,744 acres were irrigated from groundwater, combined groundwater and surface, and surface sources, respectively (Texas Department of Water Resources, 1981). This compares with an estimated 1.65 million acres of irrigable land within the five county region (Comer Tuck, personal communication).

With water a major limiting factor in the Winter Garden Region and cost of pumping increasing as groundwater levels decline and energy prices rise, serious questions as to the outlook for the agricultural sector emerge. Some strategies discussed to promote a viable agricultural sector in the Winter Garden include water saving cultural practices, water saving crops, expansion of dryland activities, and restricted levels of groundwater pumping. Basic to an analysis of new technology, alternative crop production strategies, new crops, and limitations on annual withdrawal rates is their effect on farmer profit annually and through time. The purpose of this study is to evaluate the economic implications of the above strategies. A regional linear programming model was constructed as the analytical tool. Application of the regional model provides estimates of net revenue, resource use, cropping patterns, range conversion, and livestock production associated with alternative scenarios.

Study Area

This study focuses on the Texas Winter Garden Area, broadly defined as Dimmit, Uvalde, Zavala, Frio, and LaSalle counties, as shown in Figure 1. The Edwards Plateau portion of Uvalde County is excluded. This selection of adjacent counties is based on similarities of resource base and current economic activity. The five county 1980 population was 64,773 (U.S. Department of Commerce).

The study area is part of the Rio Grande Plain located southwest of San Antonio. The altitude is about 400 to 900 feet above sea level, sloping from north to south. All of the study area, except for the southwest corner of Frio County which is in the Rio Grande River Basin, lies in the Nueces River Basin.

The climate is well suited to agriculture. The growing season is near 280 days and the average temperatures range from 40 degrees Fahrenheit in January to 99 degrees Fahrenheit in July. Average annual rainfall is 20.7 inches in LaSalle, 21.5 in Dimmit, 21.5 in Zavala, 23.4 in Frio, and 23.2 inches in Uvalde County (The Dallas Morning News). Rainfall is at a maximum typically in May-June and August-September (National Oceanic and Atmospheric Administration).

The study area contains 6,175 square miles of which 4,234 square miles or about 2.7 million acres are suitable for cultivation. Only 558,000 acres are currently reported as cropland with 249,000 acres irrigated and 309,000 acres dryland (Jack Stevens, personal communication). Soils are predominately clay loams, sandy loams, and clays. Slopes are nearly level and gently sloping. However, some problems exist with soil salinity and sodium absorption ratios (James Mulkey, personal communication).

The Edwards and Carrizo Aquifers are artesian aquifers and underly most of the study area. An artesian aquifer occurs when overlying beds of strata confine groundwater so that the pressure in the aquifer exceeds atmospheric pressure (Todd). Replenishment or recharge of a confined aquifer occurs wherever the confining bed rises to the land surface. Drilling of a well allows the water to rise above the confining bed. The water surface in the well behaves as if it were that of an unconfined aquifer, only there is no corresponding water surface outside the well casing.

The Edwards Aquifer, underlying most of the study area in Uvalde County, is also the principal aquifer for the San Antonio region (Klemt, Knowles, Elder, and Sieh). The Edwards is a porous rapidly recharged highly permeable limestone aquifer. It is bounded on the north by the Balcones Fault, on the east and west by groundwater divides in Hays and Kinney Counties, and on the south by a line parallel to U.S. Highway 90. In the defined study area, the southern edge of the aquifer is just above the Uvalde-Zavala County line. South of this line, Edwards Aquifer water contains more than 1,000 milligrams per liter of dissolved solids. The entire aquifer is about 175 miles long and ranges in width from 5 to 40 miles and has a saturated thickness of 400 to 700 feet (Texas Water Development Board). Since 1968, annual discharges from the Edwards have exceeded the recharge rate. Annual recharge for the area described above

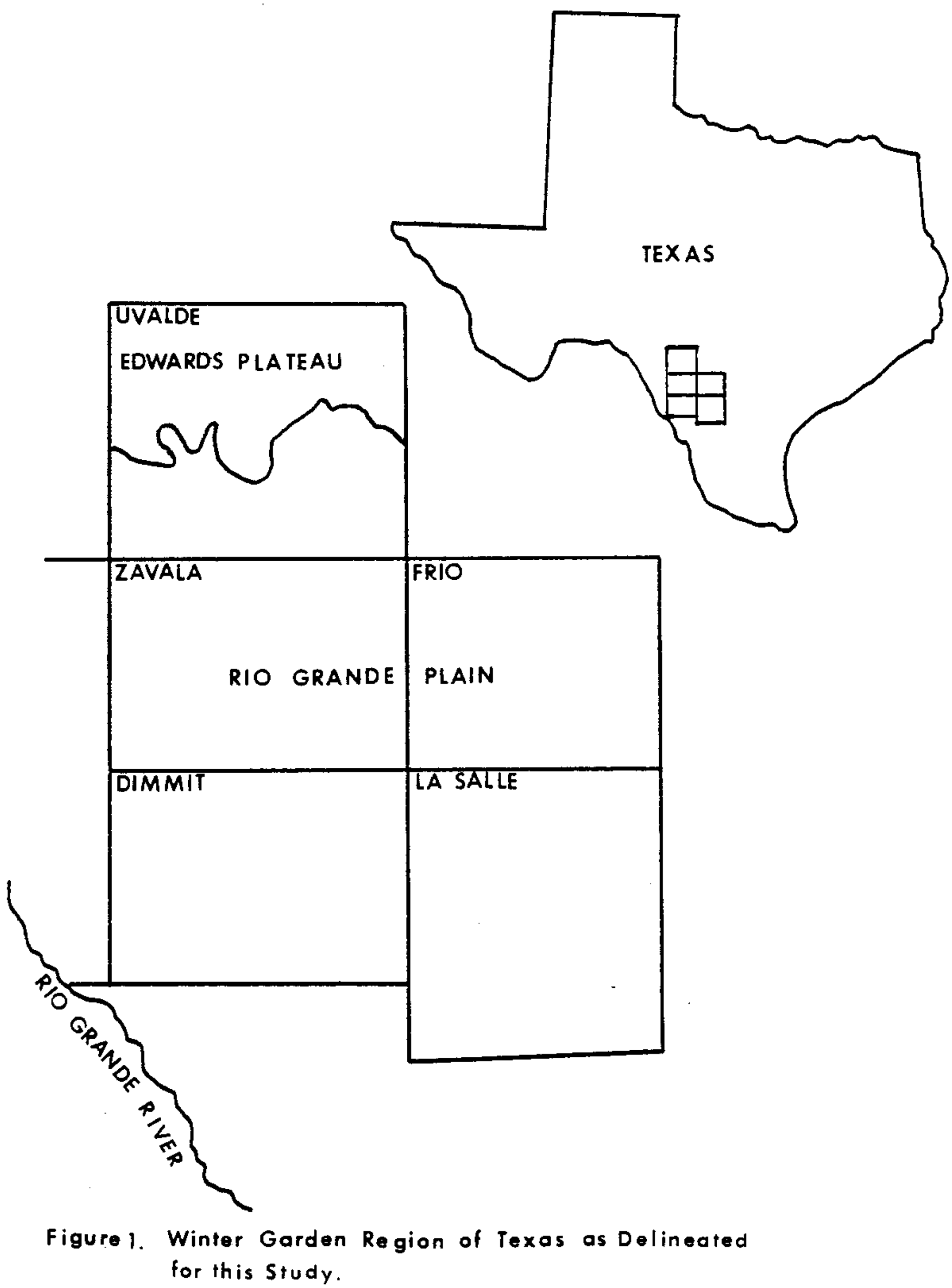

Figure 1. Winter Garden Region of Texas as Delineated for this Study.

is about 531,000 acre feet (Klemt, Knowles, Elder, and Sieh). In 1978, 808,000 acre feet were discharged with 432,000 and 376,000 from wells and springs, respectively (Edwards Underground Water District).

Increasing municipal and manufacturing use along with environmental considerations present additional challenges to appropriate management of the Edwards Aquifer. In 1978, Bexar County (San Antonio) pumped 270,000 acre feet of groundwater from the Edwards Aquifer (Edwards Underground Water District). Pumping in Bexar County is expected to increase to 382,000 acre feet annually by the year 2000 (Klemt, Knowles, Elder, and Sieh).

The ecologically sensitive San Marcos Springs (Hays County) have been designated by the U.S. Fish and Wildlife Service as a critical habitat for the San Marcos Salamander, San Marcos Gambusia, and Fountain Darter. Maintenance of the San Marcos Springs for recreation and preservation, simulating the 1925-70 recharge sequence, would impose a 425,000 acre feet limit on the amount of groundwater pumped from the Edwards Aquifer (Texas Water Development Board). According to Knowles, maintenance of a constant rate of water pumped from the Edwards Aquifer, within the 425,000 acre feet annual limit, would establish a maximum pumpage rate for Uvalde County of 68,371 acre feet (Tommy Knowles, personal communication).[1]

The Carrizo Aquifer underlies Dimmit, Frio, LaSalle, Zavala, and southeast Uvalde County and is the Winter Garden's principal and most heavily pumped aquifer. The Carrizo is thought to be connected with the Wilcox which underlies it. Although Wilcox water is of poorer quality and has sands of lower permeability, the two are usually considered as a single aquifer. The Carrizo sands are of moderate to high permeability and range in thickness from 150 to 700 feet in the study area (Klemt, Duffin, and Elder).

The region's resources are dedicated primarily to livestock and crop production. Recreational uses reflected in hunting leases are also important. In 1979, cash receipts from crops and livestock products totaled 90 million and 149 million dollars, respectively (Texas Crop and Livestock Reporting Service, 1980a). Study area farmers are major producers of vegetables, field crops and small grains. Some 30,500 acres of vegetables were harvested in 1979. Frio, Zavala, and Uvalde counties were in the top ten Texas counties for 1979 in production of fresh market vegetables. The Texas Winter Garden is the United States leader in spinach acreage with more than 5,000 acres harvested in 1979 (Texas Crop and Livestock Reporting Service, 1980c). In the same year, area producers harvested 52,000 acres of corn, 48,000 acres of wheat, 51,000 acres of grain sorghum, and 49,000 acres of cotton (Texas Crop and Livestock Reporting Service, 1980b).

Objectives

The overall objective of this study was to estimate the economic implications of new crops, new technology, and limited groundwater on

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[1]Pumping limitations utilized in this study are for comparative purposes only and are not to be construed as recommended or desirable policy objectives.

agriculture in the Winter Garden Region of Texas. Specific objectives are listed below:

1. Develop a regional linear programming model relating groundwater characteristics, soils, and range sites via typical management and 1980-81 markets to production of livestock and major crops.
2. Apply the Winter Garden linear programming model to estimate the impact of alternative static scenarios on regional net revenue, resource use, and cropping patterns. Specific scenarios include:
   a. Introduction of new crops and row damming.
   b. Restricted and projected groundwater quantities for irrigation.
   c. Conversion of brush infested range to cropland.
3. Expand application of the linear programming model to temporal analysis of water use through the year 2001 to estimate impact over time on net revenue, resource use, and cropping patterns under restricted and projected pumpage limitations with and without land clearing.

Review of Literature

There are numerous studies for other regions of Texas and the nation that closely parallel this effort. These studies provide a framework for organization and methodology applicable to analysis of agriculture in the Winter Garden where the emphasis is on use of groundwater for irrigation.

Groundwater depletion and its impact on irrigated agriculture has been studied intensively for the Ogallala Aquifer which underlies parts of Texas, New Mexico, Oklahoma, Colorado, Kansas, and Nebraska. A 1971 study of the central Ogallala formation shows misallocation of groundwater over time is not necessarily a result of common property resource characteristics of the aquifer but depends on whether or not water is the limiting factor of production. Expansion of irrigated agriculture may be constrained by availability of other resources such as capital, labor, or government program conditions (Bekure and Eidman). In another application, value of groundwater utilized for irrigation in a five county study area of the Texas High Plains was analyzed using discounting techniques. Temporal groundwater allocation was established where present marginal net returns were equated to discounted marginal net returns of future time periods. Cost modifications were made to account for increasing lift and decreasing well yields. The value of water was enhanced by lower discount rates. Non-optimal enterprise selection reduced the value of the water supply (Lacewell and Grubb).

Linear programming models have commonly been used to analyze regional water problems. A recent contribution, enhancing the analytical power and content of linear programming in regional analysis, replaces the traditional flexibility restraints with resource base heterogeneity (Laughlin, Lacewell, and Moore; Masud, et al.; Cornforth and Lacewell; Taylor and Frohberg). Estimated crop yields are obtained for each soil type from published surveys. These yields are evaluated by agronomists and suggestions incorporated where appropriate. The relationship of soil productivity to yield variations, harvesting costs, fertilizer recommendations, and other input-output variables is specified separately for each crop on each soil type.

Lacewell, Laughlin, and Moore evaluated the expected impact on agriculture of chloride control in the Red River on the Texas-Oklahoma border.

Some 254 soil types and five crops were considered. Acreages of each soil type and availability of irrigation water were limiting resources in a model used to solve for net revenues by 10 year increments over the life of the project.

Taylor and Frohberg developed a linear programming model to estimate social costs of alternative agricultural environmental policies. Eleven land capability units were defined with 17 land resource areas. Yields and corresponding input levels were developed for each of 187 land capability units.

A 1980 study focusing on integrated pest management in the Texas Coastal Bend Region included 82 soil types (Masud, et al.). A similar methodology was applied to the El Paso County Water Improvement District. Some 12 crops and six soil groups were incorporated into a linear programming model to analyze the impact of a water accumulation program (surface water) combined with use of groundwater (Cornforth and Lacewell). The same study addressed value of water carryover through time by varying farmer water accumulation and water allocations.

Regulation, new crops, and technological change have been suggested as methods of conserving groundwater resources. Restricted pumping levels to optimize Carrizo groundwater development over the period 1970-2020 are based on a differential equation aquifer model (Klemt, Duffin, and Elder). Pumping rates reflect the requirement that the Carrizo recharge zones not be dewatered and that the lift in other pumping areas reach only 400 feet by 2020.

New crops such as short-season cotton, guayule, and guar require less irrigation per season offering a potential of maintaining net revenue in the farming sector with less irrigation. Short-season cotton has a uniform fruiting pattern so that an early harvest can be accomplished through a single stripping operation. It is grown in an integrated production system in which water, energy, and insect control requirements are reduced while maintaining net returns to land and management (Lacewell, et al.). In the Texas Coastal Bend Region short-season cotton has completely displaced traditional long season production systems (Masud, et al.). The Winter Garden has been slow to adopt short-season cotton and associated management systems (Joe Peña, personal communication). In 1980, drought, low humidity, and premature fruiting were cited as problems.

Guayule, a native Texas plant and a source of natural rubber, is not currently grown commercially but is well suited to the Winter Garden. A national linear programming analysis of regional competition shows the Winter Garden Region has a comparative economic advantage in guayule production (Cornforth, et al.). Experience gained from the Emergency Rubber Project of World War II and previous commercial operations indicates that the Winter Garden's rainfall, temperature, and many of its soils are ideal for guayule cultivation (Foster, et al., 1979; Hammond and Polhamus).

On the market side, natural rubber is essential for defense and industrial uses such as airplane, truck, and bus tires (Grilli, Agostini, and 't Hooft-Welvaars). In the absence of domestic natural rubber production, imports must fill these requirements. United States natural rubber imports trended upward at about 15,000 metric tons annually or about 5 per cent per year from 1969-79 (U.S. Department of Agriculture, 1980a). Natural rubber became more competitive with synthetic rubber due to price increases of oil based feed stocks required in synthetic rubber manufacture (Grilli, Agostini, and 't Hooft-Welvaars; Mann and Blandford). These factors stimulated interest in a new guayule industry (Foster, et al., 1980).

Guar is a drought resistant annual legume crop from India (Martin, Leonard, and Stamp). Some 80,000 acres of guar were produced under contract in 1981 in the Winter Garden. This represents about one-half of domestic guar acreage (Pigg). Opportunities for increased domestic production exist since 85 per cent of U.S. guar needs are imported from India and Pakistan (Pigg).

Guar has numerous industrial and agricultural applications (Martin, Leonard, and Stamp). Guar gum or mucilage obtained from the seed is useful as a stabilizer and thickener in foods and as an ingredient in drilling muds. Guar beans and hay are valuable for livestock production. Guar is also extremely resistant to cotton root-rot organisms and it is partly resistant to root knot nematode. Therefore guar could be valuable in a cotton-guar rotation.

Possibilities of new technology include row damming. Row damming provides small catchment basins between the rows of cultivated crops so that rainfall and runoff are more fully utilized. In research on the Texas High Plains, row damming has been shown to be effective in increasing dryland cotton yields 11 to 25 per cent and in raising dryland sorghum yields by 25 to 40 per cent (Runkles).

Study Organization

The remaining parts of the study are divided into discussion of the model, results, and a summary. Chapter II describes the analytical models employed. Development, organization, and expression of input data in the form required for the construction of a linear programming model is documented.

Results of the static and temporal analysis are presented in Chapter III. Results concentrate on changes in annual groundwater use, net returns, and other resource use associated with introduction of new crops, technology, and land clearing. The final chapter consists of summary, conclusions, and study limitations.

CHAPTER II

MODEL AND PROCEDURES

The model developed to represent the Winter Garden region is general so that changes in the availability of resources and changes in prices of inputs and outputs can be easily adjusted. In this study, the model is used to evaluate the impact on net revenue, cropping patterns, and resource use of different groundwater scenarios, row damming, introduction of water saving crops, fixed cost levels, and brush clearing alternatives. A description of the analytical model is followed by a section describing data development procedures. A static linear programming model was modified to facilitate the temporal analysis of groundwater utilization.

Analytical Model

The linear programming model representing agricultural production alternatives for the study area maximizes returns to producer land, labor, and groundwater. Figure 2 illustrates the activities and constraints of the linear programming model. Activities are the processes that produce end products, intermediate products, and buy and sell inputs and outputs. Constraints define levels of resources available and specify marketing and risk limitations.

Activities

Crop production and a cow-calf enterprise are the income generating activities of the linear programming model. Supporting activities include land clearing, irrigation, fixed costs, capital, harvest, and input buying and product selling options. The model includes 37 different soils, 14 separate water resource areas, and 10 irrigated and 8 dryland crops. There is a total of 2,668 furrow, 2,664 sprinkler irrigated, and 503 dryland cropping activities. Dryland and furrow activities use one acre of cropland inventory and sprinkler irrigated activities use 1.27 acres. The center pivot sprinkler irrigation systems irrigate all but the corners of a 160 acre quarter section. The extra .27 acres for each sprinkler irrigated acre represent the unirrigated corners which are idled or under dryland cultivation in the same crop as the irrigated acreage.

Generalized inputs refer to inputs common to all activities producing a specific crop. There are 21 common activities that furnish one acre's worth of seed, agricultural chemicals (other than fertilizer), fixed machinery inputs, energy inputs, and labor to their respective enterprises. Specialized inputs, specific to individual activities such as fertilizer, irrigation water, and harvest costs, are directly related to yield.

Harvest and selling activities account for 30 vectors of the linear programming model. Some examples of these types of costs are hauling;

	Production Activities									Irrigation		Har-			Right
	Sprink-ler	Fur-row	Dry-land	Cor-ners	Disc idle	Cow-calf	Gene-ral	Range	Estb Range	Clear Range	Fixed Costs	Vari-able	vest Cost	Buy	Sell	Hand Side
Objective Function									-e	-f	-c		-b	-a	d	
Cropland Soils	1.27	1	1							-1						≤g
Corners	-.27			1	1											=0
Specific Inputs	h	h	h	h	h									-1		=0
Generalized Inputs						k	k	k	k					-1		=0
General Transfers	1	1	1	1			-1									=0
Water Area Soils	1.27	1														≤1
Irrigation Water	m	m										-n				=0
Irrigation Inputs												-1		1		=0
Irig. Transfer												1				≤p
Irig. Fixed Cost	1	1									-1					=0
Output Transfer	q	q	q	q		q									-1	=0
Harvest Costs													-1		1	=0
Grazing Transfer	s	s	s	s		-1		s								=0
Range								1	-1	1						≤t
Arable Range										1						≤u
Limitations	1	1	1	1											1	≤v

a Input prices including non-irrigation fixed costs.
b Harvest costs including harvest fixed costs.
c Irrigation fixed costs.
d Selling activities generate revenue from output sales.
e Establish buffel grass to expand improved range acreage.
f Convert range to cropland through brush clearing activities.
g Cropland acreage by soil type.
h Inputs specific to each crop such as fertilizer.
k Generalized inputs common to many crop and management activities.
l Acreages of arable soils by water resource area.
m Acre inches of groundwater required for each crop by soil type.
n Irrigation system efficiency coefficients.
p Irrigation groundwater availability by water resource area.
q Output or yields from activities.
s Grazing transfer to livestock enterprise.
t Range acreages.
u Arable range acreages by soil type in each range site.
v Limitations on vegetables, contract crops, peanuts, and crop mix.

Figure 2. Schematic Depiction of the Winter Garden Linear Programming Model.

custom combining; ginning, picking, and stripping cotton; and crop drying.

Range activities include 34 arable and 66 non-arable light, medium, and heavy brush infested range sites. Range sites produce grazing as an intermediate product and outdoor recreation through a hunting lease activity. Land clearing activities convert light, medium, and heavy brush infested arable range to cropland.

Fixed costs are annual charges which do not vary with production. All fixed costs were developed using an 8 percent interest rate. Items for which fixed costs are identified include irrigation; establishment costs for bermuda grass hay, buffel grass, and coastal bermuda grass hay; livestock; machinery; and harvesting. Irrigation fixed costs consist of well development and system fixed costs. Well development includes well drilling and casing. System costs include pumps, motors, and distribution systems for lift intervals based on depth to water. Other activities for furrow and sprinkler irrigation account for the variable costs of delivering groundwater to the crop root zone.

A single borrowing activity furnishes capital at a charge of 8 percent for one half a year. The balance of the annual capital requirement is financed by harvest cash flow.

Constraints

Constraints in the model consist of soils in cropland inventory, arable soils in water resource areas, acre inches of groundwater available for irrigation by water resource area, arable and non-arable range, and technical and institutional limitations. The cropland inventory of 37 soils restricts the acreages of each soil available for cultivation. A second soil constraint limits acreages of arable soil types in each water resource area. Groundwater limitations limit the amount of groundwater which can be used for irrigation of crops in a water resource area. Arable and non-arable rangeland constraints specify range by level of brush infestation (light, medium, or heavy) for each range site. In addition, acres of each soil type in an individual range site are specified.

The final constraint category consists of limitations on acreages, technical processes, and marketing possibilities. Historical acreages were imposed to limit acreages of processing spinach, carrots, cabbage, and forage sorghum hay as shown in Appendix Table 27. Vegetable enterprises appear to be quite lucrative in the model. However, vegetable production and marketing is complex and extremely risky. Growers compete for a small segment of the market mainly through timing of harvests.

To minimize weather related crop losses arising from non-optimal timing of field operations producers maintain a 1.63 to 1 ratio of grain sorghum to cotton (Whitson, Kay, LePori, and Rister). This insures that field operations are completed 90 percent of the time.

Upper limits on guar and peanut production reflect contract and poundage limits. Guar acreage is set on the basis of 80,000 acres of contracts that prevailed in 1982 (Joe Peña, personal communication). A peanut poundage limitation of 531,884 hundredweights is based on the 1979 effective peanut quota of 53,188,379 pounds for LaSalle, Zavala, Frio, and Dimmit Counties (State Agricultural Stabilization and Conservation Committee).

Temporal Analysis

Changes in the availability of groundwater for irrigation and in the static groundwater level were introduced to modify the static linear program for temporal analysis. Water resource constraints were changed for each water resource area using projections of the amount of groundwater available for irrigation in 1985-86, 1990-91, 1995-96, and 2000-01. The Edwards Aquifer is the only aquifer showing increased availability of irrigation groundwater overtime. Given the information about declines in the static water levels associated with pumpage in the Carrizo and Edwards Aquifers, changes in lift by water resource area were estimated based on quantity of groundwater used for all purposes during the previous period. Any changes in the fixed and variable costs of an irrigation system associated with pumping lift were incorporated into the model to be applied to the next 5 year period. An activity assessing a fixed cost per acre inch of additional groundwater developed was introduced for expansion of irrigation in the Edwards Aquifer.

Data Development Procedures

Technical, price, and quantity information in linear programming must be represented by single coefficients. Input data includes cost per unit of purchased inputs and outputs, technical instructions for processes changing resources into outputs, and specification of levels of primary resources.

This section presents basic model data and describes how the data were developed. Major data classifications discussed include; 1) soils, 2) range, 3) crop yields, 4) crop inputs, 5) soil and water resource integration, 6) irrigation costs, 7) livestock enterprises, and 8) input and output prices.

Soils

The regional programming model was developed to include acreages of 37 selected soil groupings defined from careful appraisal of study area soil series. The task of defining soil types was complicated by lack of current soil surveys for Dimmit, Zavala, Frio, and LaSalle counties. However, the Soil Conservation Service provided county acreage breakdowns based on recent fieldwork describing each soil's slope, capability class under irrigation and dryland conditions, range site, and amounts of irrigated and non-irrigated cropland (Jack Stevens, personal communication).

Description and use of arable soils are reported in Table 1. Arable soils were defined as soils suitable for irrigation with capability classes I through IV. Of the 2.7 million acres of arable land in the study area, there are 309,000 and 249,000 acres cropped as non-irrigated and irrigated, respectively (Jack Stevens, personal communication). Study area soil types, Appendix Table 28, were established from arable soils by a process of elimination and combination. Shallow soils and soils with excessive slope and salinity problems were dropped from consideration (Jack Stevens, personal communication). Arable soils of less than 20,000 acres, Appendix Table 29, were combined with other similar soils on the

Table 1. Disposition of Arable Soils: Cropland (Irrigated and Dryland Cultivation) and Range (Light, Medium, and Heavy Brush Infestation), Winter Garden, 1981.

Soil Name	Slope (Percent)	Soil Symbol	Range Site Symbol[a]	Arable Soils Total[b] (Acres)	Non-Irrigated Cropland (Acres)	Irrigated Cropland (Acres)	Total Cropland (Acres)
Amphion clay loam	0-1	AMA	CL	48,071	14,000	2,000	16,000
Atco loam	0-1	ATA	HL	40,792	7,600	6,200	13,800
Atco loam	1-3	ATB	HL	34,350	5,500	4,000	9,500
Antosa-Bobillo	0-3	ABC	S	76,420	5,000	1,000	6,000
Bookout clay loam	0-1	BKA	CL	60,628	7,300	26,500	33,800
Bookout clay loam	1-3	BKB	CL	32,622	2,200	7,700	9,900
Brystal fine sandy loam	0-1	BSA	SL	77,824	12,500	3,000	15,500
Brystal fine sandy loam	1-3	BSB	SL	180,156	15,535	10,853	26,388
Caid sandy clay loam	0-1	CAA	CL	41,159	5,300	2,800	8,100
Caid sandy clay loam	1-3	CAB	CL	31,615	3,400	1,700	5,100
Chacon clay loam	0-1	CHA	CL	70,421	2,500	3,700	6,200
Chacon clay loam	1-3	CHB	CL	28,779	1,800	700	2,500
Cotulla clay	0-1	CTA	SC	96,405	4,500	3,300	7,800
Cotulla clay	1-3	CTB	SC	61,186	2,500	1,500	4,000
Dilley fine sandy loam	1-5	DLY	SSL	88,365	4,000	1,000	5,000
Divot silty clay loam	0-1	DIA	LB	45,900	7,200	6,500	13,700
Duval fine sandy loam	0-1	DVA	SL	62,082	8,000	4,000	12,000
Duval fine sandy loam	1-3	DVB	SL	316,239	32,900	20,500	53,400
Duval loamy fine sand	0-3	DUC	LS	29,660	6,000	3,000	9,000
Duval-Melon complex	0-5	DMX	LS	142,963	42,500	16,000	58,500
Knippa clay	0-1	KNA	CL	98,523	25,000	8,000	33,000
Knippa clay	1-3	KNB	CL	21,687	3,500	1,000	4,500
Montell clay	0-1	MTA	CF	143,984	8,200	18,800	27,000
Montell clay	1-3	MTB	CF	29,064	1,500		1,500
Pryor sandy clay loam	0-1	PRA	CL	36,680	4,800	1,500	6,300
Pryor sandy clay loam	1-3	PRB	CL	99,150	3,000	3,200	6,200
Randado fine sandy loam	1-3	RNB	SSL	32,038			
Tonio fine sandy loam	0-1	TOA	GSL	23,920	600	400	1,000
Tonio fine sandy loam	1-3	TOB	GSL	75,390	1,800	3,000	4,800
Uvalde silty clay loam	0-1	UVA	CL	236,864	34,200	59,500	93,700
Uvalde silty clay loam	1-3	UVB	CL	63,879	5,700	6,000	11,700
Valco clay loam	0-3	VLC	SA	20,533		400	400
Webb fine sandy loam	0-1	WEA	TSL	40,964	4,000	2,000	6,000
Webb fine sandy loam	1-3	WEB	TSL	107,665	9,500	3,300	12,800
Winterhaven silty clay loam	0-1	WNA	LB	48,140	5,500	15,000	20,500
Zavco sandy clay loam	0-1	ZVA	CL	21,807	700	200	900
Zavco sandy clay loam	1-3	ZVB	CL	44,011	11,500	2,200	13,700
Total				2,709,936	308,735	249,453	558,188

Table 1. Continued.

Soil Name	Slope (Percent)	Soil Symbol	Range Site Symbol[a]	Arable Range Total[b] (Acres)	Brush Infestation Light (Acres)	Brush Infestation Medium (Acres)	Brush Infestation Heavy (Acres)
Amphion clay loam	0-1	AMA	CL	32,071	6,414	12,829	12,828
Atco loam	0-1	ATA	HL	24,850	8,055	13,425	5,370
Atco loam	1-3	ATB	HL	24,850	8,055	13,425	5,370
Antosa-Bobillo	0-3	ABC	S	70,420	49,294	21,126	
Bookout clay loam	0-1	BKA	CL	26,828	5,366	10,731	10,731
Bookout clay loam	1-3	BKB	CL	22,722	4,544	9,089	9,089
Brystal fine sandy loam	0-1	BSA	SL	62,324	18,697	31,162	12,465
Brystal fine sandy loam	1-3	BSB	SL	153,768	46,130	76,884	30,754
Caid sandy clay loam	0-1	CAA	CL	33,059	6,612	13,224	13,223
Caid sandy clay loam	1-3	CAB	CL	26,515	5,303	10,606	10,606
Chacon clay loam	0-1	CHA	CL	64,221	12,844	25,689	25,688
Chacon clay loam	1-3	CHB	CL	26,279	5,256	10,512	10,511
Cotulla clay	0-1	CTA	SC	88,605	35,442	44,303	8,860
Cotulla clay	1-3	CTB	SC	57,186	22,874	28,593	5,719
Dilley fine sandy loam	1-5	DLY	SSL	83,365	25,009	45,851	12,505
Divot silty clay loam	0-1	DIA	LB	32,200	6,440	19,320	6,440
Duval fine sandy loam	0-1	DVA	SL	50,082	15,025	25,041	10,016
Duval fine sandy loam	1-3	DVB	SL	262,839	78,852	131,419	52,568
Duval loamy fine sand	0-3	DUC	LS	20,660	16,528	4,132	
Duval-Melon complex	0-5	DMX	LS	84,463	67,570	16,893	
Knippa clay	0-1	KNA	CL	65,523	13,105	26,209	26,209
Knippa clay	1-3	KNB	CL	17,187	3,437	6,875	6,875
Montell clay	0-1	MTA	CF	116,984	35,095	46,794	35,095
Montell clay	1-3	MTB	CF	27,564	8,269	11,026	8,269
Pryor sandy clay loam	0-1	PRA	CL	30,380	6,076	12,152	12,152
Pryor sandy clay loam	1-3	PRB	CL	92,950	18,590	37,180	37,180
Randado fine sandy loam	1-3	RNB	SSL	32,038	9,611	17,621	4,806
Tonio fine sandy loam	0-1	TOA	GSL	22,920	6,876	11,460	4,584
Tonio fine sandy loam	1-3	TOB	GSL	70,590	21,177	35,295	14,118
Uvalde silty clay loam	0-1	UVA	CL	143,164	28,633	57,266	57,265
Uvalde silty clay loam	1-3	UVB	CL	52,179	10,436	20,872	20,871
Valco clay loam	0-3	VLC	SA	20,133	6,040	12,080	2,013
Webb fine sandy loam	0-1	WEA	TSL	34,964	6,993	20,978	6,993
Webb fine sandy loam	1-3	WEB	TSL	94,865	18,973	56,919	18,973
Winterhaven silty clay loam	0-1	WNA	LB	27,640	5,528	16,584	5,528
Zavco sandy clay loam	0-1	ZVA	CL	20,907	4,181	8,363	8,363
Zavco sandy clay loam	1-3	ZVB	CL	30,311	6,062	12,125	12,124
Total				2,151,748	653,435	974,124	524,189

Source: Jack Stevens, Soil Conservation Service, personal communication; Stevens and Richmond.

[a] Range site symbols are defined in Table 2.
[b] Non-arable range is summarized in Table 31.

basis of permeability, available moisture, salinity, and similarity to other soils as recorded in soil survey interpretation forms (U.S. Department of Agriculture, 1979).

Soil names are abbreviated to indicate soil type and slope (Table 1, Column 3). The first two letters of each name refer to the major soil type. The third letter designates slope; A, 0-1 percent; B, 1-3 percent; C, 0-3 percent; Y, 1-5 percent; and X, 0-5 percent slopes.

Range

Range acreages, obtained from detailed soil inventories, were classified as arable or non-arable according to soil types in each range site (Jack Stevens, personal communication). Brush densities by range site (Ken Starks, personal communication), Appendix Table 30, were used to allocate range into light, medium, and heavy categories of brush infestation. Range in each brush density category by arable soil type is listed in Table 1. Brush density distribution of non-arable range sites is listed in Appendix Table 31.

Range site brush density directly affects the number of acres of a range site required to support an animal unit for one year (Table 2) as well as land clearing costs if the range is converted to cropland. Range site descriptions report range conditions as excellent, good, fair, and poor, where 76-100, 51-75, 26-50, and 0-25 percent, respectively, of climax vegetation remains (Stevens and Richmond). Excellent and poor range conditions were selected to represent light and heavy brush infestation. Grazing yield for medium brush density range is the midpoint of good and fair range conditions. Light brush density range includes acreages previously converted to improved pasture. Maintenance of range in light and medium range sites requires an annual expenditure of $3.00 and $1.50 per acre, respectively (Extension Economists-Management, 1981a). Cropland can be converted to improved pasture (buffel grass) at an annual charge of $3.58 per acre, Appendix Table 32.

Costs of converting light, medium, and heavy brush infested range to cropland are summarized in Appendix Table 33. Description of steps and costs required to convert range into cropland (Peña) were expanded using machinery complement data for cotton (Joe Peña, personal communication; Extension Economists-Management, 1981b). The total costs per acre for conversion to cropland were light, $27.91; medium, $101.27; and heavy $155.35. Associated annual establishment or conversion costs were prorated over time at $2.23, $8.10, and $12.43 per acre for the respective density classifications.

Crop Yields

Relative soil productivity is reflected in crop yields and animal unit months of grazing per acre. All yields, except for guayule, were developed under the assumption of high level management which assumes use of state of the art methods of soil and water management, cultural practices, disease and pest control, and tillage operations as well as improved varieties of seed.

Appendix Table 34 reports high level management crop yields (except

Table 2. Acres per Animal Unit by Range Site and Brush Density, Winter Garden, 1981.

Range Site	Symbol	Brush Density Light (Acres)	Medium (Acres)	Heavy (Acres)
Blackland	B	7	12	15
Clayey Bottomland	CB	7	15	20
Clay Flat	CF	12	24	35
Clay Loam	CL	15	21	28
Claypan Prairie	CP	16	21	30
Deep Sand	DS	11	20	26
Gravelly Ridge	GR	22	33	40
Gray Sandy Loam	GSL	12	20	25
High Lime	HL	17	24	32
Lakebed	L	10	22	30
Loamy Bottomland	LB	7	12	23
Loamy Sand	LS	9	14	25
Ramadero	R	8	16	18
Rolling Blackland	RB	10	17	24
Rolling Hardland	RH	16	28	36
Saline Clay	SC	7	12	15
Sandstone Hill	SSH	12	21	28
Sandy	S	11	17	20
Sandy Loam	SL	10	17	22
Shallow	SH	17	25	30
Shallow Ridge	SR	15	20	25
Shallow Sandy Loam	SSL	15	25	33
Tight Sandy Loam	TSL	11	18	23
Deep Upland	DU	8	14	18
Igneous Hill	IH	16	28	36
Redland	PL	10	17	23
Rocky Hill	KH	22	40	50
Stony-Adobe[a]	STA	13	19	31

Source: U.S. Department of Agriculture, undated; Ken Starks, Range Management Specialist, Soil Conservation Service, personal communication.

[a] Combines non-arable range sites Adobe, Steep Rocky, and Low Stony Hill.

guayule which is a typical yield) and animal unit months of grazing per acre for the 37 study soil types. Yield estimates were specified for irrigated cotton, grain sorghum, peanuts, corn, processing spinach, cabbage, carrots, guayule, guar, and bermuda grass hay. Dryland crops include short-season cotton, grain sorghum, winter wheat, oats for grazing, peanuts, coastal bermuda grass, bermuda grass hay, and sorghum hay.

Estimation of yield by soil type was initiated by reviewing Soil Conservation Service "blue sheets" for major soil series (U.S. Department of Agriculture, 1979), published soil surveys for Uvalde (Stevens and Richmond) and other counties with the same and similar soils, and yields for major crops on Rio Grande Plain soils (Bill Harris, personal communication). Added detail was provided by preliminary yield estimates for Dimmit and Zavala Counties (Jack Stevens, personal communication) and yield estimates of SCS county conservationists (C. L. Girdner, personal communication). In addition to these sources of yield data, agricultural economists, soil scientists, and agronomists reviewed yields and suggested changes. Estimated crop yields developed from this process were transferred to Appendix Table 34. Additional effort was required to estimate yields for carrots, spinach, irrigated and dryland cotton, guar, guayule, oats for grazing with peanuts, dryland peanuts, and hay crops. Yield data from a pre-World War II soil survey (Smith and Huckabee) was used to distribute carrots and spinach yields (Extension Economists-Management, 1981b) assuming that the relative productivities of regional soils in production of these crops were unchanged over time.

Guar yields were based upon guidance of local scientists most familiar with the crop (Joe Peña and James Mulkey, personal communication). Dryland and irrigated yields were estimated for soil categories aggregated by texture; sandy loam, silty clay loam, loam, fine sandy loam, sand, clay loam, and clay. Guar yields for each soil within a soil texture group were proportional to the same individual soil's grain sorghum yield (Joe Peña and James Mulkey, personal communication).

Irrigated guayule yields were estimated from rubber yield per acre for various soil groupings (Retzer and Mogen). Study area soils were aggregated by texture, permeability, and water availability into 4 groups; a) clay loams and loams, b) mostly clay, c) sand loams, and d) sand. Each soil group was assigned a yield based on technical analysis of two year old guayule shrubs. Dryland guayule yields were estimated by reducing estimated irrigated yields by 34 percent (Retzer and Mogen). Cabbage yields were selected to distribute irrigated and dryland guauyule yields within soil groups, based on the observation that leafy vegetable yields closely paralleled those of guayule in Winter Garden test plots (George Miller, personal communication).

Irrigated cotton yields from the soil surveys were used to distribute long season irrigated cotton yield (800 pounds of lint per acre) and short-season irrigated cotton yield (700 pounds of lint per acre) given in the Texas Crop Budgets (Extension Economists-Management, 1981b). Dryland cotton yields were set at one-half of the short-season irrigated cotton yields (Extension Economists-Management, 1981b). Cotton seed yield in tons is .08 percent of pounds of cotton lint produced per acre (Extension Economists-Management, 1981b).

For irrigated peanuts, animal unit months of grazing was set the same as oats for grazing. Dryland peanut oat grazing yield was set at one half the irrigated peanut yield (Extension Economists-Management, 1981b).

Dryland peanut yield was estimated by weighting the Texas Crop Budget yield, 12.5 hundredweights per acre (Extension Economists-Management, 1981b), with preliminary yield estimates (C. L. Girdner, personal communication).

Forage sorghum hay yields were based on the assumption that yield of forage sorghum hay is directly proportional to grain sorghum yields. A per acre dryland yield of 4.5 tons corresponds to a 25 hundredweight yield of dryland grain sorghum (Extension Economists-Management, 1981b).

For the dryland corners in a pivot irrigation system, crops were assumed to use the same level of inputs as the irrigated activity but have reduced yields. For example, short-season cotton and grain sorghum produced as dryland in the corners of a pivot irrigated field were assigned a yield of one half of their respective irrigated yields (Extension Economists-Management, 1981b). Based on these relationships, long season cotton and bermuda grass hay were set at one half of their irrigated yields. Dryland bermuda grass hay yield is the same per cutting as irrigated but only half as many cuttings are made. Guar and guayule corner yields were fixed at their dryland levels. Peanut yields were 45 percent of irrigated yields (Extension Economists-Management, 1981b).

Yields of all high level management crop activities were adjusted to typical management, Table 3. Typical managers are assumed to realize yields 15 per cent below those reported in the basic yield matrix (Laughlin, Lacewell and Moore). Guayule yield was not reduced since the published yields represented typical management (Cornforth, et al.).

Crop Inputs

To produce one acre of a crop on a given soil type and obtain a specified yield requires a defined set of inputs. Further, there are costs associated with the selected input levels so that inputs can be expressed as quantities or dollar amounts. A discussion of input requirements for study area crops is separated into fertilizer, irrigation, other variable inputs, harvest costs, and miscellaneous fixed costs.

Fertilizer

Fertilizer coefficients for nitrogen, phosphate, and potash by crop per unit of output, Appendix Tables 35 and 36, were developed from published fertilizer recommendations (Welch, et al.) and budget data reflecting practices of better managers (Extension Economists-Management, 1981b). Recommended fertilizer levels are a function of soil fertility (Welch, et al.). Selection of fertility levels for nitrogen and postassium were based on area fertilization practices (Extension Economists-Management, 1981b) and previous studies (Cornforth and Lacewell; Laughlin, Lacewell, and Moore). Low levels of nitrogen and phosphate were assumed for all soils, except in production of small grain for grain and grazing and bermuda grass hay. For these crops, medium fertility was assumed.

The amount of potash required is dependent on soil sandiness (Welch, et al.). Potash soil fertility was assigned according to degree of soil sandiness. Rarely is potash included in crop enterprise budgets (Extension Economists-Management, 1981b). Sandy soils, Antosa-Bobillo, Duval

Table 3. Crop and Grazing Yields Under Typical Management by Soil Type, Winter Garden, 1981.[a]

Soils[b]	Vegetables: Cabbage (tons)	Vegetables: Carrots (tons)	Vegetables: Spinach (tons)	Irrigated Crops: Cotton: Short Season (lbs)	Irrigated Crops: Cotton: Long Season (lbs)	Corn (bu)	Guayule (lbs)	Peanuts (cwt)	Sorghum (cwt)	Guar (cwt)	Bermuda Hay (tons)
ABC								25.5			3.4
AMA	15.3	12.8	6.0	674.9	771.0	102.0	590.0		59.5	15.7	8.5
ATA	11.9	8.5	5.6	613.7	701.3	68.0	470.0		42.5	12.5	7.7
ATB	8.5	6.8	5.1	521.1	595.9	59.5	350.0		38.3	11.3	6.8
BKA	13.6	10.2	6.8	613.7	701.3	76.5	530.0		45.1	11.9	8.5
BKB	12.8	8.5	6.0	552.5	630.7	72.3	500.0		42.5	11.2	7.7
BSA	13.6	10.2	6.0	613.7	701.3	80.8	530.0	27.2	40.8	11.3	8.5
BSB	12.8	8.5	5.1	552.5	630.7	76.5	500.0	25.5	38.3	10.6	7.7
CAA	14.5	11.9	6.0	613.7	701.3	76.5	560.0		51.0	13.6	8.5
CAB	11.9	8.5	5.1	552.5	630.7	68.0	470.0		42.5	11.3	7.7
CHA	12.8	8.5	5.1	613.7	701.3	76.5	385.0		52.7	13.9	8.5
CHB	11.9	6.8	4.3	552.5	630.7	72.3	335.0		45.1	11.9	7.7
CTA	12.8	8.5	5.1	613.7	701.3	72.3			42.5	7.9	11.9
CTB	11.9	6.8	4.3	490.5	561.0	68.0			38.3	7.1	10.2
DIA	15.3	12.8	6.8	766.7	876.4	110.5			59.5	16.5	11.9
DLY						46.8	160.0	25.5	28.9	8.0	6.8
DMX				613.7	701.3	85.0	140.0	29.8	38.3	5.6	6.0
DUC				490.5	561.0	68.0	175.0	29.8	42.5	6.3	6.0
DVA				705.5	806.7	93.5	530.0	34.0	51.0	14.1	10.2
DVB				613.7	701.3	85.0	500.0	25.5	47.6	13.2	8.5
KNA	15.3	10.2	6.8	736.1	841.5	85.0	545.0		59.5	11.1	8.5
KNB	11.9	8.5	5.6	613.7	701.3	76.5	335.0		51.0	9.5	7.7
MTA	12.8	10.2	5.6	736.1	841.5	85.0			59.5	11.1	8.5
MTB	10.2	8.5	5.1	613.7	701.3	76.5			51.0	9.5	7.7
PRA	11.9	8.5	5.1	552.5	630.7	76.5			42.5	11.3	8.5
PRB	10.2	6.8	4.3	490.5	561.0	72.3			38.3	10.2	7.7
RNB	7.7	6.8	4.3	429.3	490.5	55.3	140.0		29.8	8.2	6.8
TOA				613.7	701.3	76.5	240.0		52.7	14.6	7.7
TOB				552.5	630.7	72.3	225.0		45.1	12.5	6.8
UVA	15.3	10.2	6.8	736.1	841.5	85.0	590.0		59.5	13.0	8.5
UVB	12.8	9.4	6.0	613.7	701.3	76.5	500.0		51.0	11.2	7.7
VLC	7.7	6.8	4.3	429.3	490.5	55.3	320.0		25.5	6.7	6.8
WEA	14.5		6.0	613.7	701.3	63.8	490.0	29.8	42.5	11.8	8.5
WEB	11.9	10.0	5.1	552.5	630.7	55.3	335.0	25.5	36.1	10.0	7.7
WNA	13.6	10.2	7.7	613.7	701.3	93.5			52.7	11.5	8.5
ZVA	12.8		6.0	613.7	701.3	76.5	500.0		51.0	13.6	8.5
ZVB	11.9		5.1	552.5	630.7	72.3	450.0		42.5	11.3	7.7

Table 3. Continued

Soils[b]	Cotton	Guayule	Sorghum	Wheat	Guar	Sorghum Hay	Peanuts	Oats for Grazing: Peanuts (Dry)	Oats for Grazing: Peanuts (Irig)	Oats for Grazing: Oats (Only)	Coastal Bermuda
	Dryland Crops										
	(lbs)	(lbs)	(cwt)	(bu)	(cwt)	(ton)	(cwt)	(aum)	(aum)	(aum)	(aum)
ABC							11.9	.9	1.7	1.7	2.6
AMA	331.5	400.0	25.5	29.8	7.7	4.6				3.0	3.0
ATA	295.0	335.0	14.9	25.5	6.9	2.7				2.1	2.6
ATB	257.6	265.0	12.8	21.3	5.9	2.3				2.1	2.6
BKA	331.5	365.0	14.5	25.5	4.3	2.6				2.6	2.6
BKB	295.0	350.0	11.9	21.3	3.6	2.1				2.1	2.6
BSA	295.0	365.0	17.0	25.5	6.2	3.1	10.7	1.1	2.1	2.1	2.1
BSB	257.6	350.0	14.5	21.3	5.2	2.6	9.5	.9	1.7	1.7	2.1
CAA	331.5	385.0	17.0	25.5	6.5	3.1				2.6	2.6
CAB	295.0	335.0	14.9	21.3	5.7	2.7				2.1	2.1
CHA	331.5	290.0	18.7	21.3	5.6	3.4				2.6	2.6
CHB	295.0	250.0	14.5	17.0	4.3	2.6				2.1	2.1
CTA	221.0		18.7	25.5	5.2	3.4				2.1	2.1
CTB	184.5		11.9	21.3	3.3	2.1				2.1	2.1
DIA	368.1		25.5	34.0	9.3	4.6				3.0	3.0
DLY		115.0		17.0			10.1	.9	1.7	1.7	1.7
DMX	147.1		17.0	12.8	4.8	3.1	11.9	.9	1.7	1.7	1.7
DUC	257.6		17.0	17.0	4.8	3.1	10.7	1.1	2.1	2.1	1.7
DVA	295.0	365.0	21.3	25.5	7.7	3.8	11.9	1.3	2.6	2.6	2.6
DVB	239.7	350.0	19.1	21.3	7.0	3.4	9.5	1.3	2.6	2.6	2.1
KNA	405.5	400.0	21.3	21.3	5.9	3.8				2.6	3.0
KNB	331.5	250.0	17.0	17.0	4.7	3.1				2.1	3.0
MTA	405.5		19.1	21.3	5.3	3.5				2.1	2.6
MTB	331.5		14.9	17.0	4.2	2.7				2.1	2.6
PRA	257.6		14.5	21.3	5.5	2.6				2.1	2.1
PRB	221.0		11.9	17.0	4.5	2.1				1.7	1.7
RNB		100.0	10.6	17.0	3.9	2.0				1.7	2.1
TOA	331.5	175.0	18.7	21.3	6.8	3.4				2.1	2.1
TOB	295.0	160.0	17.0	17.0	6.2	3.1				1.7	1.7
UVA	405.5	400.0	21.3	25.5	7.4	3.8				2.1	2.6
UVB	331.5	350.0	17.0	21.3	5.9	3.1				2.1	2.6
VLC	221.0	250.0	10.6	17.0	3.2	2.0				1.7	2.1
WEA	295.0	365.0	17.0	21.3	6.2	3.1	10.7	1.1	2.1	2.1	2.6
WEB	257.6	250.0	14.9	17.0	5.4	2.7	9.5	1.1	2.1	2.1	2.6
WNA	368.9		17.0	25.5	5.9	3.1				2.6	2.6
ZVA	331.5	350.0	17.0	21.3	6.5	3.1				2.1	2.1
ZVB	295.0	320.0	14.9	17.0	5.7	2.7				2.1	2.1

Source: Appendix Table 34.

[a] Blanks indicate the crop is not appropriate for the soil listed.
[b] Soils are described in Table 1.

Loamy Fine Sand, and Duval-Melon were assumed to be low in potash. Medium levels of fertility for potash are found in the sandy loam soil series; Brystal, Dilley, other Duval, Pryor, Tonio, Webb, and Randado. The remaining soils were judged to be high in potash and therefore adequate for most crops .

Fertilizer requirements for corn, cotton, grain sorghum, coastal bermuda, and bermuda grass hay were determined entirely from published fertilizer recommendations (Welch, et al.). Except for coastal bermuda grass hay, fertilizer recommendations for the other crops were reported for yield intervals. Fertilizer recommendation per unit of yield was found by selecting the soil fertility level in the column corresponding to the high level management yield. Multiplication of the coefficients times the yield level gives the amount of fertilizer required for that crop on a specific soil.

Tables 4 and 5 illustrate computation of fertilizer requirements on Uvalde Silty Clay Loam, 0-1 slopes, for dryland and irrigated activities, respectively. By applying the coefficients in Appendix Tables 35 and 36, specific fertilizer requirements in Tables 4 and 5 are derived. For example, multiplication of a 990 pound per acre yield for long-season irrigated cotton by fertilizer coefficients for yields above 960 pounds gives 103 pounds of nitrogen, 52 pounds of phosphate, and 31 pounds of potash as shown in Table 5.

Fertilization levels for small grain for grazing and grain (Welch, et al.) served as the basis for establishing fertilizer requirements for oats for grazing and winter wheat. Recommendations for small grains assume medium soil fertility levels for nitrogen and phosphate.

Fertilizer levels for tons of hay from perennial grasses vary by expected yield (Welch, et al.). Dryland and irrigated bermuda grass fertilizer requirements were assumed to be the same except for nitrogen. Nitrogen levels for dryland bermuda grass hay were set at three-fifths of irrigated levels, reflecting two rather than four cuttings (Extension Economists-Management, 1981b).

Fertilizer recommendations for cabbage, carrots, spinach, and coastal bermuda grass for grazing, Appendix Table 36, are based entirely on Texas Crop Budgets (Extension Economists-Management, 1981b). The basic procedure was to divide yield into fertilizer level to obtain an estimate of fertilizer needed per unit of output. Within the yield ranges of this study, such a procedure provided a reasonable method of establishing fertilizer use based on yield.

Peanut and forage sorghum hay fertilizer coefficients, Appendix Table 36, were obtained by combining Texas Crop Budget (Extension Economists-Management, 1981b) and recommended fertilization levels (Welch, et al.). Three yield intervals for peanuts were established. Fertilizer recommendations for peanut yields of 0-12.5 and 12.5 to 27.5 hundredweights are based on producer experience (Extension Economists-Management, 1981b). For the third yield category, over 27.5 hundredweights, phosphate and potash recommendations (Welch, et al.) and recommended nitrogen levels (Extension Economists-Management, 1981b) are reported in Column 5 of Appendix Table 36. Average high level management yields for irrigated peanuts were used to establish the third yield category.

Sorghum hay fertilizer recommendations do not vary by yield level (Welch, et al.). Low soil fertility resulted in recommendations of 30 pounds of phosphate, 35 pounds of potash, and 50 pounds of nitrogen per

Table 4. Dryland Crop Fertilizer Requirements, Uvalde Silty Clay Loam, 0-1 Per Cent Slopes,[a] Winter Garden, 1981.

	Units	Yield	(AUM)	Phos-phate	Nitro-gen liquid	Nitro-gen dry	Anhy-drous	Potash
Cotton	lb	477.0		30.0	50.0			
Grain Sorghum	cwt	25.0		25.0			42.0	
Winter Wheat	bu	30.0	1.5	30.0			60.0	
Oats for Grazing			2.5	30.0			60.0	
Peanuts	cwt	14.0	1.5	25.0		10.0		15.0
Bermuda Grass			3.0	14.0		41.0		
Guayule	lb	400.0						
Guar	cwt	8.7		16.0			54.0	
Bermuda Hay	ton	5.0		50.0		246.0		
Sorghum Hay	ton	4.5		30.0			80.0	

Source: Appendix Tables 35 and 36.

[a] Dryland peanut yield and fertilizer requirement furnished is for Duval fine sandy loam, slopes 0-1 percent.

Table 5. Irrigated Crop Fertilizer Requirements, Uvalde Silty Clay Loam, 0-1 Per Cent Slopes,[a] Winter Garden, 1981

	Units	Yield	(AUM)	Phos-phate	Nitro-gen liquid	Nitro-gen dry	Anhy-drous	Potash
Cotton Short[b]	lb	866.0		48.0	90.0			
Cotton Long[b]	lb	990.0		52.0	103.0			31.0
Grain Sorghum	cwt	70.0		58.0			117.0	35.0
Corn	bu	100.0		58.0			100.0	50.0
Peanuts	cwt	40.0	3.0	49.0		29.0		43.0
Guayule	lb	590.0				12.0		
Guar	cwt	15.3		39.0			87.0	
Bermuda Hay	ton	10.0		50.0		410.0		17.5
Processing Spinach	ton	8.0		138.0	86.0	43.0		
Cabbage	ton	18.0		105.0	65.0	65.0		
Carrots	ton	12.0		115.0	92.0	92.0		

Source: Appendix Tables 35 and 36.

[a] Irrigated peanut yield and fertilizer requirement furnished is for Duval fine sandy loam, slopes 0-1 percent.

[b] Short-season and long-season irrigated cotton.

acre of sorghum hay (Welch, et al.). However, based on grower experience in the region 80 pounds of nitrogen per acre was selected (Extension Economists-Management, 1981b).

Fertilizer recommendations for guayule are limited to nitrogen in production of irrigated guayule (Cornforth, et al.). Based on a 2,500 pound rubber yield over a 5 year production cycle, .02 pounds of nitrogen per year per acre per pound of rubber was established.

Irrigation Requirements

Irrigation water required at the root zone is a function of rainfall, runoff, ground cover and their interaction. These factors have been incorporated in the calculation of annual crop irrigation requirements for cotton, corn, grain sorghum, hay and pasture, deep rooted vegetables, shallow vegetables, and peanuts (Comer Tuck, personal communication). County acreages of each study area major soil series (Jack Stevens, personal communication) were used to calculate a weighted average in acre inches for annual crop irrigation requirements as shown in Table 6.

Guar and carrots were assumed to be deep rooted vegetables with irrigation requirements appropriately specified. Spinach and cabbage were assumed to be shallow rooted vegetables. The short-season cotton irrigation level was set at three-fourths that of long season cotton varieties (Extension Economists-Management, 1981b). Guayule irrigation water requirements were set at six acre inches of water per year when averaged over a 5 year production cycle (Cornforth, et al.).

Other Variable Inputs

The remaining variable inputs by crop were assumed to be the same for each soil type. Levels of seed, agricultural chemicals, and other preharvest variable inputs, labor, fuel, lubricants, and repairs are reported in Tables 7 and 8 for irrigated and dryland activities. Oil and lube, repairs, and agricultural chemicals are reported in dollar amounts.

Dryland and irrigated guayule established by seeding rather than sprigging were assumed to be cultivated under a five year production cycle. Budgets for production of guayule in the Winter Garden Region (Cornforth, et al.) were modified to conform to the input categories established for other crop alternatives. Budget data for a heavy machinery complement with a 150 horsepower tractor in production of cotton was used to estimate amounts of diesel fuel, gasoline, lubricants, machine labor, repairs, and levels of fixed costs for irrigated and dryland guayule production. Guayule inputs such as those in Tables 7 and 8, represent a composite acre obtained from a five year average of recommended input levels, Appendix Table 37.

Idle or fallowed land is disced twice a year to control unwanted vegetation. Fuel, labor, lubrication, repairs, and fixed cost coefficients, Table 8, are for discing idle land twice a year. Costs are based on fixed and variable inputs for a 100 horsepower tractor and offset disc used in production of short-season dryland cotton (Extension Economists-Management, 1981b).

Table 6. Annual Crop Irrigation Requirements in Acre Inches for Major Winter Garden Soil Groups.

Major Soil	Soil Symbol	Cotton Short Season	Cotton Long Season	Grain Sorghum	Corn	Guayule	Guar	Peanuts	Bermuda Hay	Spinach	Cabbage	Carrots
Antosa-Bobillo	AB					7.1		11.8	31.3			
Amphion	AM	10.1	13.5	11.8	13.8	5.8	10.8		30.8	8.6	8.6	10.8
Atco	AT	10.4	13.8	13.8	11.2	2.2	4.0		29.9	8.2	8.2	4.0
Bookout	BK	11.6	15.4	10.2	13.6	7.3	13.5		32.2	9.0	9.0	13.5
Brystal	BS	10.9	14.5	10.9	13.7	6.7	12.3	12.4	31.9	9.0	9.0	12.3
Caid	CA	11.0	14.7	10.8	13.6	6.7	12.4		31.6	8.9	8.9	12.4
Chacon	CH	11.3	15.1	10.4	13.6	7.0	13.0		32.3	9.1	9.1	13.0
Cotulla	CT	10.8	14.4	11.3	13.6		12.0		32.0	9.0	9.0	12.0
Dilley	DL			10.5	13.6	7.0	12.9	12.2	32.0			
Divot	DI	10.4	13.9	11.4	13.7		11.4		31.5	8.8	8.8	11.4
Duval loam	DV	10.7	14.3	11.1	13.7	6.4	11.9	12.1	31.3			
Duval sand	DU	10.5	14.0	11.3	13.7	6.2	11.5	12.5	31.8			
Duval-Melon	DM	10.0	13.4	11.9	13.9	5.8	10.7	12.0	30.2			
Knippa	KN	10.4	13.8	13.8	11.2	2.2	4.0		29.9	8.2	8.2	4.0
Montell	MT	11.0	14.6	11.5	12.9		10.2		31.5	8.8	8.8	10.2
Pryor	PR	11.6	15.5	10.1	13.5		13.6		32.5	9.1	9.1	13.6
Randado	RN	11.4	15.2	10.6	13.3	6.7	12.4		32.1	9.0	9.0	12.4
Tonio	TO	11.7	15.5	10.1	13.5	7.3	13.6		32.5			
Uvalde	UV	11.0	14.6	11.7	12.7	5.2	9.7	12.1	31.2	8.6	8.6	9.7
Valco	VL	10.4	13.9	12.6	12.5	4.1	7.7		30.2	8.2	8.2	7.7
Webb	WE	10.8	14.4	11.1	13.7	6.4	11.9	11.9	31.0	8.5	8.5	
Winterhaven	WN	11.3	15.0	10.6	13.6		12.9		31.6	8.7	8.7	12.9
Zavco	ZV	11.0	14.7	11.3	13.3	6.3	11.7		31.9	9.0	9.0	

Source: Comer Tuck, Texas Department of Water Resources, personal communication.

Table 7. Irrigated Crop Input Requirements Common to Arable Winter Garden Soils, 1981.[a]

		Cotton short	Cotton long	Grain Sorghum	Corn	Guayule[b]	Guar	Peanuts	Bermuda Hay	Spinach	Cabbage	Carrots
Variable Inputs												
Seed	lb	16.0	16.0	6.0	15.0	.3	8.0	100.0		21.0	1.5	2.0
Insecticide	$	42.5	85.0	2.5	8.0		6.0	10.5		77.0	97.5	12.0
Herbicide	$	8.0	8.0	3.75	13.0	8.0	7.5	8.0		20.0	8.0	24.0
Innoculant	$						.20					
Custom Fertilize	$							1.75			1.75	
Nematicide	$							7.0				
Fungicide	$							30.0		27.0	19.5	12.0
Chemical Application	$	12.50	25.00	6.50	4.00		6.50	15.00		15.00	37.50	37.50
Oat Seed	lb							60.0				
Machinery												
Diesel	gal	12.4	12.4	12.6	18.8	4.4	8.0	12.7	1.3	8.5	13.3	11.4
Gasoline	gal	1.2	1.2	1.2	1.2	.5	1.3	1.4	.6	.8	1.0	1.2
Oil and Lube	$	2.03	2.03	2.06	1.92	.67	1.39	2.10	.30	1.39	2.13	1.88
Repairs	$	6.46	6.46	6.26	8.35	2.34	4.19	6.98	1.44	4.69	6.60	6.57
Labor												
Machinery	hr	3.2	3.2	4.0	4.7	.9	2.6	3.0	1.2	2.0	3.0	3.2
Non-Machinery	hr	4.0	4.0				2.0	3.0		8.0	24.0	
Fixed Costs												
Establishment	$								12.58			
Machinery	$	35.88	35.88	33.95	44.04	18.91	22.54	37.37	10.05	26.22	35.15	39.82

Source: Extension Economists-Management, 1981b, unless otherwise indicated in table footnotes.

[a] Absence cf an entry indicates a particular input is not required by the crop at the head of the column.
[b] Cornforth, et al.

Table 8. Dryland Crop Input Requirements Common to Arable Winter Garden Soils.[a]

		Cotton Short	Grain Sorghum	Winter Wheat	Oats for Grazing	Peanuts	Bermuda Grass	Guayule[b]	Guar	Bermuda Hay	Sorghum Hay	Disc Land
Variable Inputs												
Seed	lb	16.0	4.0	80.0	64.0	50.		.3	8.0	17.5	30.0	
Insecticide	$	25.50	5.0			10.5			6.0			
Herbicide	$	8.0	3.75			8.0	3.5		7.5			
Innoculant	$								.2			
Custom Fertilize	$					1.75						
Nematicide	$					7.00						
Fungicide	$					15.00						
Chemical Application	$	7.50	6.50			7.5			6.5			
Oat Seed	lb					40.0						
Machinery												
Diesel	gal	8.4	11.6	15.3	3.8	12.7	1.3	3.1	7.2	.8	11.3	1.8
Gasoline	gal	1.2	1.2	1.0	1.2	1.0	.6	.3	1.0	.4	.6	
Oil and Lube	$	1.45	1.92	2.42	.78	2.03	1.29	.50	1.23	.18	1.13	.27
Repairs	$	5.32	5.84	6.26	2.88	6.60	1.26	1.48	3.66	.86	4.80	.77
Labor												
Machinery	hr	2.8	3.7	4.5	3.2	2.7	1.2	.6	2.2	.7	3.2	.5
Fixed Costs												
Establishment	$						3.94			4.72		
Machinery	$	30.15	31.23	36.14	21.31	75.17	8.96	16.95	19.97	6.03	28.86	6.92

Source: Extension Economists-Management, 1981b, unless otherwise indicated in table footnotes.

[a] Absence of an entry indicates the input is not required by the crop at the head of the column.
[b] Cornforth, et al.

Harvest Inputs

Harvest costs include variable costs of fuel, lubricants, repairs, labor, twine, custom harvest, and hauling. Variable harvest expenses are separated from other variable costs since it is not necessary to borrow capital for harvest activities.

Peanuts and guayule are harvested by the producer. Table 9 contains estimates of guayule and peanut harvest costs. Peanut harvest inputs are described by dollar amounts of lubricants and repairs, and physical units of labor and fuel.

Table 9. Guayule and Peanut Harvest Costs, Winter Garden, 1981.

		Guayule[a]		
	Unit	Dryland (ton)	Irrigated (ton)	Peanuts[b] (acre)
Variable Inputs				
Twine	feet	368.00	368.00	
Diesel	gal	1.5	1.2	13.0
Gasoline	gal	1.8	1.2	
Labor, Machinery	hour	1.05	.85	2.17
Oil and Lube	$	.52	.38	1.91
Repairs	$	2.41	2.04	5.50
Custom Dry	$			22.50 (ton)
Custom Haul	$			6.70 (ton)
Fixed Costs	$	13.89	12.35	38.32

[a] Appendix Table 37.
[b] Extension Economists-Management, 1981b

Guayule harvest occurs at the end of the third year by cutting, and during the fifth year by digging. A large round bale system to handle guayule is based on tons of harvestable residue. Assuming a 20 percent yield of rubber per pound of harvestable residue, five year yields for dryland and irrigated guayule, 1750 and 2500 pounds, respectively, translate into 8.75 tons for dryland and 12.5 tons of harvestable residue for irrigated guayule.

Harvest functions for guayule include digging, windrowing, baling, transport to roadside, and transport to the processing plant. A distance of 20 miles is assumed for irrigated guayule and 30 miles for dryland guayule (Cornforth, et al.). Custom digging was estimated based on a 150 horsepower tractor and moldboard plow using carrot enterprise budget data (Extension Economists-Management, 1981b). Cost estimates for windrowing, baling, moving to roadside, and transporting to a processing plant are based on Purdue University cost equations (Purdue University).

Dryland and irrigated guayule harvest input requirements by harvest function were estimated for a 5 year production period and are listed separately in Table 37. By applying the yield data of 12.5 tons for irrigated guayule and 8.75 tons of harvestable residue for dryland guayule, annual input estimates per year per ton of guayule harvested were estimated.

Harvest costs of other crops as shown in Table 10, can be described as inputs to harvest the crop and further prepare it for marketing (Extension Economists-Management, 1981b). Custom harvest was used for cotton, grain sorghum, corn, guar, hay, vegetables, and wheat. Stripping dryland cotton costs $1.75 per hundredweight and an eleven cent per pound charge was made for picking irrigated cotton crops. Also, a defoliant charge of $15 per acre was included for cotton.

Two custom harvest costs are used for grain sorghum and wheat. Under typical management, the charge for custom harvest of grain sorghum was $.38 per hundredweight for yields of 25.5 hundredweights or greater. Yields below this level were charged a flat rate of $18.00 per acre. For wheat yields of 25.5 bushels and higher, harvesting costs were $.20 per bushel. A fixed fee of $15.00 per acre was charged to harvest wheat when yields were less than 25.5 bushels to the acre. Custom hauling was used for grain sorghum, wheat, peanuts, guar, hay, and corn.

Additional harvest costs include ginning and baling cotton, and drying peanuts (Extension Economists-Management, 1981b). Ginning, bagging and tying picked cotton cost $49.00 per 500 pound bale. Ginning cost for stripper cotton was $1.75 per hundredweight and baling costs were 13 dollars per 1000 pound bale. Peanut drying charges were 22.50 dollars per ton.

Miscellaneous Fixed Costs

Other fixed costs consist of harvest and establishment costs. Establishment costs for perennial grasses used for hay and grazing uses are given in Appendix Table 32. The prorated annual establishment costs are $3.58 per acre for buffel grass, $3.94 for coastal bermuda grass for grazing, $4.72 for dryland bermuda grass hay, and $12.58 for irrigated bermuda grass hay.

Irrigated and dryland bermuda grass hay require the same level of inputs except for nitrogen. Nitrogen levels for dryland establishment of bermuda grass hay were assumed to be two-thirds of those for irrigated hay reflecting two cuttings of hay versus four. In dryland establishment, fuel, repairs, labor, lubricants, and fixed costs were reduced to reflect one less fertilizer application (Extension Economists-Management, 1981b).

Harvest fixed costs consist of machinery costs for peanuts and guayule, Table 9. Peanut harvest fixed costs cover equipment to dig and combine peanuts (Extension Economists-Management, 1981b).

A large round bale system was selected to bulk handle guayule (Cornforth, et al.). Per acre fixed costs for a guayule harvest system includes tractors, a pickup truck, windrower, baler, bale mover, and bale fork (Purdue University). Tractor and pickup prices were taken from Texas Crop Budgets (Extension Economists-Management, 1981b) and the prices of the remaining pieces of equipment were furnished by Texas dealers.

Table 10. Winter Garden Purchased Input Prices, 1981.

Purchased Input	Unit	Price	Purchased Input	Unit	Price	Purchased Input	Unit	Price
Nitrogen (Dry)	lb	$ .26	Oat Seed	lb	$ .10	Corn Seed	lb	$ 1.40
Phosphate	lb	.32	Guayule Seed[b]	lb	25.00	Corn Herbicide	acre	13.00
Potash	lb	.20	Guayule Herbicide[b]	acre	8.00	Apply Corn Herbicide	acre	4.00
Nitrogen (Liquid)	lb	.23	Twine (16000 feet)[c]	box	32.50	Corn Insecticide	acre	8.00
Anhydrous	lb	.15	Peanut Seed	lb	1.00	Corn Custom Harvest	acre	15.00
Diesel	gal	.98	Nematicide	acre	7.00	Corn, Custom Haul	bu	.17
Gasoline	gal	1.15	Peanut Herbicide	acre	8.00	Spinach Seed	lb	2.00
Electricity[a]	kwh	.04	Peanut Insecticide	acre	3.50	Spinach Insecticide	acre	11.00
Labor, Machinery	hour	4.50	Peanut Fungicide	acre	5.00	Spinach Fungicide	acre	4.50
Labor, Irrigation	hour	3.50	Peanut Hauling	ton	6.70	Spinach Herbicide	acre	20.00
Labor, Other	hour	3.50	Peanut Drying	ton	22.50	Spinach, Custom Harv.	ton	3.80
Custom Fertilize	acre	1.75	Cotton Seed	lb	.55	Guar Seed	lb	.24
Apply Pesticide	acre	2.50	Cotton Herbicide	acre	8.00	Guar Insecticide	acre	6.00
Coastal Herbicide	acre	3.50	Cotton Insecticide	acre	8.50	Guar Herbicide	acre	7.50
Carrot Seed	lb	6.50	Cotton Defoliant	acre	12.50	Guar, Apply Herbicide	acre	4.00
Carrot Herbicide	acre	3.00	Apply Cotton Defoliant	acre	2.50	Innoculant	acre	.20
Carrot Fungicide	acre	3.00	Cotton, Pick	lb	.11	Guar, Custom Harvest	acre	18.00
Carrot Insecticide	acre	4.00	Cotton, Bag/Gin/Tie	bale	49.00	Guar, Custom Haul	cwt	.25
Carrot Custom Harvest	celo	4.25	Cotton, Strip	cwt	1.75	Livestock Minerals	head	10.00
Cabbage Seed	lb	42.00	Cotton, Gin Stripper	cwt	1.75	Veterinarian	head	3.00
Cabbage Herbicide	acre	8.00	Cotton, Bale Stripper	bale	13.00	Cattle Range Cubes	lb	.10
Cabbage Insecticide	acre	6.50	Sorghum Seed	lb	.59	Hay	bale	1.91
Cabbage Fungicide	acre	6.50	Sorghum Herbicide	acre	3.75	Livestock Selling Cost	head	10.50
Cabbage Harvest	bag	2.20	Sorghum Insecticide	acre	2.50	Repair Water Facility	head	2.00
Wheat Seed	lb	.18	Apply Sorghum Herb.	acre	4.00	Pasture Maintenance	acre	3.00
Wheat Custom Harvest	bu	.20	Custom Combine Sorghum	acre	18.00	Mow, Rake, Bale	bale	.65
Wheat Custom Harvest	acre	15.00	Custom Combine Sorghum	cwt	.38	Hay Hauling	bale	.15
Wheat Haul	bu	.13	Sorghum Hauling	cwt	.30	Sorghum Hay Seed	lb	.30
Electric Demand Max[a]	kwh	2.41						

Source: Extension Economists-Management, 1981a and 1981b, unless otherwise indicated in table footnotes.

[a] Central Power and Light; Ray Elledge, personal communication.
[b] Cornforth, et al.
[c] Brazos Machinery Company, Bryan, Texas.

Cow-Calf Enterprise

Input requirements for beef production in the Texas Winter Garden were derived from a cow-calf enterprise depicting a 4,500 acre ranch with 250 animal units (Extension Economists-Management, 1981a). The cow-calf budget assumes an 80 percent calf crop, 3 percent death loss, and a 13 percent replacement rate, Appendix Table 38. Sales per animal unit are .4 steer calves, .27 heifer calves, and .10 cull cows totaling 3.8 hundred weights of beef per year. Death loss is used to adjust downward the physical quantities of beef for sale.

The ranch situation allowed 18 acres comprised of one-third improved pasture and two-thirds unimproved pasture per animal unit. This acreage is close to the 19.9 average acres per animal unit per year for medium brush density range sites.

Variable inputs such as fuel, lubricants, and repairs were identified on the basis of coefficients furnished in Winter Garden Area crop budgets (Extension Economists-Management, 1981b). Selling expense includes custom hauling and sales commissions. Livestock fixed costs consist of fixed equipment costs (interest and depreciation on pickup, trailer, and tack) and fixed livestock costs (livestock and depreciation).

Groundwater Resources

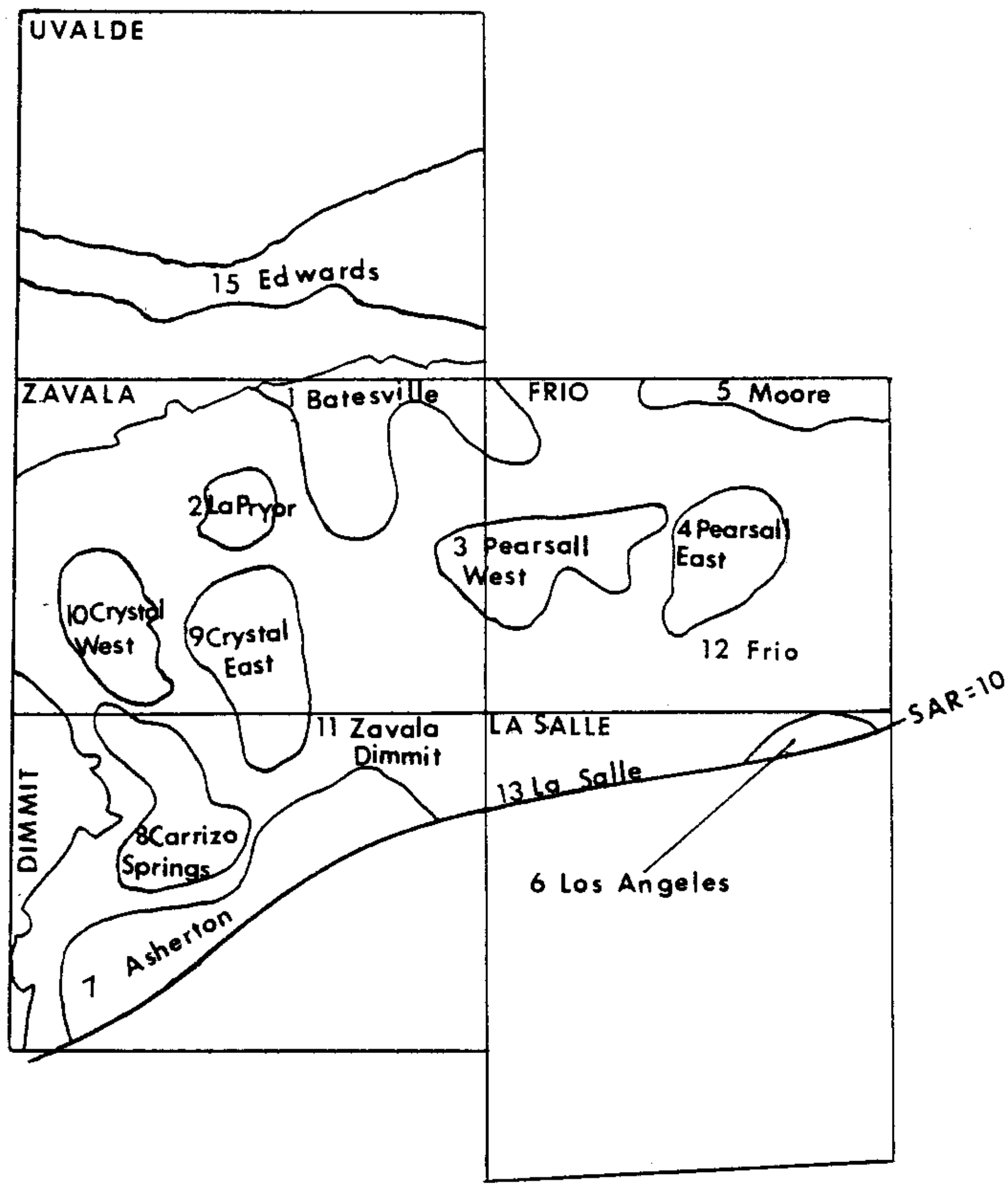
This section develops estimates of groundwater resources available for irrigation and associates them with arable soils. Distinct groundwater resource areas are identified by quantity, depth to water, and depth to the base of the aquifer. Second, groundwater availability over time and lift changes associated with pumpage are addressed. Finally, estimates of arable soil acreages within each water resource area are developed.

Water Resource Areas

Some 14 water resource areas were identified in the study area, Figure 3. The Carrizo Aquifer resource areas 1-13, and the Edwards Aquifer resource area, 15, are listed in Table 11. Resource areas 7, 6, 13, and 11 were reduced in area to correct for sodium hazard in Dimmit and LaSalle counties. In view of soil types and dissolved solids in Carrizo water, the maximum value of the sodium absorption ratio (SAR), a measure of sodium hazard, is 10 (Seward, Knowles, and Tuck). South of a contour line representing a SAR of 10, Figure 3, only dryland cultivation is assumed.

Carrizo Aquifer

Estimates of projected and restricted groundwater pumpage levels for each water resource area are reported in Table 11. For areas 1-13 multiplication of restricted acre feet per square mile times square miles gives each area's annual restricted pumpage in acre feet. Restricted annual pumpage rates govern groundwater pumpage over time limiting lifts to a maximum of 400 feet and preventing de-watering of the aquifer recharge



Source: Klemt, Duffin, and Elder, p. 67; Seward, Knowles, and Tuck, p. 10.

Figure 3. Water Resource Areas, Texas Winter Garden, 1981.

Table 11. Restricted and Projected Levels of Groundwater Pumpage by Water Resource Area, Winter Garden, 1981.[a]

Water Resource Areas		Area Square Miles	Ac. Ft./Sq. Mile Restricted	Ac. Ft./Sq. Mile Projected	Ac. Ft. of Groundwater Restricted	Ac. Ft. of Groundwater Projected
1	Batesville	190.9	55	165.5	10,499.5	31,594.0
2	La Pryor	41.4	58	24.2	2,401.2	1,001.9
3	Pearsall West	138.9	113	30.9	15,695.7	4,292.0
4	Pearsall East	101.8	110	126.7	11,198.0	12,898.1
5	Moore	95.5	22	85.7	2,101.0	8,184.0
6	Los Angeles	4.7	104	4.3	488.8	20.2
7	Asherton	300.1	61	2.6	18,306.1	780.3
8	Carrizo Springs	121.7	60	96.2	7,302.0	11,707.5
9	Crystal East	140.8	157	271.4	22,105.6	38,213.1
10	Crystal West	97.4	76	69.8	7,402.4	6,798.5
11	Zavala-Dimmit	1,119.6	c	29.8	33,364.1	33,364.1
12	Frio	788.4	c	56.4	44,465.8	44,465.8
13	LaSalle	144.1	c	39.9	5,749.6	5,749.6
15	Edwards	914.6[b]			68,371.0[d]	89,225.0[e]
	Total Sq. Miles	4,199.9				
	Total Carrizo	3,285.3				

[a] Klemt, Duffin, and Elder, unless otherwise indicated.
[b] Klemt, Knowles, Elder, and Sieh.
[c] Area fully developed.
[d] Tommy Knowles, Texas Department of Water Resources, personal communication.
[e] Edwards irrigation base plus 9,127 acre feet accounting for 1981 non-irrigation uses.

areas prior to 2020. Three types of areas have been specified to fulfill the restricted pumpage assumptions; areas with increased potential, 2, 3, 6, 7, and 10; areas in which reductions in pumpage are advised, 1, 4, 5, 8, and 9; and areas judged to be fully developed, 11, 12, and 13.

Projected 1980-81 groundwater discharges in the Carrizo Aquifer are represented by 1963-69 pumpage levels. Appendix Table 39 indicates that recorded irrigation from groundwater reached a peak of 317,732 acre feet in 1964 declining to 276,248 acre feet in 1969. In 1979, irrigation groundwater pumpage for the same region was only 217,459 acre feet.

Restricted and projected 1980-81 acre feet available for irrigation as shown in Tables 12 and 13, respectively, were developed by subtracting non-irrigation uses from projected and restricted levels of pumpage. Total groundwater pumpage levels are shown in Table 11 by water resource area. Estimates of acre feet required for non-irrigation uses; municipal, manufacturing, mining, livestock, and electric steam power, are reported in Appendix Table 40. Census incorporated and designated places were assigned to individual water resource areas to account for per capita municipal and manufacturing uses. Pumpage reductions for livestock use and the remaining municipal and manufacturing were uniformly distributed over each county's water resource areas. Mining requirements were assumed to be met by the Queen City-Bigford and Sparta-Laredo aquifers which together pumped less than 4,850 acre feet for irrigation in 1969 (Klemt, Duffin, and Elder).

Edwards Aquifer

Restricted groundwater pumpage limitation for the Edwards Aquifer, Area 15, is 68,371 acre feet per year, Table 11. Subtraction of 1980 non-irrigation uses (9,127 acre feet as shown in Appendix Table 40) gives a restricted groundwater pumpage rate for irrigation of 59,244 acre feet, Table 12.

Projected 1980-81 irrigation pumpage in the Edwards Aquifer (80,098 acre feet as shown in Column 2, Table 13) was found by increasing 1979 groundwater pumped for irrigation (75,915 acre feet, Appendix Table 39) by a forecasted annual rate of increase in groundwater pumpage. The projected rate of increase in groundwater pumpage for irrigation in Uvalde county is 5.51 percent (Klemt, Knowles, Elder, and Sieh, p. 51). The expected groundwater use levels for the period 1980-2020 are presented in Appendix Table 41.

Aquifer Characteristics

Estimates of depth from the surface to base of the aquifers and to groundwater were developed for each water resource area, Appendix Table 42. Average depth to water for Area 15 is an average of selected Uvalde County wells in the Edwards Aquifer south of the Edwards outcrop (Tommy Knowles, personal communication).

Carrizo Aquifer resource areas, Figure 3, were copied onto maps of Frio, Zavala, Dimmit, and LaSalle Counties showing the location of selected water, oil, and gas wells (Marquardt and Rodriguez). Averages of depth to water observations furnished estimates of depth to water for each

Table 12. Maximum Restricted Levels of Irrigation Groundwater Pumpage in Acre Feet by Water Resource Area, Winter Garden, 1980-2000.

Water	Resource Areas	1980-81	1985-86	1990-91	1995-96	2000-01
1	Batesville	10320.1	10277.0	10233.5	10188.7	10144.0
2	LaPryor	2361.0	2351.7	2342.3	2332.5	2322.8
3	West Pearsall	15569.1	15537.7	15506.1	15473.4	15440.9
4	Pearsall	8866.9	8617.6	8368.5	8093.6	7819.4
5	Moore	2011.1	1989.4	1967.7	1945.3	1922.9
6	Los Angeles	486.5	485.4	484.3	483.3	482.1
7	Asherton	17790.0	17698.4	17597.5	17489.8	17382.6
8	Carrizo Springs	5547.3	5279.3	5011.8	4711.0	4411.1
9	East Crystal	19708.3	19609.3	19514.4	19379.0	19244.9
10	West Crystal	7308.3	7286.3	7264.1	7241.3	7218.4
11	Zavala-Dimmit[a]	31592.5	31275.0	30956.0	30615.2	30275.6
12	Frio[a]	42941.2	42683.9	42425.8	42152.8	41880.9
13	LaSalle[a]	5613.5	5581.0	5548.2	5514.3	5480.6
15	Edwards[b]	59243.8	57457.8	55671.8	53198.8	50725.8
	Total	229368.6	226129.8	222892.0	218819.0	214752.0
	Total Carrizo	170124.8	168672.0	167220.2	165620.2	164026.2

Source: Table 11 and Appendix Table 40.

[a] Portions of counties without prescribed changes in pumping rates are assumed to be fully developed.

[b] Uvalde County, Edwards Aquifer, and Area 15 refer to the same water resource area.

Table 13. Maximum Projected Levels of Irrigation Groundwater Pumpage in Acre Feet by Water Resource Area, Winter Garden, 1980-2000.

Water	Resource Area	1980-81	1985-86	1990-91	1995-96	2000-01
1	Batesville	31420.1	31377.0	31175.5	31130.6	31086.0
2	LaPryor	961.0	951.7	937.2	927.5	917.8
3	West Pearsall	4169.1	4137.7	4258.3	4225.6	4193.1
4	Pearsall	10566.9	10317.5	10525.1	10250.2	9976.1
5	Moore	8092.8	8071.3	8339.2	8316.8	8294.4
6	Los Angeles	15.8	14.8	14.4	13.3	12.2
7	Asherton	263.3	162.7	57.8	0.0	0.0
8	Carrizo Springs	9947.2	9679.3	9353.3	9052.5	8752.6
9	East Crystal	35804.1	35709.2	35423.4	35288.0	35153.9
10	West Crystal	6708.2	6686.3	6630.1	6607.2	6584.4
11	Zavala-Dimmit[a]	31592.5	31275.0	30789.2	30448.4	30108.8
12	Frio[a]	42941.2	42683.9	43999.9	43726.9	43455.0
13	LaSalle[a]	5613.5	5581.0	5751.7	5717.9	5684.1
15	Edwards[b]	80098.0	89189.0	106480.0	126687.0	139194.0
	Total	268193.7	275836.4	293735.1	312391.9	323412.4
	Total Carrizo	188095.7	186647.4	187255.1	185704.9	184218.4

Source: Table 11 and Appendix Table 40.

[a] Portions of counties without prescribed changes in pumping rates are assumed to be fully developed.

[b] Uvalde County, Edwards Aquifer, and Area 15 refer to the same water resource area.

resource area. Comparison of these estimates with averages of observation wells for the same water resource areas (Texas Natural Resources Information System, personal communication) showed a slightly greater depth to water for the first set of estimates. The first set of depth to water estimates was used in all areas except 6. Due to a low number of reported wells, Area 6 depth to water is based on both sources.

Depth to the base of the aquifer (Appendix Table 42) is also the drilling depth required for well development. The depth to the base of the Carrizo Aquifer water resource areas is measured at the approximate center of each water resource area's heaviest irrigation activity. Depth to the base of the Edwards Aquifer is reported for a well located in the middle of the intensive irrigation area centering on Knippa, Texas.

Temporal Groundwater Resources

Availability of groundwater for irrigation over time and changes in depth to water surface are based on projections of groundwater use for irrigation and non-irrigation uses through 2001. Non-irrigation uses, 1980-81 to 2000-01, are listed in Appendix Table 40.

Projected irrigation groundwater pumpage for Area 15, Edwards Aquifer in Uvalde County, is defined on a base of 80,098 acre feet for irrigation in 1980-81. Projected groundwater available for irrigation (Table 13) is the change in predicted groundwater pumpage (Klemt, Knowles, Elder, and Sieh) added to the 1980-81 base and corrected for non-irrigation uses. Restricted groundwater pumpage levels are also adjusted downward for non-irrigation uses.

Projected pumpage levels in the Carrizo Aquifer were expected to change very little over the period 1963-2020 (Klemt, Duffin, and Elder). Gross pumpage rates for the periods 1980-1990 and 1990-2020 show a decrease in pumpage between the two periods of .5 percent in water resource areas 1, 2, 7, 8, 9, 10 and 11. A 3.54 percent increase in pumpage is expected in areas 3, 4, 5, 6, 12 and 13. These one time adjustments were made in the gross pumpage base beginning in 1990-91. These groundwater quantities were adjusted for projected non-irrigation uses through 2001, Appendix Table 40. Restricted and projected groundwater available for irrigation through 2001 are reported in Tables 12 and 13.

Acre-feet pumped per foot increase in lift for each water resource area (Appendix Table 42) relates excess pumpage above recharge to increases in the depth to water. The initial depths to water for areas 1-13 were subtracted from 400 feet and divided by 50 years to get the annual increase in lift under restricted pumpage patterns. Division of the annual increase in lift into the restricted pumpage gives acre feet pumped per foot increase in lift for each water resource area.

Acre-feet pumped per foot increase in lift for the Edwards Aquifer is based on a projected 262.5 foot decline in water levels at Knippa, Texas, 1972-2020 (Klemt, Knowles, Elder, and Sieh). Assuming that irrigation pumpage expands at an annual rate of 5.51 percent per year, gross pumpage over the 48 year period is about 8,228,000 acre feet. Gross pumpage divided by 262.5 feet gives 31,344.8 acre feet pumped per foot increase in lift for water resource area 15.

Arable Soils

Acres of arable soils within each water resource area (Appendix Table 43) were developed from general soils maps of study area counties (Soil Conservation Service, 1980b, 1980c; Jack Stevens, personal communication), water resource area map (Figure 3), and detailed soil inventories (Jack Stevens, personal communication). Water resource areas, aquifer boundaries, and the sodium absorption boundary were copied to the general soil maps. A planimeter was used to estimate acreage of each general soil association in individual water resource areas as well as acreages excluded from water resource areas.

General soil associations in each county were separated into detailed soil types (Duval soils were treated as a unit and slopes were not considered). Percentages of major soil series in each general association, names of associated soil series in the general soil associations, and detailed soil inventories were used in a weighting scheme to distribute all soils into general associations while maintaining correct soil totals by counties.

Detailed soils were aggregated into 21 soil types for each water resource area. In this process, resource areas crossing county boundaries were combined. Acreage proportions for 0-1 and 1-3 percent slopes and distribution of Duval soils, from Table 1, were used to expand soils to the 37 arable soil types. Soils without groundwater resources are designated for dryland cultivation only and are listed by soil type under Dryland in Appendix Table 43.

Irrigation Costs[2]

Physical characteristics of the aquifers and end use of irrigation water are important determinants of irrigation system design. Well output of 1000 gallons per minute is assumed adequate for furrow irrigation of 100 acres or center pivot sprinkler irrigation of 126 acres. Actual lifts or pumping depths are the vertical distance water is pumped plus a draw down factor of 50 feet. A 50 feet draw down was added to the initial water levels. These lifts were used to assign water resource areas to six discrete lift intervals which increase in steps of 50 feet from 101 to 400 feet. Groundwater utilization assumptions and system specifications appear in Appendix Table 44.

Acre inch capacity of irrigation systems was determined by considering crop irrigation requirements (Comer Tuck, personal communication) and overall system efficiencies. An average of 14.6 acre inches was required in the root zone for cotton production across counties. Division of the average cotton acre inch requirement by irrigation application efficiencies (.65 for furrow and .80 for sprinkler) furnishes design capacity acre inches of groundwater (22.5 and 18.3, respectively) to be pumped by each irrigation system. Each system is used to make three applications or sets of irrigation water where a set is analogous to an irrigation period (Extension Economists-Management, 1981b).

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[2]Irrigation costs are based on technical advice and component costs furnished by Winter Garden Area drilling and irrigation firms.

Pump, motor, and other technical data were specified to reflect the predominance of electric motor application in Winter Garden irrigation. About 70 percent of irrigation wells are electric, 20 percent natural gas, and 10 percent diesel (Joe Peña, personal communication).

Choices of sprinkler or furrow irrigation were limited for some crops and soils. Vegetable crops were assumed to be produced only under furrow irrigation and bermuda grass hay was restricted to sprinkler irrigation.

Suitability of soils for irrigation by a particular system is a function of slope and soil texture. All soils were assumed favorable for sprinkler irrigation. Furrow irrigation was not allowed on Antosa-Bobillo, Duval, or Tonio soil series due to excessive sandiness. Extreme slope, 1-5 percent, prohibits the use of furrow irrigation on Dilley soils.

Well Development Costs

Well development fixed costs per acre for furrow and sprinkler systems are listed in Appendix Table 45. Since irrigation wells are drilled to the base of the aquifers, depth to base (Appendix Table 42) directly affects the quantity of pipe and drilling and installation charges. Well development costs are approximately $40 to $50 per foot.

Differences in water quality and aquifer materials contribute to a cost advantage for the Edwards Aquifer. In the sandy Carrizo Aquifer, complete casing of the well is necessary. In the Edwards Aquifer limestone, wells are cased only to the base of the confining bed plus 10 feet. Well life is assumed to be longer in the Edwards (30 years) than in the Carrizo (25 years) due to differences in water quality.

Under temporal anaysis, development of new wells is expected only in the Edwards Aquifer. A per acre marginal well development charge per acre inch of $1.11 is charged for groundwater pumpage above the 1980-81 projected level of 80,100 acre feet.

System Fixed Costs

Fixed costs are presented in Appendix Table 46 by distribution system and lift interval. The procedures for calculating fixed cost (Kletke, Mapp, and Harris) were applied for the maximum lift in each lift interval specified in the Edwards and Carrizo Aquifer. System fixed costs are annual costs per acre for column pipe, pump components, bowls, motor, and distribution system.

Electric engine sizes were determined from standard formulas (Kletke, Mapp, and Harris). Brake horsepower, which is purchased horsepower for electric motors, was found by dividing water horsepower by a pump efficiency of .725. It is not necessary to derate electric motors since an overload factor of 10 to 15 percent is built in to account for temperature variations and voltage conditions (Schwab, Howell, Garton, and Harp). Motor sizes selected approximate those used in the study area under similar conditions.

Center pivot and furrow systems correspond to systems currently available (Joe Peña, personal communication). The center pivot system is a seven span, seven drive unit using six and five-eights inch pipe on a 16 foot overhang. Additional components include 1,370 feet of 10 inch 80 pounds per square inch (p.s.i.) plastic mainline, a pad for the pivot, control cable, nozzles and drop for water application, and a large gate valve.

The furrow components for 100 acre furrow irrigation system are 2,100 feet of slotted aluminum pipe, three hydrants, one end plug, 2,100 feet of 10 inch 40 p.s.i. plastic pipe, and a large gate valve. Slotted aluminum pipe is moved from hydrant to hydrant to apply water directly to the field.

One significant difference in fixed costs per acre between the two aquifers is bowl life. Carrizo sand entering the suction tube accelerates impeller wear promoting higher maintenance costs and shorter bowl life (Joe Peña, personal communication). Carrizo bowl life (4 years) is one half the Edwards bowl life (8 years).

System Variable Costs

Variable inputs per acre inch by distribution system and lift interval are reported in Appendix Table 47. Kilowatt hours of electricity, labor, repair costs, and lubricant costs were estimated for furrow and sprinkler systems in the alternative lift situations (Kletke, Mapp, and Harris).

Repairs cover pump, motor, and distribution system. A differential in repair costs between the aquifers originates in a Carrizo pump life set at one half the assumed 30,000 hour Edwards pump life (Joe Peña, personal communication).

Kilowatt hours required for each system are based on water horsepower required for each lift situation (Kletke, Mapp, and Harris) and power to operate the pivot system (Joe Peña, personal communication). Kilowatt hours per acre inch pumped are estimated from the midpoint of each lift interval. Electric pivot drive motors and a motor equalizing water pressure require .71 KWH for each acre inch of water pumped.

Prices

Commodity prices and input prices were specified for the model. These prices represent 1980-81 conditions in the Winter Garden.

Output Prices

Output prices for 1981 were estimated from 1977-81 commodity prices and expected 1981 contract prices. The 1981 prices of individual commodities except for spinach, guar, and guayule are an average of the 1977-81 indexed prices and are shown in Table 14. Prices for the above commodities and price indices for major commodity groups of cotton, oil bearing crops, feed grains and hay, food grain, vegetables, and meat animals were used to express each year's prices in 1981 dollars (Texas Crop and Livestock Reporting Service, 1980a, 1981a, 1981b, and 1981c).

The 1981 contract prices were assumed for processing spinach and guar. Processing spinach prices were $78.50 per ton plus one dollar per

Table 14. Prices Received by Farmers, Winter Garden, 1981.

Product	Units	Price
Cotton[a]	lb	.67
Cotton Seed[a]	ton	80.50
Guar[b]	cwt	19.50
Peanuts[a]	cwt	29.90
Grain Sorghum[a]	cwt	4.82
Bermuda Grass Hay[ac]	ton	66.17
Forage Sorghum Hay[ac]	ton	61.17
Wheat[a]	bu	3.79
Corn[a]	bu	3.15
Cabbage[a]	bag	6.86
Carrot[a]	celos	5.45
Beef Cattle[a]	cwt	60.73
Guayule[d]	lb	.30
Spinach[b]	ton	78.50
Spinach Seconds[b]	ton	1.00
Hunting Lease[e]	lease	2.50

[a] Average, previous 5 years prices in 1981 dollars, Texas Crop and Livestock Reporting Service, 1980a, 1981a, 1981b, 1981c.

[b] Pigg.

[c] Extension Economists-Management, 1981b.

[d] Farm level price equals smoked rubber sheet price less net processing costs.

[e] Per acre on heavy and medium brush infested range and one-fourth this amount on light brush for bird hunting (Joe Peña, personal communication).

ton for seconds (Extension Economists-Management, 1981b). Contract price for number one guar was $20.00 per hundredweight (Pigg).

Although a market for natural rubber is well developed, guayule does not share in it. Guayule is not grown commercially. In the absence of guayule pricing information, knowledge of processing costs coupled with a market price of natural rubber provides a basis to approximate a market clearing price for guayule.

Deresinated guayule rubber is indistinguishable from natural rubber (Foster, et al., 1979). Therefore the New York smoked sheet price of hevea rubber also represents the price of fully processed guayule rubber. A simple average of the Wednesday cash smoked sheet prices for 1981 (Wall Street Journal) gives an imputed 1981 price for processed guayule rubber of 56.60 cents per pound.

A farm level price was established by estimating a processing cost margin and subtracting it from natural rubber market price. Processing cost per pound of 37.6 cents (Nivert, Glymph, and Snyder) was reduced by 12 cents (Soltes) for sales of resin and wax guayule byproducts leaving a net processing cost of 25.6 cents per pound. Imputed 1981 guayule price less net processing cost gives an approximate price per pound for unprocessed guayule rubber of 30 cents per pound.

Hunting leases are an important source of revenue in the Winter Garden. Hunting leases are sold at $2.50 per acre on heavy and medium brush and at 63 cents per acre for bird hunting on light brush.

Input Prices

Input prices assign a dollar cost to all purchased fertilizers, energy inputs, other agricultural chemicals, custom work, harvest costs, and the opportunity cost of money. Purchased input prices as shown in Table 10, except for twine, electricity charges, and borrowing costs, originated in the Winter Garden Texas Crop Budgets (Extension Economists-Management, 1981a and 1981b). Twine prices were furnished by a machinery dealer.

A real interest rate was utilized in discounting net returns, calculating fixed costs, estimating annual cost for land improvements, and charging for borrowed operating capital. The real interest rate is a function of the nominal interest rate and rate of inflation. A nominal interest rate of 18 percent with an assumed 10 percent annual inflation rate gives a real interest rate of 8 per cent.

Electric service rates are composed of three parts; demand, energy and fuel adjustment, and service guarantee charges. The service guarantee charge is a flat rate per horsepower rating given the motor by its manufacturer. The fixed service guarantee charge is credited against costs of electricity used during the year and does not affect costs when systems are operated at design capacity.

The energy and fuel adjustment charges are paid per kilowatt hour used. In 1980-81 the energy charge was 1.41 cents (Central Power and Light) and the fuel adjustment charge was 2.5 cents (Ray Elledge, personal communication) for a total charge per kilowatt hour of 3.91 cents.

The demand charge was $2.41 per kilowatt of maximum demand (Central Power and Light). Maximum demand is a kilowatt load determined by a 15 minute period of maximum monthly use and is calculated for this study using annual hours of system use, annual acre inches pumped, and KWH required for each irrigation system. For example, a furrow system for lift interval 3 (200-249 feet), Appendix Table 47, required 34.7 KWH per acre inch of groundwater pumped. Some 27 minutes or about 1.28 KWH per minute are needed to pump an acre inch of groundwater. Multiplying KWH per minute, 1.28, times 45 minutes (15 minutes per month) gives an annual maximum demand of 57.5 KWH. Annual maximum demand per acre inch, .0255 for furrow system 3, was obtained from dividing 57.5 KWH by the design capacity of furrow systems, 2,252 acre inches. Maximum demand coefficients are reported in Appendix Table 47 for systems representing each furrow and sprinkler lift interval.

CHAPTER III

RESULTS

This study was designed to estimate impact of new crop alternatives, land clearing, and alternative water use levels through time for the Winter Garden region of Texas. For the overall analysis, alternative scenarios are compared to a Base solution. A detailed discussion of the Base solution is presented followed by analysis of static and temporal solutions. Two other sections characterize temporal changes in ground water resources and net returns.

A complete solution to the Winter Garden linear programming model requires 35 pages of computer print out due to the multiple crops, soil groups, and water resource regions. In the interest of efficiency in presentation of results, items useful to describe changes in net returns, resource use, and cropping patterns are summarized in tables in this chapter.

Crop alternatives which do not enter into any solution, or the level of the alternative in solution does not vary are omitted from the tables. Vegetable crop acreages were the same for all solutions, cabbage 2,398; carrots 3,572; and spinach 5,872 acres. Oats for grazing acreage was identical to peanut acreage since the only oats for grazing to enter solutions were double cropped with peanuts.

Base Solution

The Base for this study included guar and short-season irrigated cotton as crop alternatives along with all the other typical crops of the region. Groundwater availability was the 1981 projected level reported in Table 13; 80,100 acre feet in the Edwards Aquifer, and 188,100 acre feet in the Carrizo Aquifer. Cropland acreage was fixed at the 1981 level, 558,188 acres in Table 1. A summary of this solution appears in Column 3 of Table 15.

Returns to land, management, and groundwater are 42.9 million dollars. Resources included major soil types, range sites, and groundwater and soil types by water resource areas. Cropped acres totaled 454,700 acres, 293,700 in dryland and 161,000 under irrigaton. This compares with 309,000 acres dryland (Table 1) and 189,000 acres irrigated from groundwater only (Texas Department of Water Resources, 1981). Irrigation groundwater pumpage was 215,700 acre feet, 135,600 acre feet in the Carrizo and 80,100 acre feet in the Edwards. Reported 1979 groundwater pumpage in the Carrizo and Edwards Aquifers was 217,000 and 76,000 acre feet, respectively (Texas Department of Water Resources, 1981).

Table 16 shows the estimated irrigated cropping pattern and groundwater utilized for irrigation by water resource area and type of irrigation. Groundwater pumpage in two of the water resource areas (both have lifts over 300 feet) was zero. Furrow irrigation accounted for 144,346 and sprinkler 16,671 irrigated acres or 89.6 and 10.4 percent of irrigated

Table 15. Winter Garden Net Returns, Resource Use, and Cropping Patterns for Solutions with Guar, Short-Season Irrigated Cotton, Guayule, Fixed Costs, and Conversion of Range to Cropland, 1981 Projected Groundwater Pumpage.

Items		Scenarios					
		Base[a]	Fixed Costs[b]	Delete Fixed Costs[c]	Exclude Guar, SS Irig Cotton[d]	Irig Cotton[e]	Guayule[f]
Revenue Summary	(000)						
Net Revenue	Dollars	42864	39439	89561	39649	39872	46911
Resource Utilization[g]	(000)						
Dryland Cultivation	Acres	293.7	388.5	326.5	307.2	292.7	355.6
Carrizo, Irrigated	Acres	91.8	34.9	155.9	75.3	89.5	78.0
Edwards, Irrigated	Acres	69.2	60.4	74.9	50.7	52.3	69.3
Carrizo, Groundwater	Acre Feet	135.6	48.8	188.1	110.5	130.3	114.8
Edwards, Groundwater	Acre Feet	80.1	80.1	80.1	80.1	80.1	80.1
Range, Arable	Acres	2128.2	2128.2	2149.7	2128.2	2128.2	2128.2
Buffel Grass Estb	Acres			11.0			
Light Brush Clearing	Acres						
Medium Brush Clearing	Acres						
Heavy Brush Clearing	Acres						
Cropping Patterns[h]	(000)						
Short-Season Cotton Ir	Acres	11.5	.2	80.1		14.6	
Cotton, Dryland	Acres	184.9	216.0	184.7	232.7	218.9	116.3
Guayule, Dryland	Acres						178.8
Peanuts, Irrigated	Acres	16.5	16.5	16.5	16.5	16.5	16.5
Grain Sorghum, Irig	Acres	84.7	49.0	86.5	91.6	92.7	64.2
Grain Sorghum, Dry	Acres	35.7	83.5	75.8	51.1	50.4	7.1
Guar, Irrigated	Acres	30.3	13.8	35.8			49.7
Guar, Dryland	Acres	49.7	66.2	44.2			30.3
Bermuda Hay, Irig	Acres	6.1	3.9		6.1	6.1	5.1
Bermuda Hay, Dry	Acres	1.7	1.1		1.7	1.7	1.4
Cropped Acres	Acres	454.7	483.8	557.3	433.2	434.5	502.9
Cow-Calf	Units	202.4	202.4	210.6	202.4	202.4	202.3

Table 15. Continued.

		Conversion of Brush Infested Range to Cropland[i]					
		Light	Medium	Heavy	Light	Medium	Heavy
		Excludes Guayule			Includes Guayule		
Revenue Summary	(000)						
Net Revenue	Dollars	59907	68058	69232	68768	88449	93262
Resource Utilization[g]	(000)						
Dryland Cultivation	Acres	771.7	1104.3	1163.2	878.7	1647.0	1992.5
Carrizo, Irrigated	Acres	88.9	117.3	117.7	98.5	104.7	110.6
Edwards, Irrigated	Acres	72.4	74.1	74.2	68.3	68.2	66.8
Carrizo, Groundwater	Acre Feet	135.4	153.7	153.6	141.2	144.3	152.0
Edwards, Groundwater	Acre Feet	80.1	80.1	80.1	80.1	80.1	80.1
Range, Arable	Acres	1555.5	1250.9	1183.7	1527.7	865.8	526.0
Buffel Grass Estb	Acres	109.4	77.6	85.5	137.3	24.9	14.8
Light Brush Clearing	Acres	588.2	525.3	533.2	622.1	509.8	510.5
Medium Brush Clearing	Acres		367.4	367.4		774.1	774.1
Heavy Brush Clearing	Acres			59.4			339.1
Cropping Patterns[h]	(000)						
Short-Season Cotton Ir	Acres	19.3	11.9	9.4	6.0	1.9	
Cotton, Dryland	Acres	469.2	710.5	750.1	354.1	457.5	514.1
Guayule, Dryland	Acres				332.0	948.6	1210.4
Peanuts, Irrigated	Acres	15.9	15.9	15.9	15.6	15.7	15.7
Grain Sorghum, Irig	Acres	62.7	111.6	115.0	78.8	96.5	105.6
Grain Sorghum, Dry	Acres	236.8	331.3	350.6	142.0	185.1	209.6
Guar, Irrigated	Acres	38.9	38.9	38.9	51.2	45.6	42.9
Guar, Dryland	Acres	41.1	41.1	41.1	28.8	34.4	37.1
Bermuda Hay, Irig	Acres	12.8	1.4	1.0	3.4	1.4	1.4
Bermuda Hay, Dry	Acres	3.5	.4	.3	.9	.4	.4
Cropped Acres	Acres	933.0	1295.7	1355.1	1045.5	1819.9	2169.9
Cow-Calf	Units	159.2	143.4	141.5	159.2	116.9	102.7

[a] Base solution includes guar and short-season irrigated cotton.
[b] Fixed costs solution includes well development costs in addition to fixed costs in the Base.
[c] All fixed costs were omitted.
[d] Base solution excluding guar and short-season irrigated cotton.
[e] Base solution with short-season irrigated cotton, guar excluded.
[f] Base solution with guayule.
[g] Other range totals 1,155,200 acres except for the solution with all fixed costs when it is 1,257,700 acres.
[h] Acreages of the following crops were the same in all solutions; spinach 5,872; carrots, 3,512; cabbage 2,398; and sorghum hay 5,208 acres. Oats for grazing acreage equals peanut acreages.
[i] Light, Medium, and Heavy designate conversion of light, light and medium, and light, medium, and heavy brush to cropland.

Table 16. Acres of Irrigated Crops and Acre Feet of Groundwater Utilized for Irrigation by Water Resource Area, Winter Garden Base Solution.[a]

Item	Water Resource Areas							
	Batesville	LaPryor	West Pearsall	Pearsall	Moore	Los Angeles	Asherton	Carrizo Springs
Furrow Acres								
Cotton, SS[b]	262	193	1,916		166		197	13
Peanuts	380				1,254			831
Grain Sorghum	19,064		1,093		2,732			4,851
Spinach			165					
Cabbage						14		
Carrots								
Guar								
Total								
Sprinkler Acres								
Peanuts	343				1,481			1,642
Bermuda Hay	1,140				55			
Total								
Total Irrigated	21,189	193	3,174	00,000	5,689	14	197	7,337
Acre Feet Pumped								
Furrow	21,193	257	4,169		6,044	16	263	7,889
Sprinkler	4,227				2,049			2,059
Total Acre Feet	31,420	257	4,169	00,000	8,093	16	263	9,947

Table 16. Continued.

Item	Water Resource Areas: East Crystal	West Crystal	Zavala-Dimmit	Frio	LaSalle	Uvalde-Edwards	Totals
Furrow Acres[a]							
Cotton, SS[b]		467	1,848	6,423			11,485
Peanuts				3,083	452		6,000
Grain Sorghum			6,317	7,706	677	42,295	84,735
Spinach				5,707			5,872
Cabbage						2,384	2,398
Carrots				3,512			3,512
Guar				5,789		24,555	30,344
Total							144,346
Sprinkler Acres							
Peanuts			3,895		3,168		10,529
Bermuda Hay		200	4,747				6,142
Total							16,671
Total Irrigated	00,000	667	16,806	33,220	4,297	69,234	161,017
Acre Feet Pumped							
Furrow		623	10,887	42,941	1,620	80,098	182,000
Sprinkler		667	20,706		3,993		33,700
Total	00,000	1,290	31,592	42,941	5,613	80,098	215,700

[a] Base solution: 1981 cropland levels (no land clearing); guar, short-season cotton, and other crops typical to the Winter Garden; and groundwater limited to projected groundwater pumpage by water resource area.

[b] Irrigated short-season cotton.

acreages, respectively. Grain sorghum and guar had the largest irrigated acreages, 84,700 and 49,700 acres, respectively.

Acre feet of groundwater pumped in furrow and sprinkler irrigation by water resource area were also reported in Table 16. Some 182,000 acre feet were pumped for furrow irrigation and 33,700 acre feet were pumped for sprinkler irrigation.

Static Analysis

Projected 1981 groundwater pumpage for the Carrizo and Edwards Aquifers is 188,066 and 80,098 acre feet, respectively (Table 13). The static analysis considers alternative groundwater use levels, row damming, and guayule price analysis. Groundwater scenarios included projected 1981 use, a restricted level of use, and a restriction of no groundwater pumpage. Impact of changes in crop alternatives, acres of brush cleared, fixed costs, and row damming on net revenue, resource use, and cropping patterns was compared to the Base solution.

Projected 1981 Groundwater Use

Crop alternatives examined under this section include short-season irrigated cotton, guar, and guayule. Land clearing alternatives to increase cultivated acres were clear light; clear light and medium; and clear light, medium, and heavy brush. Also, comparisons were made of solutions with and without fixed costs. The results are summarized in Table 15.

Fixed Cost Impact

The Base solution includes all fixed costs as cost items except well development costs. Well development costs added as a cost item to the Base scenario are presented in column 4 of Table 15. Net revenue for a solution without fixed costs was 89.6 million dollars, Column 5, Table 15, compared to 38.4 million dollars when all fixed costs were included.

Fixed costs significantly affect cropping patterns. When fixed costs are omitted, the solution emphasizes irrigated agriculture. The entire 1981 groundwater allocation is utilized, 188,100 acre feet in the Carrizo Aquifer and 80,100 acre feet in the Edwards Aquifer. About 230,800 acres are irrigated, 155,900 in the Carrizo, and 74,900 in the Edwards. Consideration of all fixed costs including well development costs does not diminish Edwards groundwater pumpage, but Carrizo pumpage falls to 48,800 acre feet. Only 95,300 acres are irrigated when well development costs are included as a cost item in the model.

Without fixed costs, irrigated crops were lead by short-season cotton, 80,100 acres, and grain sorghum, 86,500 acres. Cotton and grain sorghum dominated dryland activities at 184,700 and 75,800 acres, respectively. Establishment of 11,000 acres of buffel grass leads to an increase in animal units in beef production.

Inclusion of well development costs as a cost item in the model practically eliminates short-season irrigated cotton and almost halves irrigated grain sorghum acreage placing emphasis on dryland. Dryland grain sorghum accounted for 83,500 acres and dryland cotton 216,000 acres.

Short-Season Irrigated Cotton

To estimate the impact of short-season irrigated cotton, the Base without guar and short-season cotton (Column 6, Table 15) was compared to the Base without guar (Column 7, Table 15). Introduction of short-season irrigated cotton to the Texas Winter Garden Region increased net returns by 223,000 dollars or from 39.6 to 39.8 million dollars according to these results. Cultivated acreage was stable, 433,000-435,000 acres, but some shift between dryland and irrigated acreages were observed. Irrigated acreages in the Carrizo and Edwards Aquifers increased 14,200 and 1,600 acres, respectively. Dryland cultivation declined by 14,500 acres to 292,700. Carrizo groundwater pumpage increased by 19,800 to 130,300 acre feet and Edwards remained constant at 80,100 acre feet. Cropping pattern changes were negligible with exception of dryland cotton which dropped by 13,800 acres to 218,900.

Guar

A comparison of the Base with guar and short-season irrigated cotton (Column 3, Table 15) and the Base with irrigated cotton (Column 7, Table 15) shows the impact of introduction of guar. Net returns rise 3 million dollars, or 7.5 percent. Cultivated acres increased by 20,200 to 454,700 acres. Some 161,000 acres were irrigated, 91,800 and 69,200 acres in the Carrizo and Edwards Aquifers, respectively. This represents a 2,300 acre increase for the Carrizo and a 16,900 acre increase for the Edwards Aquifer. Edwards Aquifer groundwater use remains the same while Carrizo increases to 135,600 acre feet, a rise of 5,300 acre feet or 4 percent.

For this study, guar acreage is restricted to 80,000 acres which approximates current contract levels. Cropping patterns show 30,300 and 49,700 acres of irrigated and dryland guar, respectively. The addition of 80,000 acres of guar with only 20,200 additional acres brought into cultivation resulted in deletion of about 60,000 acres of other crops. Listed by magnitude of acreage, these crops were; dryland cotton 34,000, dryland grain sorghum 15,000, irrigated grain sorghum 7,000, and irrigated short-season cotton 3,000.

Guayule

Incorporating guayule into the model (Column 8, Table 15) boosts net revenue by 4 million dollars over the Base (Column 3, Table 15). Total cultivated acreage rises by 48,200 to 502,900 acres, an increase of 10.6 percent. A fall in irrigated acreage to 147,300 acres comes almost entirely from a Carrizo irrigated acreage decline of 13,800 acres. Carrizo Aquifer irrigated acreages with guayule were 78,000 acres while Edwards irrigated acreages remained at about 69,000 acres. A 20,800 acre foot reduction in groundwater pumpage was realized in the Carrizo Aquifer. However, acre feet of groundwater pumped remained about the same in the

Edwards Aquifer.

Guayule acreage reached 178,800 acres. Some 130,600 of these acres were a result of the following reduction in acreages; dryland cotton, 68,600; short-season irrigated cotton, 11,500; irrigated grain sorghum, 20,500; dryland grain sorghum, 28,600; and irrigated and dryland bermuda grass hay, 1,300.

Land Clearing without Guayule

The Base, without guayule production alternatives, was considered for each land clearing alternative; light; light and medium; and light, medium, and heavy brush clearing. Solutions without a guayule option are reported in columns 11, 12, and 13 of Table 15. Net revenue jumps from 42.9 million dollars in the Base (Column 3, Table 15) to 59.9 million dollars with clearing of light brush land (Column 11), a gain based on expansion of dryland crop activities. Land clearing increases the amount of cropland and reduces arable range. Some 588,200 acres of light brush were cleared and 109,400 acres of buffel grass were established for a net cropland gain of 478,800 acres.

Total cultivated acreage was about 933,000 acres. Irrigated acreage was 161,300 acres and groundwater usage 215,000 acre feet or about the same as in the Base. Large increases in dryland acreages were accounted for by dryland cotton up from 184,900 to 469,200 acres and dryland grain sorghum from 35,700 to 236,800 acres.

Modest acreage increases were observed for other crops. Irrigated short-season cotton acreage increased from 11,500 in the Base to 19,300 acres with clearing of light brush. Bermuda grass hay increased from 7,800 to 16,300 acres. Peanut acreage declined slightly. Numbers of animal units dipped from 202,000 to about 159,000.

With clearing of light and medium brush (Column 12, Table 15), net returns were estimated to increase 25.2 million dollars to 68.1 million dollars, an increase of 59 percent compared to the Base solution in Column 3. A total of 892,700 acres of brush infested range was cleared and 77,600 acres of buffel grass were established giving a net gain in cropland inventory of 815,100. Addition of medium brush clearing to light brush clearing (Column 11) yielded an net addition to cropland of 336,300 acres.

Total cultivated acreage was about 1.3 million acres (Column 12). Some 191,400 acres were irrigated, 74,100 in the Edwards and 117,300 in the Carrizo. Compared to the Base in Column 3, use of irrigation water in the Edwards Aquifer remains at its upper limit and increases 13.3 percent to 153,700 acre feet in the Carrizo.

Cropping pattern changes were lead by dryland cotton which rose to 710,500 acres, an increase of 51.4 percent over the solution with light brush clearing included as an option (Column 11). Dryland grain sorghum increased to 331,300 acres from 236,800 acres and irrigated grain sorghum nearly doubled rising from 62,700 acres to 111,600 acres. Numbers of animal units in beef production declined to 143,000.

Addition of heavy brush to land clearing alternatives (Column 13) yielded only a modest 1.7 percent increase in net revenue when compared to the light and medium brush clearing alternative, 69.2 versus 68.1 million dollars. Groundwater pumpage was about the same as the previous solution, 234,000 acre feet. Irrigated acreages remained approximately the same but dryland cultivation increased to 1.2 million acres. Total cropland rose 59,400 acres, the approximate acreage of heavy brush cleared. The additional acreage added to cropland matched increases in dryland cotton acreage at 39,600, and dryland grain sorghum at 19,300 acres.

Land Clearing with Guayule

Solutions for land clearing alternatives with a guayule option included are reported in columns 14, 15, and 16 of Table 15. Net returns were estimated to be 68.8, 88.4, and 93.3 million dollars for clearing light brush; light and medium brush; and light, medium, and heavy brush, respectively. This is compared to 46.9 million dollars for the Base with guayule but without land clearing (Column 8).

Only the Carrizo Aquifer registered changes in acre feet pumped for irrigation. The three land clearing scenarios with guayule were associated with increases of 26,400; 29,500; and 37,200 acre feet pumped when compared to base guayule which omitted land clearing (Column 8). However, in a comparison of groundwater use and land clearing, with and without guayule, after a slight increase in groundwater pumped and irrigated acreages for light brush clearing, groundwater pumpage declines in the Carrizo Aquifer for clearing of light and medium and light, medium, and heavy brush when guayule is included as an option. Irrigated acreages also decline in both aquifer areas.

With the addition of guayule, cultivated acres increased by 112,500, 524,200, and 814,800 over the analogous brush clearing alternatives without guayule (light; light and medium; and light, medium, and heavy). Maximum cultivated area occurred for clearing of light, medium, and heavy brush for cropland, 2.2 million acres, Column 16. For the three clearing scenarios, guayule acreage was 332,000, 948,600, and 1,210,400. The increased guayule acreage across clearing activities was also supported by reductions in acreages of short-season irrigated cotton and dryland grain sorghum. As land clearing alternatives are added livestock production is scaled back due to range clearing and reduction in buffel grass establishment. Animal units drop from 202,300 in the Base with guayule to 102,700 in light, medium, and heavy brush clearing with guayule.

Restricted 1981 Groundwater Use

Table 17 contains results for the Base, Base with guayule, and land clearing activities with guayule with water use restricted to 1981 restricted pumpage levels. From Table 12, restricted groundwater pumpage levels for the Carrizo and Edwards Aquifers were 170,125 and 59,200 acre feet, respectively. The impact of these reductions on net revenue, resource use, and cropping patterns are compared with solutions in Table 15.

Base

Comparison of the Base with projected groundwater use (Column 3,

Table 17. Restricted Groundwater Pumping with Base Solution, Guayule, and Conversion of Range to Cropland, Winter Garden, 1981.

		Base[a]	Guayule[b]	Light[c]	Medium[d]	Heavy[e]
Revenue Summary	(000)					
Net Revenue	Dollars	42516	46686	68494	88197	92921
Resource Utilization[f]	(000)					
Dryland Cultivation	Acres	315.8	380.7	890.8	1658.7	2017.3
Carrizo, Irrigated	Acres	96.2	84.1	100.6	106.8	111.2
Edwards, Irrigated	Acres	55.8	55.3	54.1	54.1	54.1
Carrizo, Groundwater	Acre Feet	141.8	126.0	141.9	143.5	149.3
Edwards, Groundwater	Acre Feet	59.2	59.2	59.2	59.2	59.2
Range, Arable	Acres	2128.2	2128.2	1529.2	865.8	511.2
Buffel Grass Estb	Acres			135.7	25.0	16.5
Light Brush Clearing	Acres			620.6	509.8	527.0
Medium Brush Clearing	Acres				774.1	774.1
Heavy Brush Clearing	Acres					337.4
Cropping Patterns[g]	(000)					
Short-Season Cotton	Acres	12.1				
Cotton, Dryland	Acres	192.5	124.3	367.5	464.6	519.0
Guayule, Dryland	Acres		181.7	321.7	941.8	1217.0
Peanuts, Irrigated	Acres	16.5	16.5	15.6	15.6	15.6
Grain Sorghum, Irig	Acres	75.7	53.9	70.1	87.2	94.1
Grain Sorghum, Dry	Acres	49.7	22.3	155.2	197.6	224.0
Guar, Irrigated	Acres	29.8	51.1	55.1	46.2	43.7
Guar, Dryland	Acres	50.2	28.9	24.9	33.8	36.3
Bermuda Hay, Irig	Acres	6.1	6.1	2.0	.1	.1
Bermuda Hay, Dry	Acres	1.7	1.7	.5		
Cropped Acreage	Acres	467.8	520.1	1045.5	1819.6	2182.6
Cow-Calf	Units	202.4	202.3	159.2	117.0	101.1

[a] Base solution with 1981 restricted groundwater pumpage as a conservation goal.
[b] Base solution with guayule.
[c] Base solution with guayule and conversion of light brush infested range to cropland.
[d] Base solution with guayule and conversion of light and medium brush density range to cropland.
[e] Base solution with guayule and conversion of light, medium, and heavy brush infested range to cropland.
[f] Non-arable range is 1,155,200 acres in all solutions.
[g] Acreages of the following crops are the same in all solutions; spinach, 5872; carrots, 3512; cabbage, 2398; and sorghum hay, 5208 acres. Oats for grazing acreage equals peanut acreages.

Table 15) and the Base restricted groundwater pumpage (Column 3, Table 17) shows that conservation contributed to reductions in net revenue of about 350,000 dollars. However, total area cultivated increased by 13,100 acres to a total of 467,800 acres, dryland cultivation increasing by 22,100 acres and irrigated acreages declining by approximately 9,000 acres. Edwards Aquifer irrigated acreages declined by 13,400 acres while Carrizo irrigated acreages increased by 4,400 acres.

Total groundwater pumpage for irrigation declined 6.8 percent to 201,000 acre feet. Groundwater pumped from the Edwards was constant at the restricted level of 59,200 acre feet for all Table 17 scenarios, about 26 percent below the projected use rate. Carrizo Aquifer groundwater pumpage for the Base solution with restricted use rose 6,200 acre feet to 141,800 acre feet.

Cropping patterns were very stable between the two solutions. With reduced groundwater use, dryland cotton rises to 192,500 acres acres from 184,900 acres. Irrigated grain sorghum decreases by 9,000 acres to 75,700 acres and dryland grain sorghum rises from 35,700 acres to 49,700 acres, an increase of 39.2 percent.

Guayule

A comparison of the Base with guayule and restricted groundwater pumpage (Column 4, Table 17) and the Base with guayule and projected groundwater pumpage (Column 8, Table 15) shows expected annual net revenue for the projected water use level exceeded that for the restricted water use level by about 225,000 dollars. Dryland cultivation rose to 380,700 acres from 355,600 acres while irrigated acreages declined to 139,400 from 147,300 acres. Introduction of restricted pumpage for the Base with guayule is associated with a decline in groundwater pumpage from 194,900 to 185,200 acre feet, a net change of 9,700 acre feet. The Edwards Aquifer restricted groundwater pumpage resulted in a forced reduction in groundwater pumpage for irrigation of 20,400 acre feet while the Carrizo groundwater pumpage actually increased by 11,200 acre feet.

Cropping patterns for guayule with restricted groundwater indicate increased specialization in dryland activities. Dryland guayule and dryland cotton increase slightly, 178,800 to 181,700 acres and 116,300 to 124,300 acres, respectively. Dryland grain sorghum increased threefold to 22,300 acres. Irrigated grain sorghum decreased by 10,300 acres to 53,900 acres.

Land Clearing

Introduction of clear light; light and medium; and light, medium, and heavy brush (Columns 5, 6, and 7 of Table 17) with guayule and restricted 1981 groundwater pumpage did not significantly affect income or total cultivated area when compared to the with guayule and projected groundwater pumpage (Columns 14, 15, and 16 in Table 15). Net revenue decreased by 274,000, 252,000, and 341,000 dollars to 68.5, 88.2, and 92.9 million dollars, respectively. Carrizo Aquifer groundwater pumpage with guayule and land clearing is about the same under projected and restricted groundwater pumpage. Aggregate reductions in groundwater pumpage are realized almost entirely by the 20,900 acre foot reduction imposed in Edwards groundwater pumpage.

The net addition to cropland is about the same for land clearing with guayule for both restricted and projected 1981 groundwater pumpage limitations, about 485,000, 1.3 million, and 1.6 million acres of cropland, respectively. Total acres cultivated do not change significantly. The biggest difference between guayule land clearing scenarios with alternative groundwater pumpage assumptions was shifts between dryland and irrigated cultivation. With projected groundwater pumpage, as land clearing progressed dryland acreages rose from 878,700 to a little less than two million acres. With restricted groundwater pumpage, as land clearing changed from light to light, medium, and heavy options, dryland cultivation rose from 890,800 acres to a little more than two million acres. In a comparison of irrigated acreages between corresponding solutions, light brush clearing with projected groundwater pumpage versus light brush clearing with restricted groundwater pumpage etc., Carrizo irrigated acreages were about the same in corresponding solutions. Edwards irrigated acres were consistently 14,000 acres less for each clearing option under restricted pumpage assumptions.

Cropping patterns show increased specialization in dryland cotton and dryland grain sorghum alternatives when the three clearing alternatives are introduced under restricted groundwater limitations. Acreages of irrigated grain sorghum and short-season irrigated cotton decline. Guayule acreages decline for the first two clearing options and rise for the light, medium, and heavy clearing alternative.

Irrigated Alternatives Eliminated

Irrigation activities were deleted from four scenarios; Base, with and without light brush clearing; and Base with Guayule, with and without light brush clearing. The results are presented in Table 18. Net revenue, cropping patterns, and land use, were compared with the corresponding solutions in Table 15. Net revenue for the Base without irrigation (Column 3, Table 18) was 28.6 million dollars, a reduction of 14.3 million dollars or 33.4 percent when compared to the Base (Column 3, Table 15). Some 554,800 acres were in dryland activities, cotton and grain sorghum dominating. For the Base with dryland farming only, cultivated area exceeded acreage cropped in the Base with irrigation by 100,000 acres.

Including the opportunity to clear light brush (Column 4, Table 18) resulted in a net revenue of 46.1 million dollars which is 13.8 million dollars less than the same scenario with projected groundwater pumpage (Column 11, Table 15). With clearing, cultivated acres rose by 441,300 acres and cropland increased by 447,700 acres, 6,500 acres of cropland being abandoned. This compares to a 478,800 increase in cropland under light brush conversion in the Base solution with projected groundwater use (Column 11, Table 15). The 441,300 acre increase in cropland corresponded to a 273,600 acre increase in cotton acreages and a 167,700 acre increase in grain sorghum acreages.

In a comparison of the Base with and without guayule, both without land clearing, introduction of guayule increased net revenue to 32.6 million dollars (Column 5, Table 18). Without land clearing net revenue is

Table 18. Winter Garden Base Solution and Conversion of Light Brush Infested Range to Cropland, With and Without Guayule, Dryland Farming Only, 1981.

Item		Base[a]	Light Brush[b]	Guayule[c] Base	Guayule[c] Light Brush
Revenue Summary	(000)				
Net Revenue	Dollars	28553	46110	32563	55370
Resource Utilization	(000)				
Acres in Cropland	Acres	510.1	951.4	555.3	1148.0
Range, Arable	Acres	2128.2	1557.2	2128.2	1408.7
Buffel Grass Estb	Acres		138.8		148.1
Light Brush Clearing	Acres		586.5		741.0
Cropping Patterns	(000)				
Cotton, Dryland	Acres	235.7	509.3	161.4	407.5
Guayule, Dryland	Acres			170.2	360.8
Peanuts, Dryland	Acres	44.7	44.7	44.7	44.7
Grain Sorghum, Dry	Acres	144.5	312.2	98.9	249.8
Guar, Dryland	Acres	80.0	80.0	80.0	80.0
Sorghum Hay	Acres	5.2	5.2		5.2
Cultivated Acres[d]	Acres	554.8	996.1	600.0	1192.7
Cow-Calf	Units	202.5	161.9	202.5	147.9

[a] Base with irrigated activities deleted.
[b] Base with conversion of light brush infested range to cropland.
[c] Base with guayule and land conversion.
[d] Oats for grazing and peanuts are double cropped.

14.3 million dollars less than that of the corresponding irrigated solution of 46.9 million dollars (Column 8, Table 15). Cultivated acreage, 600,000, is larger than the 502,900 acres estimated for the Base with guayule and irrigation. Guayule acreages of 170,200 were 2,600 acres less under dryland farming only than with projected groundwater use (Column 8, Table 15).

Allowing the option of light brush conversion with guayule (Column 6, Table 18) results in a 55.4 million dollar net revenue which is 13.4 million dollars less than the same scenario with irrigated crop alternatives (Column 14, Table 15). Cropland inventory increases 592,900 acres and cultivated acres total 1.2 million. Under projected groundwater pumpage with clearing of light brush (Column 14, Table 15), fewer total acres are converted to cropland, 592,900, and fewer total acres are cropped, about 1 to 1.1 million. The levels of dryland grain sorghum, dryland cotton, and guayule in solution for dryland farming with light brush clearing are 249,800, 407,500, and 360,800 acres versus 142,000, 354,100, and 332,000 with guayule and projected groundwater pumpage (Column 14, Table 15).

Row Damming

Row damming tillage which increases dryland crop yields for sorghum and cotton was included in the model assuming 1981 projected groundwater pumpage rates. Implications of row damming for Winter Garden net returns, resource utilization, and cropping patterns are shown in Table 19.

Introduction of land clearing with row damming boosts net revenue to the highest levels of the entire analysis. Row damming gave the following net revenue changes by scenario; Base increasing by 6.7 to 49.5; light brush clearing increasing by 18.6 to 78.5; light and medium brush clearing increasing by 30.3 to 98.3; and light, medium, and heavy brush clearing increasing by 32.9 to 102.2 million dollars.

Groundwater pumpage was sharply reduced with the introduction of row damming. Edwards Aquifer pumpage was 11,900, 40,300, and 14,900 acre feet less than the projected limit of 80,100 acre feet in all but the final scenario, clear light, medium, and heavy brush clearing where it reached the usual limit. Carrizo pumpage decreased 53,700, 38,900, 56,200, and 51,400 to 81,900, 96,500, 97,500, and 102,200 acre feet for Base; clear light brush; clear light and medium brush; and clear light, medium, and heavy brush alternatives, respectively.

The three land clearing solutions clear more land and contribute larger net additions to cropland than their non-row damming counterparts. With row damming, light; light and medium; and light, medium and heavy brush clearing resulted in respective net additions to cropland of 563,000, 1.2 million, and 1.5 million acres. Net additions to cropland exceed those of corresponding land clearing solutions given Table 15 by 83,800, 405,800, and 583,000 acres, respectively. Consequently, as all land clearing alternatives are introduced numbers of animal units in livestock production are reduced 202,400 to 105,100 versus 202,400 to 141,500 for land clearing without row damming.

The highest number of irrigated acres with row damming (clear light, medium, and heavy brush) remains below the Base irrigated acreages without land clearing and without row damming. Under light, medium, and heavy brush clearing 148,000 acres are irrigated with the row damming scenario

Table 19. Impact of Row Damming and Land Clearing on Winter Garden Net Revenue, Resource Utilization, and Cropping Patterns, 1981 Projected Groundwater Pumping Rates.

			Range Conversion to Cropland		
Item		Base[a]	Light[b]	Medium[c]	Heavy[d]
Net Revenue	(000)				
Row Damming	Dollars	49544	78522	98320	102167
Without Row Damming	Dollars	42864	59907	68058	69232
Difference	Dollars	6680	18615	30262	32935
Resource Utilization[e]	(000)				
Dryland Cultivation	Acres	444.1	1017.2	1649.5	1870.5
Carrizo, Irrigated	Acres	53.8	62.8	67.4	74.1
Edwards, Irrigated	Acres	56.7	43.1	64.3	73.9
Carrizo, Groundwater	Acre Feet	81.9	96.5	97.5	102.2
Edwards, Groundwater	Acre Feet	68.2	39.8	65.2	80.1
Range, Arable	Acres	2128.2	1438.3	840.5	640.2
Buffel Grass Estb	Acres		142.6	82.3	46.0
Light Brush Clearing	Acres		705.4	645.1	608.9
Medium Brush Clearing	Acres			658.1	682.7
Heavy Brush Clearing	Acres				211.9
Cropping Patterns[f]	(000)				
Short-Season Cotton Ir	Acres		10.6	7.1	
Cotton, Dryland	Acres	260.2	594.8	1006.5	1165.8
Peanuts, Irrigated[g]	Acres	16.5	15.6	15.6	15.9
Grain Sorghum, Irig	Acres	24.8	3.6	18.3	30.0
Grain Sorghum, Dry	Acres	134.7	367.6	603.0	685.7
Guar, Irrigated	Acres	49.4	50.0	64.7	80.0
Guar, Dryland	Acres	30.6	30.0	15.3	
Bermuda Hay, Irig	Acres	8.0	14.3	14.2	11.3
Bermuda Hay, Dry	Acres	2.2	3.9	3.8	3.0
Sorghum Hay, Dry	Acres		5.2	5.2	
Cropped Acreage	Acres	554.6	1123.1	1781.2	2018.5
Cow-Calf	Units	202.4	149.9	114.4	105.1

[a] Base (short-season cotton and guar) includes row damming in dryland cotton and dryland grain sorghum.
[b] Base with conversion of light brush infested range to cropland.
[c] Base with conversion of light and medium brush infested range to cropland.
[d] Base with clearing of light, medium, and heavy brush infested range.
[e] Non-arable range totals 1,155,200 acres.
[f] Spinach, carrots, cabbage, and sorghum hay acreages remained constant at 5,872; 3,512; 2,398; and 5,208 acres, respectively.
[g] Oats for grazing acreage equals peanut acreage.

(Column 6, Table 19) versus 161,000 acres without row damming and without land clearing (Column 3, Table 15).

For each alternative with row damming, dryland acreages are higher than dryland acreages for corresponding base solutions without row damming. Without row damming, dryland acreages increase from 293,700 acres without land clearing to 1,163,200 acres with all land clearing alternatives (Column 13, Table 15). With row damming and no land clearing, 444,100 acres were cultivated as dryland. Maximum dryland cultivation, 1,870,500 acres, was attained when all three types of brush clearing were possible (Table 19).

Dryland cotton and grain sorghum are the dominant crops under row damming. Cotton acreages rise from 260,200 acres to 1,165,800 acres in Base without clearing to Base with all land clearing alternatives (Table 19). Without row damming, dryland cotton acreages range from 184,900 acres without land clearing to 750,100 acres with clear light, medium, and heavy brush (Column 13, Table 15). Grain sorghum acreages were estimated to rise from 134,700 acres for row damming without land clearing to 685,700 acres with row damming and all land clearing options in effect. This is compared to the solutions without row damming where the dryland grain sorghum acreage range was 35,700 to 350,600 acres.

Guayule Price Analysis

Additional solutions were obtained for guayule prices of 25 and 35 cents per pound so that along with the previous guayule scenarios at 30 cents per pound some observations could be made about the impact of changes in guayule price on net returns, groundwater utilization and cropping patterns. Solutions with 25, 30, and 35 cent per pound guayule with 1981 projected groundwater pumpage are reported in Table 20 for Base without land clearing; clear light; clear light and medium; and clear light, medium, and heavy brush. The results indicate that the impact of guayule is greater for prices above 30 cents per pound.

Net revenue for 25, 30, and 35 cent guayule was 44.3, 46.9, and 50.7 million dollars (Columns 3, 9, and 15) when land clearing was excluded from the model. With the introduction of all land clearing options, net returns were 75 and 116.5 million dollars for 25 cent and 35 cent guayule, respectively.

Groundwater pumpage and irrigated acreage trended downward as the price of guayule rose. Only in the clearing of light brush with 30 cent per pound guayule price did both pumpage and irrigated acreage increase slightly. Without clearing (Base, Table 20), irrigated acreages declined from 157,200 acres when guayule is priced at 25 cents to 147,200 acres at 30 cents, and to 134,400 acres when guayule is priced at 35 cents per pound. These irrigated acreages are less than the 161,000 irrigated acres for the Base without guayule, Table 15.

As guayule price rose acre feet of groundwater pumped for irrigation declined. Edwards groundwater, 80,100 acre feet per year, is fully utilized in each of the 12 guayule pricing runs. Accordingly, the declines in pumpage are realized in the Carrizo Aquifer. Carrizo Aquifer acre feet utilized for irrigation declined from 143,900 to 114,800 and to 96,000 acre feet for guayule prices per pound of 25, 30, and 35 cents. In the Base without guayule (Table 15) Carrizo Aquifer groundwater pumped for

Table 20. Impact of Alternative Guayule Prices on Winter Garden Net Revenue, Cropping Patterns, and Resource Use, 1981 Projected Groundwater.

			Guayule, 25 cents per pound		
Item		Base[a]	Light[b]	Medium[c]	Heavy[d]
Revenue Summary	(000)				
Net Revenue	Dollars	44253	63317	73513	74972
Resource Utilization	(000)				
Dryland Cultivation	Acres	329.7	883.4	1539.1	1781.6
Carrizo, Irrigated	Acres	87.8	97.3	117.1	116.9
Edwards, Irrigated	Acres	69.4	64.8	67.9	67.9
Carrizo, Groundwater	Acre Feet	123.6	141.8	152.6	152.6
Edwards, Groundwater	Acre Feet	80.1	80.1	80.1	80.1
Range, Arable	Acres	2128.2	1522.4	967.2	727.3
Buffel Grass Estb	Acres		142.5	19.1	16.6
Light Brush Clearing	Acres		627.3	503.9	501.5
Medium Brush Clearing	Acres			678.7	678.7
Heavy Brush Clearing	Acres				242.3
Cropping Patterns	(000)				
Short-Season Cotton Ir	Acres		11.9	8.7	5.4
Cotton, Dryland	Acres	130.4	372.3	537.5	593.9
Guayule, Dryland	Acres	143.9	284.6	714.4	871.1
Peanuts, Irrigated	Acres	16.5	15.6	15.6	15.6
Grain Sorghum, Irig	Acres	79.5	84.6	121.9	125.0
Grain Sorghum, Dry	Acres	.4	150.9	213.0	242.4
Guar, Irrigated	Acres	47.3	28.0	26.7	26.7
Guar, Dryland	Acres	32.7	52.0	53.3	53.3
Bermuda Hay, Irig	Acres	2.0	10.1	.2	.2
Bermuda Hay, Dry	Acres	.6	2.7		
Sorghum Hay, Dry	Acres	5.2	5.2	5.2	5.2
Cropped Acreage	Acres	486.9	1045.5	1724.1	1966.4
Cow-Calf	Units	202.4	159.2	121.9	112.5

Table 20. Continued.

Item		Base[a]	Guayule, 30 cents per pound Light[b]	Medium[c]	Heavy[d]
Revenue Summary	(000)				
Net Revenue	Dollars	46911	68768	88449	93262
Resource Utilization	(000)				
Dryland Cultivation	Acres	355.6	878.7	1647.0	1992.5
Carrizo, Irrigated	Acres	78.0	98.5	104.7	110.6
Edwards, Irrigated	Acres	69.3	68.3	68.2	66.8
Carrizo, Groundwater	Acre Feet	114.8	141.2	144.3	152.0
Edwards, Groundwater	Acre Feet	80.1	80.1	80.1	80.1
Range, Arable	Acres	2128.2	1527.7	865.8	526.0
Buffel Grass Estb	Acres		137.3	24.9	14.8
Light Brush Clearing	Acres		622.1	509.8	510.5
Medium Brush Clearing	Acres			774.1	774.1
Heavy Brush Clearing	Acres				339.1
Cropping Patterns	(000)				
Short-Season Cotton Ir	Acres		6.0	1.9	
Cotton, Dryland	Acres	116.3	354.1	457.5	514.1
Guayule, Dryland	Acres	178.8	332.0	948.6	1210.4
Peanuts, Irrigated	Acres	16.5	15.6	15.7	15.7
Grain Sorghum, Irig	Acres	64.2	78.8	96.5	105.6
Grain Sorghum, Dry	Acres	7.1	142.0	185.1	209.6
Guar, Irrigated	Acres	49.7	51.2	45.6	42.9
Guar, Dryland	Acres	30.3	28.8	34.4	37.1
Bermuda Hay, Irig	Acres	5.1	3.4	1.4	1.4
Bermuda Hay, Dry	Acres	1.4	.9	.4	.4
Cropped Acreage	Acres	502.9	1045.5	1819.9	2169.9
Cow-Calf	Units	202.3	159.2	116.9	102.7

Table 20. Continued.

			Guayule, 35 cents per pound		
		Base[a]	Light[b]	Medium[c]	Heavy[d]
Revenue Summary	(000)				
Net Revenue	Dollars	50739	76581	107446	116460
Resource Utilization	(000)				
Dryland Cultivation	Acres	394.0	847.3	1658.8	1991.2
Carrizo, Irrigated	Acres	62.1	67.6	75.6	83.8
Edwards, Irrigated	Acres	72.3	66.9	66.1	65.1
Carrizo, Groundwater	Acre Feet	96.6	117.3	129.3	135.2
Edwards, Groundwater	Acre Feet	80.1	80.1	80.1	80.1
Range, Arable	Acres	2128.2	1548.1	840.7	516.5
Buffel Grass Estb	Acres		135.4	29.6	14.8
Light Brush Clearing	Acres		601.7	514.5	499.6
Medium Brush Clearing	Acres			794.6	794.6
Heavy Brush Clearing	Acres				339.1
Cropping Patterns	(000)				
Short-Season Cotton Ir	Acres	20.7	11.1	3.9	
Cotton, Dryland	Acres	18.9	68.8	145.1	182.2
Guayule, Dryland	Acres	324.2	700.5	1407.3	1697.4
Peanuts, Irrigated	Acres	17.8	17.6	17.8	17.8
Grain Sorghum, Irig	Acres	24.3	26.9	46.7	62.6
Grain Sorghum, Dry	Acres		22.0	44.6	49.2
Guar, Irrigated	Acres	53.7	51.2	45.6	44.0
Guar, Dryland	Acres	26.3	28.8	34.4	36.0
Bermuda Hay, Irig	Acres	6.1	16.0	16.0	12.8
Bermuda Hay, Dry	Acres	1.7	4.3	1.3	3.5
Cropped Acreages	Acres	528.4	981.8	1800.5	2140.1
Cow-Calf	Units	201.9	161.2	116.1	103.0

[a] Base includes guar and short-season irrigated cotton with guayule.
[b] Base with conversion of light brush infested range to cropland.
[c] Base with conversion of light and medium brush infested range to cropland.
[d] Base with conversion of light, medium, and heavy brush infested range to cropland.

irrigation was 135,600 acre feet.

Guayule prices of 25, 30, and 35 cents per pound were associated with 143,900, 178,800 and 324,200 acres of guayule when land clearing was blocked (Columns 3, 9, 15). A 20 percent price increase, 25 to 30 cents, was accompanied by a 25 percent increase in pounds of guayule produced and a 24 percent increase in guayule acreage. At the same time both dryland cotton and total grain sorghum acreages declined by 11 percent.

A guayule price increase from 30 cents per pound up to 35 cents per pound was associated with an 89 percent increase in quantity harvested, to 116.3 million pounds and an 81 percent increase in acreage. While price increased 17 percent, dryland cotton acreage declined by 83 percent to 18,900 and total grain sorghum acreage declined 65 percent to 24,300. Similar trends were noted for guayule, dryland cotton, and total grain sorghum under the three land clearing scenarios. In Figures 4 and 5 guayule price is plotted against pounds of natural rubber produced (Figure 4) and acres of guayule under cultivation (Figure 5).

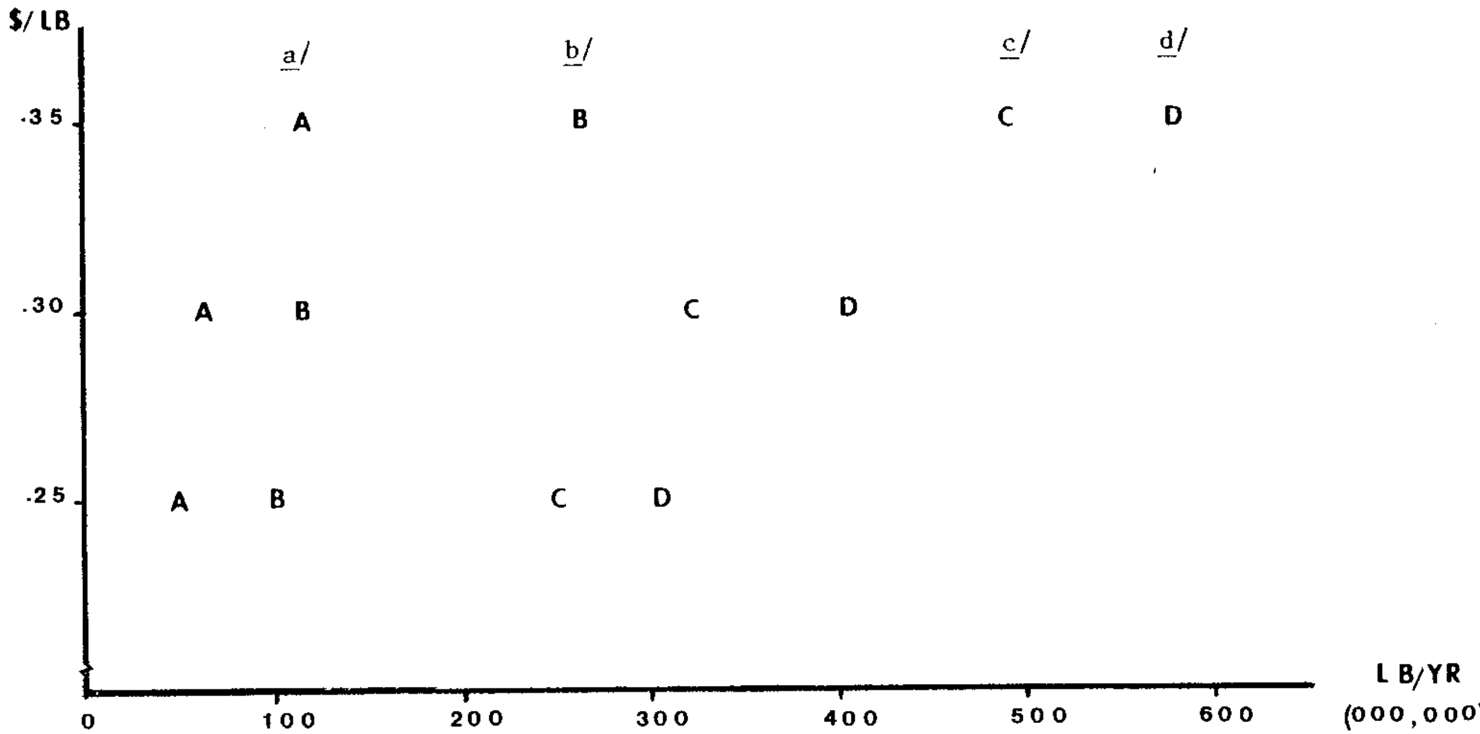
Temporal Results

In a temporal framework, groundwater is affected by level of irrigation, non-irrigation uses, and characteristics of the aquifer. This analysis through time considers a) growth in non-irrigation uses which reduces availability of groundwater for irrigation, b) increases in depth to water as pumpage exceeds known recharge rates, and c) projected estimates of recharge rates, aquifer development, and utilization of the groundwater resources.

Trends in resource use, net revenue, and cropping patterns are observed through comparisons of two major scenarios; projected and restricted groundwater pumpage for irrigation, with and without simultaneous clearing of light and medium brush. To describe the temporal implications for agriculture in the Winter Garden, a sequence of solutions is compared. Aggregate groundwater pumpage and ending pumping lifts are calculated for each scenario with and without land clearing. The present values of the expected stream of agricultural net returns are also calculated and compared.

Projected Groundwater Use

As in the static analysis, the level of groundwater use for irrigation per year as projected by the Texas Department of Water Resources provided upper limits to groundwater pumpage for irrigation by water resource area in the model. The analysis consists of two sets of solutions, one with land clearing activities omitted and the second with conversion to cropland of light and medium brush infested range. The temporal analysis of a selected scenario was based on a solution for consecutive five year periods beginning with its static solution reported in either Table 15 or 17. After each solution new pumping lifts were calculated as a function of acre feet of groundwater pumped for irrigation and non-irrigation uses (Appendix Tables 40 and 42). Water resource areas were then assigned to lift intervals and irrigation systems were changed for water resource areas which had to shift to new lift intervals. The projected pumpage



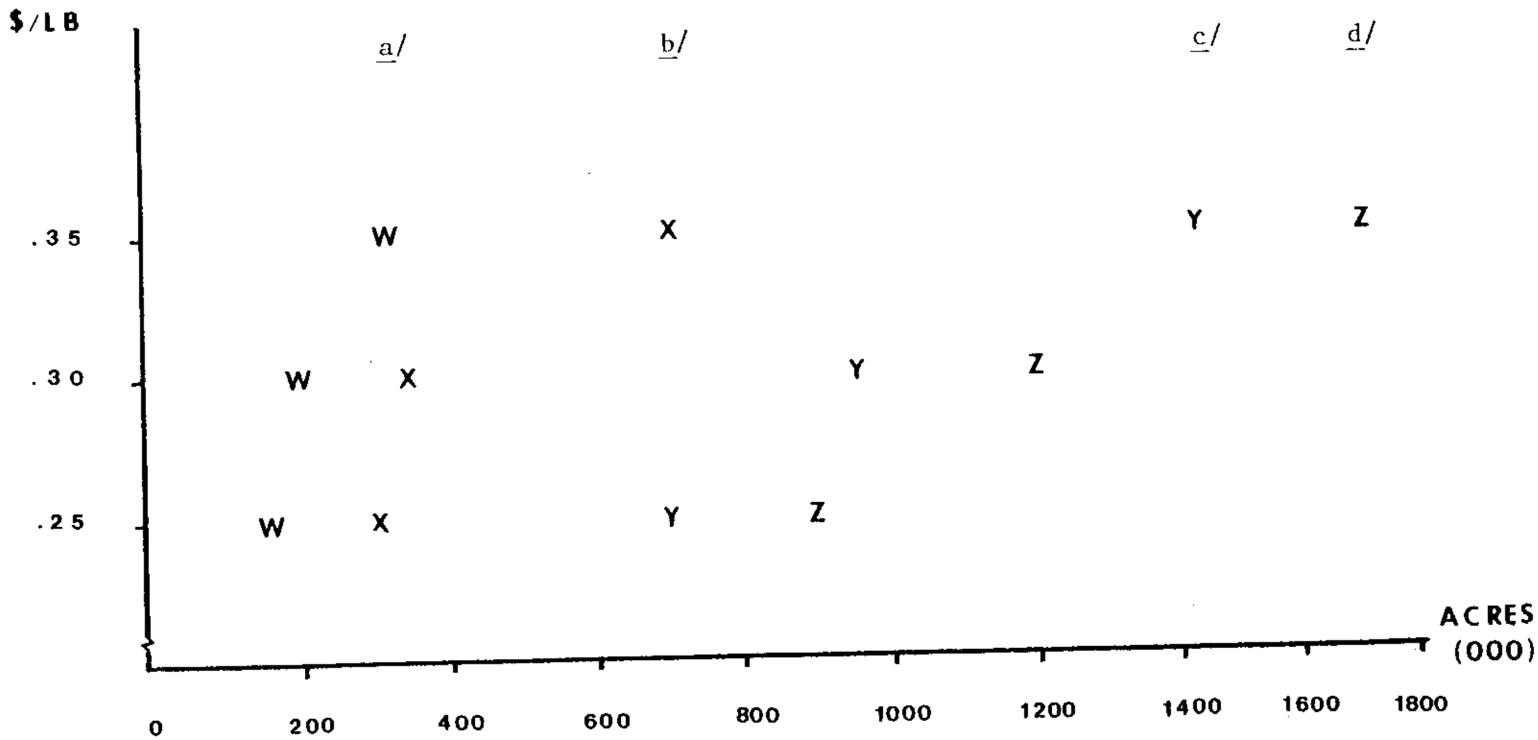
a/ No land clearing, A.

b/ Clear light brush infested range, B.

c/ Clear light and medium brush infested range, C.

d/ Clear light, medium, and heavy brush infested range, D.

Figure 4. Guayule Price per Pound and Pounds of Rubber Production With and Without Land Clearing.



a/ No land clearing, W.

b/ Clear light brush infested range, X.

c/ Clear light and medium brush infested range, Y.

d/ Clear light, medium, and heavy brush infested range, Z.

Figure 5. Guayule Price per Pound and Acres of Guayule Cultivated With and Without Land Clearing.

level was adjusted by water resource area to reflect changes in availability of groundwater for irrigation over time. For the years between each solution, results were obtained by linear interpolation. The final solution applied only to 2001.

No Land Clearing

Table 21 shows annual results, by five year period, for agriculture in the Winter Garden Region, with and without land clearing, using projected groundwater pumpage as an upper limit. Without brush conversion to cropland, net revenue declines from 42.9 in 1981 to 41.2 million dollars in 2001. Total acreage cultivated increased from 454,700 to 481,100 acres as dryland acreages increased and irrigated acreages declined from 161,000 to 138,100 acres.

Acres irrigated from the Carrizo Aquifer declined from 91,800 to 61,300 over the 20 year period. However, Edwards Aquifer irrigated acreage rose from 69,200 in 1981, to 73,100 in 1986, to 84,300 in 1991, stabilizing at 76,800 in 1996 and 2001.

Groundwater pumpage from the Carrizo Aquifer declined from 135,600 to 90,400 acre feet. During the same period, availability of groundwater for irrigation decreased from 188,100 to 184,100 acre feet due to forecasted growth in non-irrigation uses. Availability exceeded use for all time periods.

Edwards groundwater pumpage was 80,100 acre feet in 1981, rising to 89,200 in 1986 and 106,500 acre feet in 1991. Edwards pumpage for irrigation then dropped to 95,200 acre feet for 1996 and 2001. A comparison of acre feet pumped from the Edwards Aquifer to groundwater available for irrigation indicates pumpage for irrigation at the upper limit for 1981, 1986, and 1991. In 1996 and 2001, pumpage for irrigation was 31,500 and 44,000 acre feet less than the upper limit specified in the model. Rising costs associated with increased pumping lifts explains the reduction of actual pumpage below upper limits specified in the model for both the Carrizo and Edwards Aquifers.

Cropping patterns show irrigated cotton and grain sorghum acreages declining and dryland acreages increasing over the period of analysis. Irrigated short-season cotton declines only slightly while dryland cotton increases from 184,900 to 202,200 acres and irrigated grain sorghum declines from 84,700 to 69,800 acres. Dryland grain sorghum increases from 35,700 to 60,700 acres.

Light and Medium Brush Clearing

Combining optional conversion to cropland of light and medium brush infested range sites with projected groundwater use for irrigation gives a net revenue decline from 68 to 66.2 million dollars, or a difference of 1.8 million dollars between the 1981 and 2001 solutions. These results are reported in Table 21.

Total cultivated area was about 1.3 million acres in each solution with the brush clearing alternatives. Some 815,000 acres were added to cropland in each solution. This acreage is the difference between buffel grass establishment and land cleared for use as cropland. Dryland

Table 21. Temporal Impact of Projected Groundwater Pumpage on Winter Garden Net Revenues, Resource Use, and Cropping Patterns, With and Without Brush Conversion to Cropland, 1981-2001.

Item	Units	Without Brush Conversion to Cropland				
		1981	1986	1991	1996	2001
Revenue Summary	(000)					
Net Revenue	Dollars	42864	42599	41940	41535	41165
Resource Utilization[a]	(000)					
Dryland Cultivation	Acres	293.7	312.8	315.3	334.8	343.0
Carrizo, Irrigated	Acres	91.8	78.6	64.6	64.4	61.3
Edwards, Irrigated	Acres	69.2	73.1	84.3	76.8	76.8
Carrizo, Groundwater	Acre Feet	135.6	113.6	93.8	93.5	90.4
Edwards, Groundwater	Acre Feet	80.1	89.2	106.5	95.2	95.2
Arable Range	Acres	2128.2	2128.2	2128.2	2128.2	2128.0
Buffel Grass Estb	Acres					
Light Brush Clearing	Acres					
Medium Brush Clearing	Acres					
Cropland Change[b]	Acres					
Cropping Patterns[c]	(000)					
Short-Season Cotton	Acres	11.5	11.4	10.7	10.5	10.5
Cotton, Dryland	Acres	184.9	191.1	191.6	199.2	202.2
Peanuts, Irrigated	Acres	16.5	16.5	16.5	16.5	16.
Grain Sorghum, Irig	Acres	84.7	78.8	73.2	65.7	69.8
Grain Sorghum, Dry	Acres	35.7	45.4	50.8	62.8	60.7
Guar, Irrigated	Acres	30.3	27.0	30.6	30.6	23.4
Guar, Dryland	Acres	49.7	53.0	49.4	49.4	56.6
Bermuda Hay, Irig	Acres	6.1	6.1	6.1	6.1	6.1
Bermuda Hay, Dry	Acres	1.7	1.7	1.7	1.7	1.7
Cropped Acreage	Acres	454.7	464.5	464.2	476.0	481.1
Cow-Calf	Units	202.4	202.4	202.4	202.4	202.4

Table 21. Continued.

Item	Units	With Brush Conversion to Cropland 1981	1986	1991	1996	2001
Revenue Summary	(000)					
Net Revenue	Dollars	68058	67755	67039	66611	66228
Resource Utilization[a]	(000)					
Dryland Cultivation	Acres	1104.3	1107.3	1117.2	1113.6	1115.0
Carrizo, Irrigated	Acres	117.3	108.2	89.1	81.6	79.0
Edwards, Irrigated	Acres	74.1	79.5	89.0	99.9	101.0
Carrizo, Groundwater	Acre Feet	153.7	140.9	111.6	102.1	101.4
Edwards, Groundwater	Acre Feet	80.1	89.2	106.5	125.9	126.7
Arable Range	Acres	1250.9	1244.0	1237.5	1240.0	1237.5
Buffel Grass Estb	Acres	77.6	84.6	91.1	88.7	91.1
Light Brush Clearing	Acres	525.3	532.3	538.7	536.3	538.8
Medium Brush Clearing	Acres	367.4	367.4	367.4	367.4	367.4
Cropland Change[b]	Acres	815.1	815.1	815.0	815.0	815.1
Cropping Patterns[c]	(000)					
Short-Season Cotton	Acres	11.9	11.9	11.9	11.1	11.1
Cotton, Dryland	Acres	710.5	709.7	710.0	710.0	709.1
Peanuts, Irrigated	Acres	15.9	15.6	15.7	15.6	15.6
Grain Sorghum, Irig	Acres	111.6	107.3	98.0	101.2	98.6
Grain Sorghum, Dry	Acres	331.3	335.0	344.6	340.8	342.9
Guar, Irrigated	Acres	38.9	38.9	38.9	38.9	38.9
Guar, Dryland	Acres	41.1	41.1	41.1	41.1	41.1
Bermuda Hay, Irig	Acres	1.4	2.2	1.9	2.8	4.0
Bermuda Hay, Dry	Acres	.4	.6	.5	.8	1.1
Cropped Acreages	Acres	1295.7	1295.0	1295.3	1295.1	1295.0
Cow-Calf	Units	143.4	143.5	143.5	143.5	143.5

[a] Non-arable range is 1,155,200 acres in all solutions.
[b] Net addition to cropland is acres of range cleared less acres of buffel grass established.
[c] Acreages of the following crops were the same in all solutions: spinach, 5872; carrots, 3512; 2398; and sorghum hay, 5208. Acreages of oats for grazing are equal to peanut acreages.

cultivation increased in each solution, rising from 1,104,300 in 1981 to 1,115,000 acres in 2001. Total irrigated acreage was 191,400 acres in 1981 but declined to 178,100 in 1991 stabilizing at about this level in 1996 and 2001. Solutions for 1996 and 2001 indicated that declines in the Carrizo Aquifer were offset by increases in irrigated acreages in the Edwards Aquifer. Acreage irrigated from the Carrizo declined from 117,300 to 79,000 acres and increased for the Edwards from 74,100 to 101,000 acres.

Total acre feet pumped declined from 233,800 in 1981 to 218,100 in 1991 and rose to about 228,000 for 1996 and 2001. Declines in total groundwater pumpage over the 1981 through 1991 solutions were associated with larger declines in Carrizo groundwater pumpage relative to increases in Edwards groundwater pumpage. Groundwater pumpage from the Carrizo Aquifer declined from 153,700 in 1981 to 101,400 acre feet in 2001. When clearing of light and medium brush is an option more groundwater is pumped in every solution.

Groundwater use for irrigation from the Edwards Aquifer increased from 80,100 to 126,700 acre feet from 1981 to 2001. At the same time availability of groundwater for irrigation increased from 80,100 acre feet to 139,194 acre feet per year. With land clearing, groundwater pumpage is greater than pumpage in the corresponding 1996 and 2001 solutions without land clearing. Even with land clearing, groundwater availability in the Edwards Aquifer exceeded solution requirements by 800 and 12,500 acre feet in 1996 and 2001, respectively.

Cropping patterns and animal units were very stable approximating 1981 levels over the 20 year period. Grain sorghum and bermuda grass hay were the only exceptions. Irrigated bermuda grass hay acreage increased from 1,400 to 4,000 acres.

Irrigated grain sorghum declined from 111,600 to 98,600 acres, while dryland grain sorghum increased from 331,300 to 342,900 acres. The trend was interrupted in the 1991 solution when irrigated grain sorghum dropped to 98,000 acres and dryland grain sorghum reached a peak of 344,600 acres.

Restricted Groundwater Use

Solutions to the Base using restricted groundwater pumpage for irrigation as a limitation for 1981, 1986, 1991, 1996, and 2001 are reported in Table 22. Comparison with solutions for 1981 through 2001 with and without brush conversion to cropland using projected groundwater pumpage shows the impact of groundwater conservation.

No Land Clearing

In the absence of land clearing options net revenue declined from 42.5 to 40.9 million dollars. This drop of 1.7 million dollars is the same as the temporal decline estimated for projected groundwater use without land clearing (Table 21). In a comparison of solutions with restricted and projected groundwater pumpage, restricted groundwater limitations on pumping are always associated with lower net revenues. Net revenues for restricted groundwater pumpage without land clearing were reduced below the corresponding projected groundwater use solutions by the

Table 22. Temporal Impact of Restricted Groundwater Pumpage on Winter Garden Net Revenues, Resource Use, and Cropping Patterns, With and Without Brush Conversion to Cropland, 1981-2001.

	Units	Without Brush Conversion to Cropland				
		1981	1986	1991	1996	2001
Revenue Summary	(000)					
Net Revenue	Dollars	42516	42315	41514	41290	40860
Net Revenue Change[a]	Dollars	348	284	426	245	305
Resource Utilization[b]	(000)					
Dryland Cultivation	Acres	315.8	324.8	382.5	382.8	382.8
Carrizo, Irrigated	Acres	96.2	93.8	70.8	72.3	74.0
Edwards, Irrigated	Acres	55.8	54.7	53.4	51.7	50.0
Carrizo, Groundwater	Acre Feet	141.8	138.4	106.5	108.5	111.2
Edwards, Groundwater	Acre Feet	59.2	57.5	55.7	53.2	50.7
Range, Arable	Acres	2128.2	2128.2	2128.2	2128.2	2128.2
Buffel Grass Estb	Acres					
Light Brush Clearing	Acres					
Medium Brush Clearing	Acres					
Cropland Increase[c]	Acres					
Cropping Patterns[d]	(000)					
Short-Season Cotton	Acres	12.1	11.9	11.4	11.4	11.4
Cotton, Dryland	Acres	192.5	196.1	217.2	217.3	217.3
Peanuts, Irrigated	Acres	16.5	16.5	16.5	16.5	16.5
Grain Sorghum, Irig	Acres	75.7	72.2	50.1	49.9	53.8
Grain Sorghum, Dry	Acres	49.7	55.3	90.1	90.3	86.4
Guar, Irrigated	Acres	29.8	30.0	28.2	28.2	24.3
Guar, Dryland	Acres	50.2	50.0	51.8	51.8	55.7
Bermuda Hay, Irig	Acres	6.1	6.1	6.1	6.1	6.1
Bermuda Hay, Dry	Acres	1.7	1.7	1.7	1.7	1.7
Cropped Acreage	Acres	467.8	473.3	506.7	506.8	506.8
Cow-Calf	Units	202.4	202.4	202.4	202.4	202.4

Table 22. Continued.

	Units	With Brush Conversion to Cropland 1981	1986	1991	1996	2001
Revenue Summary	(000)					
Net Revenue	Dollars	67752	67536	66617	66363	65922
Net Revenue Change[a]	Dollars	306	219	422	248	306
Resource Utilization[b]	(000)					
Dryland Cultivation	Acres	1119.4	1122.1	1128.3	1142.5	1148.3
Carrizo, Irrigated	Acres	116.1	114.7	109.2	100.9	100.3
Edwards, Irrigated	Acres	59.9	58.7	57.9	56.5	54.9
Carrizo, Groundwater	Acre Feet	148.6	146.7	139.6	128.7	127.9
Edwards, Groundwater	Acre Feet	59.2	57.5	55.7	53.2	50.7
Range, Arable	Acres	1238.4	1237.5	1237.5	1237.5	1237.5
Buffel Grass Estb	Acres	90.2	91.0	91.1	91.1	91.1
Light Brush Clearing	Acres	537.9	538.7	538.7	538.8	538.8
Medium Brush Clearing	Acres	367.4	367.4	367.4	367.4	367.4
Cropland Increase[c]	Acres	815.1	815.1	815.1	815.1	815.1
Cropping Patterns[d]	(000)					
Short-Season Cotton	Acres	12.5	11.1	10.3	9.6	9.6
Cotton, Dryland	Acres	710.8	712.1	713.0	716.6	718.9
Peanuts, Irrigated	Acres	15.8	15.8	15.7	15.6	15.6
Grain Sorghum, Irig	Acres	97.0	95.6	90.2	81.4	79.2
Grain Sorghum, Dry	Acres	346.5	347.8	353.2	363.8	367.4
Guar, Irrigated	Acres	38.9	38.9	38.9	38.9	38.9
Guar, Dryland	Acres	41.1	41.1	41.1	41.1	41.1
Bermuda Hay, Irig	Acres	.1	.2	.2	.2	.2
Bermuda Hay, Dry	Acres					
Cropped Acreage	Acres	1295.5	1295.5	1295.4	1299.9	1303.5
Cow-Calf	Units	143.5	143.4	143.5	143.5	143.5

[a] Reduction in net revenue associated with use of restricted as opposed to projected groundwater pumpage rates, Tables 12 and 13, respectively.

[b] Non-arable range is 1,155,200 in all solutions.

[c] Net addition to cropland is acres of range cleared less acres of buffel grass established.

[d] Acreages of the following crops were the same in all solutions: spinach, 5872; carrots, 3512; carrots, 2398; and sorghum hay, 5208. Acreages of oats for grazing are identical to peanut acreage.

following dollar amounts: 348,000 in 1981; 284,000 in 1986; 426,000 in 1991; 245,000 in 1996; and 305,000 in 2001.

Total land under cultivation increased from 468,000 to 507,000 acres in 1991, and did not change for the remaining solutions. Dryland cultivation increases from 315,800 in 1981 to 382,500 in 1991 and remains about the same through 2001. Irrigated acreage falls from 152,000 in 1981 to 124,200 in 1991 and remains steady for the 1996 and 2001 solutions. Acres irrigated from the Edwards Aquifer decline from 55,800 to 50,000 as non-irrigation uses of limited groundwater increase (Appendix Table 40). Irrigated acres from the Carrizo Aquifer fall from 96,200 in 1981 to 71,000 in 1991 and then rise to 74,000 in 2001 reflecting Carrizo replacement of irrigated acreages lost in the Edwards Aquifer area (Table 22). Total cultivated acreage was greater when groundwater was restricted than when projected groundwater limitations were in effect.

Groundwater pumpage declined 39,000 acre feet from 201,000 to 162,000 acre feet between the 1981 and 2001 solutions. This compares to a 30,000 acre feet change for the projected groundwater limitation without brush conversion to cropland (Columns 3 through 7, Table 21). Net reductions in acre feet pumped compared to the projected groundwater pumping scenario were realized in each year; 14,700 in 1981; 6,900 in 1986; 38,100 in 1991; 27,000 in 1996; and 23,700 in 2001. Edwards groundwater pumpage fell from 59,200 to 50,700 acre feet reflecting a shift of groundwater to other than irrigation uses. In each period, Edwards groundwater pumpage for irrigation attained the maximum permitted by model specifications.

Groundwater pumpage in the Carrizo Aquifer under the restricted pumpage rates exceeded pumpage estimated with the projected rate scenario in every solution (Columns 3 through 7 of Tables 22 and 21, respectively) i.e., increases of 6,000, 25,000, 13,000, 15,000, and 21,000 acre feet for the 1981, 1986, 1991, 1996, and 2001 solutions. For the restricted pumpage scenarios, Carrizo groundwater pumpage fell from 141,800 to 106,500 acre feet in 1991 but rose to 111,200 acre feet in 2001.

Comparison of the restricted pumpage rate with the projected groundwater pumpage scenario solutions, without land clearing, shows greater specialization in dryland cotton and dryland grain sorghum. Acreages of short-season irrigated cotton declined slightly and dryland cotton acreages rose stabilizing at 11,400 and 217,200 acres, respectively, in 1991, 1996, and 2001. Irrigated grain sorghum acreage fell from 75,700 in 1981 to about 50,000 acres in 1991 and 1996. In 2001, 54,000 acres of irrigated grain sorghum were in solution. Dryland grain sorghum rose from about 50,000 acres in 1981 to 90,000 in 1991 and 1996. The final grain sorghum acreage was about 86,400 in 2001. Irrigated guar declined slightly relative to dryland guar.

Light and Medium Brush Clearing

Introduction of options to clear light and medium brush infested range for cropland, under restricted groundwater pumpage limitations (Columns 8 through 14 in Table 22), reduces net revenue from 67.8 million dollars in 1981 to 65.9 million dollars in 2001. Compared to results using projected groundwater limitations (Columns 8 through 14 in Table 21), net revenue falls 306,000 dollars in 1981. The decline in net revenue narrows to 219,000 dollars in 1986 and increases to 422,000 dollars in 1991. The net revenue difference falls to 248,000 in 1996 and increases to 306,000 for the 2001 solution. Reductions in net revenue were significantly less for the 1981 and 1986 solutions under restricted groundwater use scenarios with land clearing than the reductions in net revenue for restricted groundwater pumpage without land clearing. Reductions in net revenue with restricted groundwater pumping with and without conversion of light and medium brush to cropland were about the same for 1991, 1996, and 2001.

Some 1.3 million acres were under cultivation and 815,000 acres were added to cropland for each solution. The level of dryland cultivation in the solution rose from 1.119 to 1.148 million acres in a comparison of the 1981 and 2001 solutions. About 15,000 and 33,000 more acres were under dryland cultivation in 1981 and 2001 under brush conversion to cropland with restricted groundwater pumpage than in the corresponding projected groundwater scenarios. Over the 20 year period, irrigated acreages declined by 20,100 acres to 155,900 acres. This compares to a 11,400 acre decline for the same period under projected groundwater assumptions. Irrigated acreages in the Carrizo Aquifer declined 15,800 from 116,100 in 1981 to 100,300 in 2001. With land clearing and projected groundwater limitations, Carrizo irrigated acreage fell 38,300 over the same period. Irrigated acreages in the Edwards Aquifer area fell 5,000 acres to 54,900 acres over the period of analysis. This compares to a 26,900 rise in irrigated acreage associated with unrestricted development of the Edwards Aquifer as an irrigation source.

Total groundwater pumpage declined in each solution from a high of 207,800 acre feet in 1981 to a low of 186,000 acre feet in 2001. Pumpage from the Carrizo decreased from 148,600 to 127,900 acre feet yet, Carrizo Aquifer pumpage under restricted pumpage limitations with land clearing exceeded that of corresponding scenarios with projected groundwater pumpage and land clearing for the 1986, 1991, 1996, and 2001 solutions. With projected groundwater use rates and land clearing, the corresponding decline for the Carrizo Aquifer was 52,300 acre feet, 153,700 to 101,400.

Groundwater pumpage in the Edwards Aquifer, limited by pumpage restrictions and losing water to non-irrigation uses declined from 59,200 acre feet in 1981 to 50,700 acre feet in 2001, remaining at the same level as the restricted pumpage solutions without land clearing.

Additional cropland is allocated to dryland cotton and dryland grain sorghum. Overtime, dryland cultivation increases relative to irrigated cultivation. Dryland cotton acreage increased from 710,800 to 718,900 being greater for each solution. Dryland grain sorghum acreage increases from 346,500 in 1981 to 367,400 in 2001. Irrigated grain sorghum falls from 97,000 to 79,200 acres. In 1981, short-season irrigated cotton acreage with land clearing and restricted groundwater pumping rates was at its highest level, 12,500 acres. It reached its lowest level in the temporal analysis in the same scenario, 9,500 acres in 2001.

The restricted groundwater pumping scenario solutions with land clearing are relatively more specialized in dryland cultivation, reporting larger acreages of dryland cotton and dryland grain sorghum. The range of decline in irrigated acreages was smaller for projected groundwater pumpage rate with brush conversion than for restricted groundwater pumpage with brush conversion. Irrigated and dryland guar acreages were the same in both sets of solutions. Under restricted groundwater pumpage with land clearing, bermuda grass hay production was negligible, but in the projected groundwater pumpage scenario with land clearing, bermuda grass hay acreage increased from 1,800 acres in 1981 to 5,100 in 2001.

Groundwater Resource Summary, 1981-2001

The impact on groundwater resources of restricted groundwater limitations versus projected groundwater use levels with and without range conversion is shown in total groundwater pumpage for irrigation, initial and final pumping lifts, and 1981 and 2001 lift intervals of each water resource area. Changes in lift intervals relate higher lifts to reduced groundwater pumpage as higher lifts increase pumping costs.

Beginning and Ending Lifts

Beginning and ending lifts for each water resource area are reported in Table 23. Pumping lifts are measured as depth to water plus 50 feet drawdown. Non-irrigation groundwater usage is factored into the lift calculations.

Beginning or initial lift refers to the estimated 1981 lift for each resource area and final lift is calculated at the end of the 2001 irrigation season. Ending lifts are reported for restricted and projected groundwater pumpage with and without conversion of range to cropland.

Restricted groundwater limitations reduce the variation in pumping lifts among the Carrizo Aquifer water resource areas. Average pumping lifts for the Carrizo water resource areas were greater under restricted than projected groundwater limitations. However, the standard deviations, a measure of dispersion, for averages of the final lifts under restricted groundwater pumpage were about half of the standard deviations of the average pumping lifts for projected groundwater pumpage.

Average initial lift for the Carrizo Aquifer was 264 feet, increasing in the restricted pumpage limitation to 328 feet and 335 feet without and with range conversion, respectively. Pumping lifts for the Carrizo under projected groundwater pumping limitations increased to 320 feet without range conversion and 326 feet with range conversion.

Lift changes for individual water resource areas are also shown in Table 23. For example, area 5 had an initial representative lift of 200 feet. Lifts increased to 305 feet under restricted groundwater pumping scenarios and to 391 feet under projected groundwater pumping scenarios. In area 15, the Edwards Aquifer initial lift was 169 feet and remained constant under restricted groundwater scenarios which assumed groundwater discharges balanced aquifer recharge. Under the projected rate of aquifer development with land clearing, lifts in area 15 increased to 245 feet. If lifts reached 400 feet, resource areas were omitted from further consideration as a source of groundwater for irrigation. Under land clearing alternatives for restricted and projected groundwater pumpage, water resource area 9 was removed from consideration for 1996 and 2001.

Total Groundwater Pumpage for Irrigation

Aggregate groundwater pumpage and pumpage for each scenario by

Table 23. Initial and Final Pumping Lifts[a] Associated with all Groundwater Pumpage for the 20 Year Period, 1981-2001.

Water Resource Areas	Initial Lift (1981)	Final Lifts in Feet (2001): Restricted Groundwater		Projected Groundwater	
		Conversion of Range to Cropland			
		No	Yes	No	Yes
1. Batesville	269	332	345	349	382
2. La Pryor	340	352	373	351	354
3. West Pearsall	195	302	302	225	225
4. Pearsall	305	322	349	323	349
5. Moore	200	305	305	399	391
6. Los Angeles	139	270	270	145	145
7. Asherton	282	320	322	285	285
8. Carrizo Springs	244	318	321	345	330
9. East Crystal	394	397	402	397	402
10. West Crystal	338	361	385	351	381
11. Zavala-Dimmit	276	349	349	349	349
12. Frio	223	318	318	320	320
13. LaSalle	223	318	318	320	320
15. Edwards[b]	169	169	169	239	245
Average Carrizo Lifts	264	328	335	320	326
Standard Deviation	69.9	31.4	36.6	69.1	72.3

[a] Includes a 50 foot drawdown.
[b] Uvalde-Edwards lift remains constant over the restricted groundwater pumpage scenarios to represent balancing of ground water pumpage with average recharge.

aquifer are reported in Table 24. Total groundwater pumpage was lowest for restricted groundwater development without land clearing, 3.8 million acre feet. The highest total groundwater pumpage, 4.8 million acre feet, was realized for projected groundwater limitations with optional conversion of range to cropland. Restricted groundwater pumpage with land clearing and projected groundwater pumpage without land clearing were 4.1 and 4.2 million acre feet, respectively.

Although restricted groundwater pumpage scenarios show reduced total groundwater pumpage for the region, they lead to greater collective groundwater withdrawals from the Carrizo Aquifer. Carrizo Aquifer restricted groundwater pumpage totals with and without range clearing were greater than those for respective solutions with projected groundwater pumpage limitations. Carrizo groundwater pumpage under restricted limitations with and without range conversion exceeded corresponding solutions with projected limitations by 302,517 and 313,698 acre feet. The increase in pumpage for the Carrizo is associated with the restriction of total pumpage in the Edwards to 1,178,591 acre feet under restricted pumpage scenarios. Under projected groundwater limitations with range clearing, 2,134,817 acre feet were pumped. Total Carrizo pumpage exceeded total Edwards pumpage by 508,285 acre feet for projected groundwater pumping

Table 24. Total Groundwater Pumpage in Acre Feet for Each Irrigation Scenario, Winter Garden, 1981-2001.

Aquifer	Units	Restricted Pumpage		Projected Pumpage	
		Conversion of Range to Cropland			
		no	yes	no	yes
Carrizo	Acre Feet	2,587,158	2,945,619	2,273,460	2,643,102
Edwards	Acre Feet	1,178,591	1,178,591	1,949,785	2,134,817
Total	Acre Feet	3,765,749	4,124,210	4,223,245	4,777,919

limitations with land clearing. For restricted groundwater pumping limitations with land clearing, the Carrizo pumpage exceeded Edwards Aquifer total pumpage by 1,767,028 acre feet.

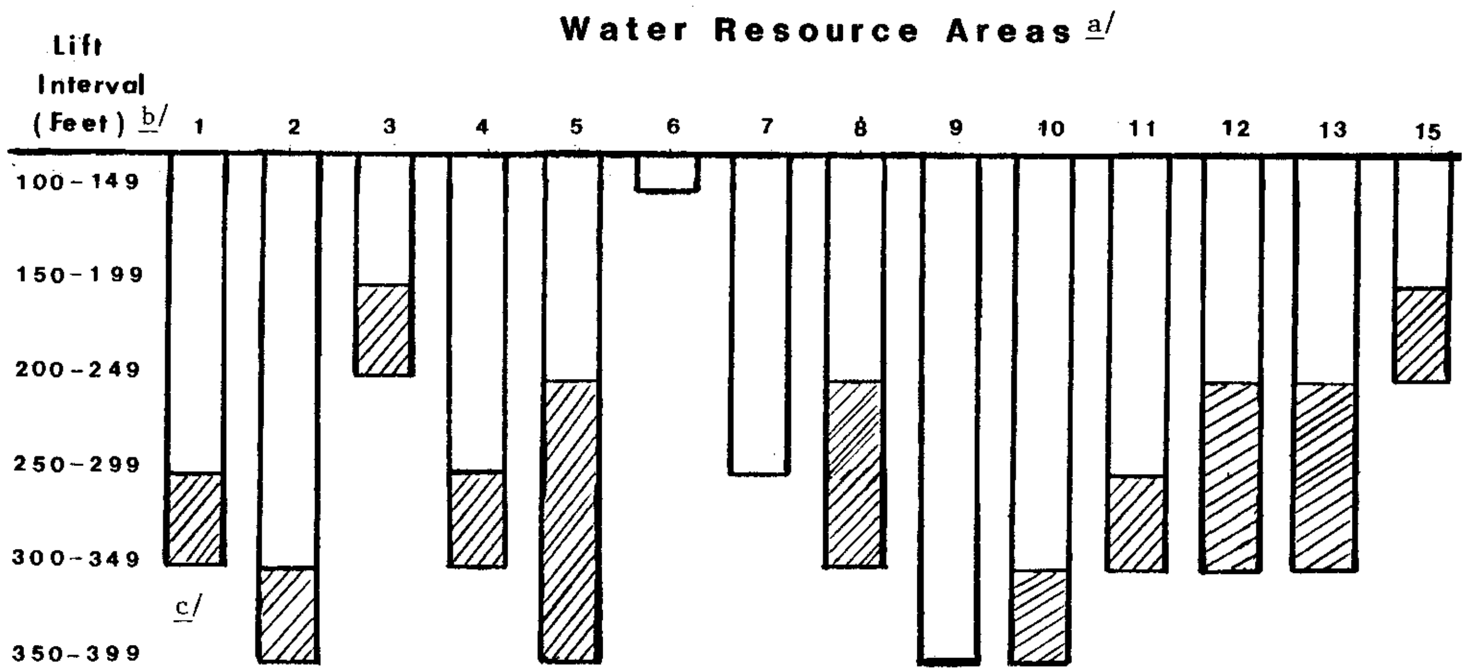
Irrigation was assumed to cease in individual water resource areas when non-irrigation uses equaled projected pumping or restricted pumping quantities of water assigned to the area. Under projected groundwater pumpage limitations, all available groundwater in area 7 was assigned to non-irrigation uses in 1996 and 2001.

Lift Intervals, 1981 and 2001

In Figures 6 and 7, beginning and ending lift intervals for projected and restricted groundwater pumpage are represented by bar graphs. The top of the figure represents the land surface. The open area above the shaded area represents the 1981 lift and the shaded area represents the shift to higher lift intervals associated with groundwater pumping over time. For example, in Figure 6, water resource area 5 was assigned to the 200-249 foot lift interval in 1981. Its final lift interval in 2001 was 350-299 feet.

Figure 6 depicts beginning and ending pumping lifts under projected groundwater pumpage scenarios. For projected groundwater pumpage, with and without land clearing, ending lift intervals were identical except in water resource areas 1 and 9. Area 1 was in lift interval 5 in the absence of range conversion and in lift interval 6 with range conversion. For the projected groundwater pumping scenario including range conversion, the final lift in area 9 was over 400 feet.

In Figure 7, ending lift intervals for restricted groundwater pumpage with and without land clearing were the same except for water resource area 9. In water resource area 9, pumping lift was greater than 400 feet in 1996 and 2001 when range conversion was included as an option. In a comparison of Figures 6 and 7 note the uniformity of final lifts associated with restricted groundwater pumpage.

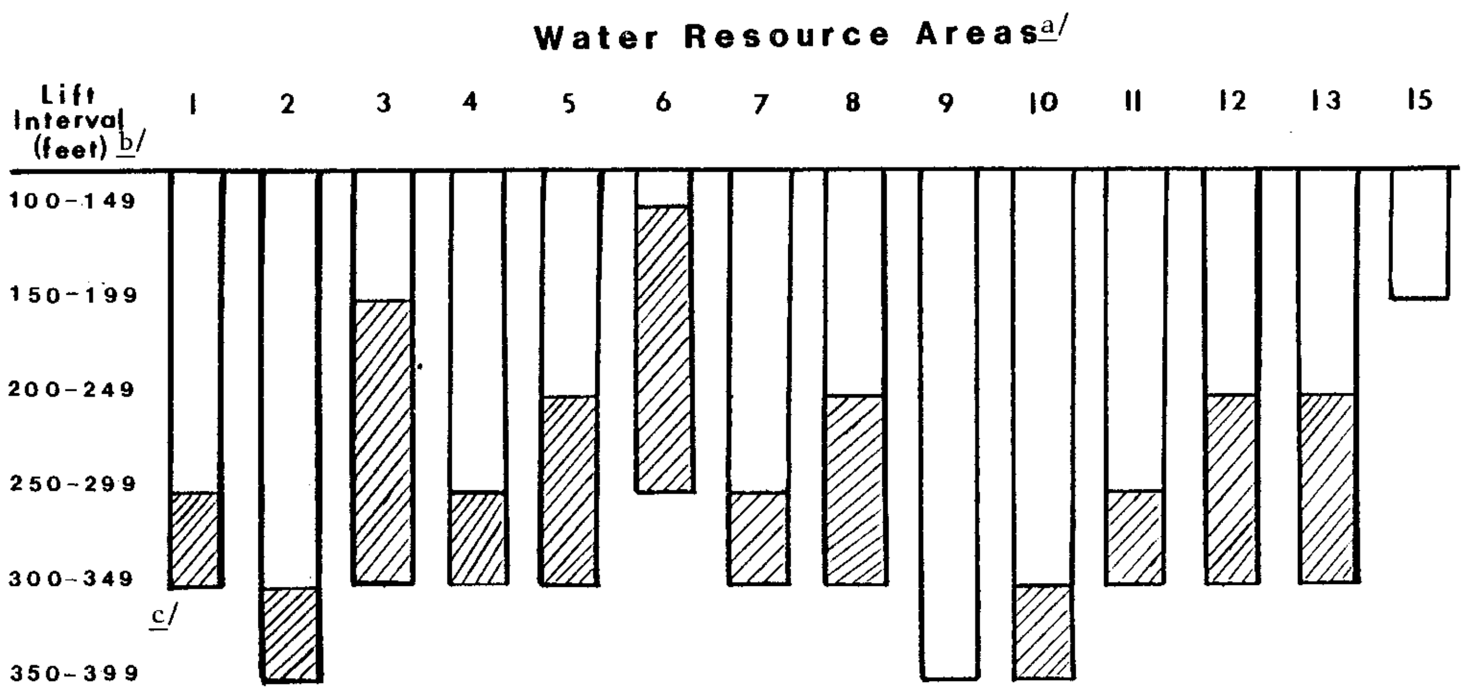


a/ See Table 23 for descriptions of water resource areas.

b/ Ending lift intervals with and without land clearing were the same in all water resource areas except areas 1 and 9. With land clearing, the final lift interval for area 1 was 350-399 feet and the final lift in area 9 exceeded 400 feet.

c/ Shaded area represents changing lift intervals.

Figure 6. Depiction of Initial (1981) and Final (2001) Pumping Lifts with Projected Groundwater Pumpage Rates.



[a] See Table 23 for descriptions of water resource areas.

[b] Ending lift intervals are the same with and without land clearing except in area 9. With land clearing, final lifts in area 9 exceed 400 feet.

[c] Shaded area represents changing lift intervals.

Figure 7. Depiction of Initial (1981) and Final (2001) Pumping Lifts with Recommended Ground-water Pumpage Rates.

Net Revenue Summary, 1981-2001

Net returns were used to calculate present values of each temporal scenario. Some adjustments were made in net revenue before the present values were computed.

Net Revenue Adjustments

Net returns were corrected for declines in the levels of land improvement activities and then transformed to an annual basis. Adjusted net returns of the four temporal scenarios are reported in Table 25. When acreages of establishment of bermuda grass hay and buffel grass or brush converted to cropland fell below levels recorded in the previous solution, net revenue was adjusted downward by the cost per acre of these activities (Appendix Tables 32 and 33) times the amount of the decline. For projected groundwater pumpage including land clearing (light and medium brush options only), 1986 net revenue was reduced to account for reductions in bermuda grass hay acreage. Similar reductions in 1996 net revenue were made for buffel grass establishment and conversion of light brush infested range to cropland. Net revenue adjustments were not required for restricted groundwater pumping scenarios.

Table 25. Adjusted Net Revenue for Solution Years Under Projected and Restricted Groundwater Use, Winter Garden, 1981-2001.

Solution Year	Restricted Pumpage		Projected Pumpage	
	Conversion of Range to Cropland			
	no	yes	no	yes
1981	$42,516,224	$67,751,872	$42,864,192	$68,057,728
1986	42,314,512	67,535,552	42,598,880	67,750,458[a]
1991	41,514,480	66,617,168	41,940,416	67,039,136
1996	41,289,936	66,363,152	41,535,232	66,597,470[a]
2001	40,859,968	65,921,696	41,164,960	66,227,792

[a] 1986 and 1996 net revenue adjusted for annual establishment and land clearing charges.

An examination of Table 25 indicates that net returns of land conversion scenarios with restricted and projected groundwater pumping levels decline at about the same annual rate, 99,900 and 99,200 dollars per year, respectively. Without brush conversion to cropland, the trend of annual decline was 89,200 and 91,900 dollars per year for restricted and projected groundwater pumpage. The more rapid decline was associated with a continuation of projected (forecast) groundwater pumpage. The rate of decline in net revenue was slowest for restricted groundwater pumping limitations without land clearing.

Before calculating the present values of the four temporal scenarios, a series of annual net revenues was developed. Each solution except that for 2001, covered a 5 year period. The solution for 2001 represents only the final year of the study period. Net revenue for intervening years without a solution was estimated by linear interpolation.

Present Values of Net Returns

The present value of net returns was estimated in 1981 dollars using discount rates of 8, 12, and 16 percent (Table 26). At an 8 percent discount rate, projected groundwater pumpage with conversion of light and medium brush infested range to cropland had the highest present value, 729.2 million dollars. At the same discount rate, restricted groundwater pumping levels with range conversion omitted returned the lowest present value, 453.8 million dollars. The present value of projected groundwater pumping without land clearing exceeds that of restricted pumpage without land clearing by 3.5 million dollars. With introduction of brush conversion to cropland, the difference in present values narrowed. The present value of the projected groundwater pumpage scenario exceeded that of the restricted groundwater pumpage level by 3.2 million dollars.

Table 26. Present Values of Winter Garden Regional Net Returns, 1981-2001, in 1981 Dollars.

		Groundwater Usage			
		Restricted		Projected	
Discount		Conversion of Range to Cropland			
Rate	Dollars	no	yes	no	yes
.08	(000,000)	$453.8	$726.0	$457.3	$729.2
.12	(000,000)	356.1	569.3	358.9	571.8
.16	(000,000)	291.8	466.4	294.2	468.4

At higher discount rates the ranking of present values remains the same, projected groundwater pumpage scenarios exceeding restricted groundwater pumpage scenarios. However, the difference between present values of different scenarios at the same discount rate diminished for higher discount rates. Selecting a discount rate of 16 percent, the present value of projected groundwater pumpage solutions with and without brush conversion to cropland exceeded corresponding restricted groundwater pumpage solutions with and without brush conversion to cropland by 2.4 and

2.0 million dollars, respectively.

The relationship between present value of the stream of net returns and total groundwater pumpage indicates that relatively small reductions in present value of net returns were associated with significant savings in groundwater. Restricted and projected groundwater pumpage without land clearing were compared, assuming an 8 percent discount rate. A 3.5 million dollar reduction in present value of net returns was associated with a savings of 457,496 acre feet of groundwater (Table 24) over the period 1981 through 2001. This savings is more than twice the estimated current annual rate of groundwater pumpage for irrigation, Column 3, Table 15.

When brush conversion to cropland is introduced into the groundwater scenarios, present value declined 3.2 million dollars when groundwater was restricted to restricted levels. However, the reduction was related to a 653,709 aggregate reduction in groundwater pumping for irrigation over the period of analysis.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Irrigation is important to the Winter Garden. Some 44.7 percent of all cropland is irrigated (Jack Stevens, personal communication). In 1979, 86.2 percent of total acre feet of irrigation water applied was from groundwater sources (Texas Department of Water Resources, 1981). About 92.4 percent of all groundwater pumped in 1979 was used for irrigation (Texas Department of Water Resources, 1981; William Moltz, personal communication). The Winter Garden's chief sources of groundwater are the Edwards and Carrizo Aquifers. In 1979, 76,000 and 217,000 acre feet of groundwater were pumped from the Edwards and the Carrizo Aquifers, respectively (Texas Department of Water Resources, 1981).

Insufficient recharge of aquifers relative to groundwater use, increasing pumping lifts associated with groundwater mining, and the limited nature of the Carrizo Aquifer compared to irrigable acres have generated interest in strategies to more efficiently use water for irrigation and maintain agricultural sector revenue. Introduction of new crops, technology, and groundwater management represent some of the options for agriculture in the Winter Garden. But, a method is needed to evaluate the economic implications of these alternatives.

The objectives of this study were to develop a regional linear programming model of agriculture which could be applied in a static and temporal mode to evaluate alternative strategies available to agriculture. Specifically, the model was used to estimate the economic impact of new technology (row damming), new crops (short-season cotton, guar, and guayule), brush conversion to cropland, and restricted (forced conservation) groundwater pumpage rates.

Methodology

The analytical tool used in this analysis was a linear programming model of agriculture in the Texas Winter Garden. The linear programming model included specification of input levels for major crops, crop and range site yields, irrigation activities, land conversion activities, transfers, and buy and sell activities. The model was formulated to maximize returns to land and management. Production activities consisted of major crops on each soil type, range sites by brush density, and a cow-calf enterprise to utilize pasture and rangeland. Acreages of arable soil types, arable and non-arable range by brush density, cropland inventory, and groundwater availability and arable soils by water resource area were constraints to the model. Estimates of current and restricted groundwater pumpage were adjusted for non-irrigation uses giving residual groundwater available for irrigation.

Water resource areas were identified by acres of each soil type, projected groundwater pumpage, and restricted groundwater pumpage. Some 14 individual water resource areas were selected, 13 in the Carrizo and one for the Edwards Aquifer in Uvalde County. Estimates of acreages of soil types of each resource area were developed by overlaying soil conservation soils maps with maps of the water resource areas.

In the Carrizo Aquifer, restricted groundwater pumpage is a rate of extraction which will not dewater the aquifer's recharge zones, nor lead to more than a 400 foot lift throughout the aquifer by the year 2020. Edwards Aquifer restricted groundwater pumpage is set at Uvalde County's average recharge level. Projected groundwater pumpage represents current and expected rates of pumpage as modified by forecasted changes in aquifer development.

Each water resource area is distinguished by variation in depth to water and groundwater availability. For temporal analysis, change in pumping lift in each resource area is a function of groundwater pumped in the previous period and the average expected decline per acre foot pumped. Irrigation costs were established for representative wells for each water resource area. Variations in pumping lift, details of well completion, and motor and pump complements were the major factors influencing variations in irrigation costs.

Input requirements were obtained from crop and livestock enterprise budgets for the Winter Garden Area. Crop and livestock enterprise production budgets were adjusted for variations in the individual soils. Water and fertilizer requirements vary by crop across individual soils. Further, harvesting costs were established as a function of yield. Specific buying activities include purchase of seed, fetilizer, insecticides, herbicides, fuel, custom appplications, and custom harvesting. Output prices, except for contract prices and guayule, were normalized regional farm prices for the previous five years.

The static linear programming model was used to compare impact on resource use, net returns, and cropping patterns from introduction of guayule, guar, short-season irrigated cotton, and brush conversion to cropland with current and projected groundwater pumping limitations. The method of analysis relied on comparison with a base solution. The base solution utilized 1981 projected groundwater pumpage and included crops currently grown in the Winter Garden. Other static scenarios contrasted with the base results were solutions with and without fixed costs, changes in guayule prices, row damming, and dryland farming only.

A temporal analysis of resource use, net revenue, and cropping patterns was pursued in four scenarios; restricted and projected groundwater pumpage levels each with and without optional conversion of light and medium brush infested range sites to cropland. Each scenario was continued through the period 1981-2001 by a series of solutions at 5 year intervals. Irrigation system costs and groundwater availability for irrigation were updated in each time period to reflect changes in pumping lifts, groundwater availability, and non-irrigation groundwater uses. Total groundwater pumpage and present value for the four scenarios were reported and compared.

Static Results

The following results were summarized from individual solutions using 1981 projected groundwater pumping quantities, unless noted otherwise. Net returns represent returns above all variable costs and fixed costs except well development costs.

New Crops

New crops introduced were guar, short-season cotton, and guayule, Table 15. Introduction of guar and short-season irrigated cotton was associated with increased groundwater pumpage, increased irrigated acreages (even though these crops use less irrigation water per acre), and increased net revenue. Carrizo groundwater pumpage rose from 110,500 acre feet to 135,600 acre feet while Edwards Aquifer groundwater pumpage remained constant at its maximum level, 80,100 acre feet per year. Total irrigated acreages rose from 126,000 to 161,000 acres; increasing to 69,200 and 91,800 acres in the Edwards and Carrizo Aquifers, respectively. Net returns increased by 3.2 million dollars or 8 percent.

Introduction of guayule, given a guayule price of 30 cents per pound, reduced total groundwater pumpage and irrigated acreages, but only in the Carrizo Aquifer. Carrizo Aquifer groundwater pumpage fell from 135,600 to 114,800 acre feet and Carrizo Aquifer irrigated acreages acreages fell from 91,800 to 78,000 acres. Net returns increased by 4.2 million dollars or 9.4 percent. Some 178,800 acres of guayule entered the solution.

At guayule prices per pound of 25 and 35 cents, without land clearing, net returns were 44.3 and 50.7 million dollars. With guayule at 25 cents per pound, 143,900 acres of guayule were cultivated compared to 324,200 acres at 35 cents per pound. Groundwater pumpage remained constant in the Edwards Aquifer, but was reduced in the Carrizo Aquifer as guayule price rose. Some 123,600 acre feet of groundwater were pumped from the Carrizo when the guayule price per pound was 25 cents. At 35 cents per pound, Carrizo groundwater pumpage declined to 96,600 acre feet per year. Carrizo irrigated acreages dropped with each price increase.

Range Conversion to Cropland

Conversion of range to cropland was associated with increases in irrigated acreages, groundwater pumpage, and net returns, Table 15. Converting light; light and medium; and light, medium, and heavy brush infested range to cropland increased net returns above the base by 17, 25.2, and 26.4 million dollars, respectively. Irrigated acreages rose from 161,000 with and without light brush clearing to 191,000 with clearing of light and medium and light, medium, and heavy brush. For the three land clearing scenarios, respective additions to cropland were 478,800, 815,100, and 874,500 acres.

For the Base and clearing of light brush, Carrizo groundwater pumpage was about 135,000 acre feet, but jumped to 154,000 acre feet for clearing light and medium and light, medium, and heavy brush. Groundwater pumpage remained steady at 80,100 acre feet in the Edwards Aquifer.

Row Damming

Row damming increased dryland grain sorghum and dryland cotton yields, Table 19. By making dryland cultivation of these crops more attractive, row damming reduces groundwater pumpage more than the introduction of guayule while substantially increasing net returns. Increases in net revenue attributable to row damming were estimated to be 7 million without land clearing, 18.6 million with light brush clearing, 30.3 million with light and medium brush clearing, and 32.9 million dollars for light, medium, and heavy brush clearing. Row damming was associated with conversion of brush infested range to cropland in about the same amounts as introduction of guayule with restricted and projected groundwater pumpage, 1.1, 1.8, and 2.1 million acres.

The base solution without land clearing is representative of ground water pumpage reductions achieved through row damming (only with all land clearing options did the Edwards Aquifer reach its 80,100 acre feet limit). With row damming, aggregate groundwater pumpage fell from 215,700 acre feet to 150,100 acre feet. For introduction of guayule, aggregate groundwater pumping only declined to 194,900 acre feet. With row damming, Edwards groundwater pumpage fell to 68,200 acre feet from 80,100 acre feet. At the same time, Carrizo Aquifer pumpage declined to 81,900 acre feet from 135,600 acre feet.

Fixed Cost Effect

When well development costs were included as a cost item, Table 15, net returns fell 3.5 million dollars to 39.4 million dollars. The decline in net revenue was associated with a sharp drop in Carrizo Aquifer groundwater pumpage, 135,600 to 48,800 acre feet. Edwards groundwater pumpage was not affected. When fixed costs of machinery, irrigation, livestock, and well development are omitted, net returns rise to 89.6 million dollars and the Carrizo Aquifer reaches its maximum projected pumpage limit, 188,100 acre feet.

Groundwater Pumping Restrictions

Restricted groundwater pumpage limitations were suggested by the Texas Department of Water Resources; a) to balance discharges from the Edwards Aquifer with recharge and b) to manage Carrizo Aquifer groundwater pumpage so that pumping lift would not exceed 400 feet by 2020. Restricted groundwater pumpage restricts pumpage from the Edwards Aquifer but increases total pumpage in the Carrizo Aquifer, Table 17.

In a comparison of projected and restricted groundwater pumpage without land clearing, net returns declined 400,000 dollars to 42.5 million dollars. The difference in net returns was not as great as expected in view of declines in aggregate pumpage and irrigated acreages. Total irrigated acreages declined from 161,000 to 152,000 acres and aggregate groundwater pumpage fell from 215,700 acre feet to 201,000 acre feet. Edwards Aquifer groundwater pumpage for irrigation was restricted to 59,200 acre feet per year, a decline from 80,100 acre feet. Maintenance of net returns was supported by increases in Carrizo Aquifer groundwater pumpage; 135,600 acre feet to 141,800 acre feet per year; and increases in dryland cultivation, 293,700 acres to 315,800 acres.

Irrigation Impact

Without irrigation, Table 18, net returns fell from a base of 42.9 to 28.6 million dollars. Dryland acreages increased to 510,000 from 293,700.

Conversion of light brush infested range to cropland increased net returns to 46.1 million dollars and cultivated acres to 951,400 acres. With and without clearing light brush, guayule increased net returns and cultivated acreages. Guayule acreages were 170,000 and 361,000 acres with and without land clearing.

Temporal Results

Temporal analysis, 1981 through 2001, estimated the impact of restricted and projected groundwater pumpage, with and without land clearing, on net revenue, groundwater pumpage, cropping patterns, and on other resources. Clearing of light and medium brush infested range was the only land clearing alternative considered in the temporal analysis. The following results were obtained from recursive solutions to the Winter Garden linear programming model.

Projected Groundwater Pumpage

Projected groundwater pumpage limitations were intended to mirror current and probable uses of groundwater. Over the 20 year period, this scenario realized a pumpage of 4.2 million acre feet of groundwater and realized a present value of 457.3 million dollars, at an 8 percent discount rate. Net revenue declined from 42.9 million (1981) to 42 million dollars (2001), an annual average decline of about 91,900 dollars, Table 21.

Cropped acres rose from 454,700 to 481,100 acres over the 20 year period. Irrigated acreages decline from 161,000 acres to 138,100 acres. Carrizo Aquifer irrigated acreages fell from 91,800 to 61,300 acres, and Edwards Aquifer irrigated acres rose from 69,200 acres to 76,800 acres. Dryland cultivation rose from 293,700 acres to 343,000 acres. Under projected groundwater pumpage, the Carrizo Aquifer pumpage declines from a maximum of 135,600 acre feet per year in 1981 to 90,400 acre feet per year in 2001. Edwards Aquifer groundwater pumpage rises from 80,100 to a peak of 106,500 acre feet in 1991 and declines to 95,200 acre feet per year in 1996 through 2001, as higher pumping lifts are encountered. Over the period of analysis, increasing acreages of dryland cotton and dryland grain sorghum were realized. Short-season irrigated cotton acreages remained steady at about 11,000 acres.

Restricted Groundwater Pumpage

The restricted groundwater pumpage scenario, Table 22, over the twenty year period, showed groundwater withdrawal of 3.8 million acre feet and a present value of 453.8 million dollars, assuming an 8 percent discount rate. Compared to the projected groundwater scenario, a loss of 3.5 million dollars was associated with a reduction in total groundwater pumped of 458,000 acre feet.

Net revenue declined from 42.5 to 40.9 million dollars, an annual average reduction of 89,200 dollars. Net revenue for projected groundwater pumpage always exceeded that for restricted groundwater pumpage and the difference widened over time.

The relationship between net revenue, dryland acreages, and Carrizo Aquifer groundwater pumpage, first observed when restricted and projected groundwater pumpage were compared in static scenarios, was maintained in the temporal scenarios. Dryland culivation rises from 315,800 acres to 382,800 acres and always exceeds dryland cultivation in the corresponding projected pumpage scenarios. Irrigated acreages decline from 152,000 acres in 1981 to 124,000 acres in 1991 through 2001 and are always less than irrigated acreages for projected groundwater pumpage. The net effect is a greater total of cropped acres under restricted groundwater pumpage than for projected groundwater pumpage.

Introduction of restricted groundwater pumpage limitations resulted in a decline in groundwater withdrawals from the Carrizo Aquifer from 141,800 acre feet in 1981 to 106,500 acre feet in 1991, followed by an increase to 111,200 acre feet in 2001. Edwards Aquifer irrigation groundwater pumpage declined from 59,200 acre feet to 50,700 acre feet in 2001. Restricted groundwater pumpage led to greater groundwater withdrawals over the 20 year period for the Carrizo Aquifer than projected groundwater pumpage, 2.6 million acre feet versus 2.3 million acre feet.

Projected and Restricted Groundwater Pumpage with Land Clearing

Projected groundwater pumpage realizes higher net revenues in every solution. These revenues translate into present values of 729.2 and 726 million dollars, using an 8 percent discount rate.

Aggregate groundwater withdrawals for projected groundwater pumpage with land clearing (4.8 million acre feet) exceeded restricted groundwater pumpage (4.1 million acre feet) by 654,000 acre feet. Under the projected groundwater use scenario, Carrizo Aquifer total groundwater pumpage was 2.6 million and Edwards Aquifer groundwater pumpage was 2.1 million acre feet. But with the restricted scenario, Carrizo Aquifer pumpage rose to 2.9 million acre feet and Edwards Aquifer total pumpage fell to 1.2 million acre feet. Compared to the two scenarios without land clearing, the total acres cropped under restricted and projected groundwater pumpage with land clearing remained about the same, 1.3 million acres over the 20 year period. Acres of brush cleared in the two land clearing scenarios were also about the same over the period of analysis, 906,000 acres. Of this total about 367,000 acres were medium brush and 539,000 acres were light brush, but about 91,000 acres of buffel grass were established so that the net contribution to cropland was only 815,000 acres.

Implications

General implications about the future of irrigated agriculture in the Winter Garden are based on the results of the static and temporal models:

1. Irrigated agriculture will expand in the Edwards Aquifer relative to the Carrizo Aquifer, as long as groundwater pumpage is

unregulated.

2. High well drilling and casing costs in the Carrizo Aquifer, relative to commodity prices, discourage development of new wells.
3. In the Carrizo Aquifer area, further declines in irrigated agriculture are likely as the present stock of wells and irrigation equipment become obsolete.
4. Increasing pumping lifts resulting in higher variable and fixed costs relative to commodity prices are effectively limiting groundwater pumpage in the Carrizo Aquifer.
5. New crops which use less irrigation water per acre may lead to increases in groundwater pumpage as irrigated acreages expand.
6. Conservation through imposition of groundwater withdrawal limitations to realize restricted levels of groundwater pumpage will severely restrict irrigation activities in the Edwards Aquifer and vigorous producer opposition would be expected.
7. Enforcement of restricted pumpage levels in the Carrizo Aquifer could have a significant distributional impact across individual farm operations in different resource areas.
8. Techniques to improve efficiency of water use, such as row damming, represent a dramatic opportunity and rapid adoption is expected.
9. Any factors increasing net returns of cultivated crops will be associated with increased conversion of brush to cropland.
10. A productive base conducive to guayule cultivation makes the Winter Garden a likely growing area if processing and marketing problems are solved.

Limitations

In a study as broad as this, there are by necessity many assumptions and limitations. Thus, the results must be viewed with these factors in mind. The model developed for this study lacks a method to characterize preferences of individual landowners and institutional factors which affect the actual employment of resources. Preferences of individual operators take on added significance when measures to avoid risk are taken into consideration. Operators alter cropping patterns to avoid risk originating from weather, equipment complements, marketing, and institutional factors. Marketing techniques and strategies related to the marketing of vegetables are difficult if not impossible to include in a regional linear programming model. Decisions on many commodities, such as vegetables, are made on a daily basis as operators compete to fill in small gaps in the market left by other producing areas.

Institutional factors such as credit markets and land tenure affect cropping patterns and resource use. Lending institutions may influence selection of enterprises through loan agreements. Much of the land in the Winter Garden Region is in large tracts which are devoted to livestock production and hunting leases. It is unlikely that much of this land will be converted to cropland in the near future.

The assumptions regarding resources, purchased inputs, and outputs condition the results obtained from a linear programming model. An unlimited supply of capital was assumed to be readily available at an 8 percent interest rate. A perfectly elastic supply of labor at the stated wage rates was assumed. The role of surface water for irrigation was not explored. Full well development costs, if counted in the costs of switching from the current groundwater use levels to the restricted levels in the Carrizo Aquifer would impose a formidible barrier to new groundwater development. Soil types are tied to each water resource area. The method of assignment of individual soil types to the water resource areas is not as precise as a direct enumeration would be. In the future, research techniques need to be developed to link information bases together in such a way that individual parcels of land can be identified by soil type, water availability, farm improvements, and infrastructure.

The linear programming model assumes constant levels of technology and constant input and output prices. The drawdown coefficients, developed to represent the increase in depth to water associated with groundwater pumpage for each resource area, are more appropriate under the assumption that the groundwater allowed for each period is completely utilized. Adjustments for prolonged drouth were not built into the model since this would be difficult due to the constant proportions linear programming activities.

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APPENDIX

Technical Data

Table 27. Harvested Acreages of Selected Winter Garden Crops, 1970-1980.[a]

Crops	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Cotton											
Dryland	1,100		1,200		200		1,150	5,600	9,500	23,350	4,500
Irrigated	6,500	4,400	5,100	4,450	13,200	3,650	9,350	27,500	16,800	24,700	29,900
Corn	15,000	23,200	16,400	27,600	23,000	37,100	30,200	44,600	47,000	51,000	38,100
Grain Sorghum											
Dryland	54,600	36,450	43,100	68,700	60,300	87,200	39,000	43,400	14,000	33,700	23,200
Irrigated	35,900	23,250	33,400	32,300	33,000	70,100	26,000	21,750	16,600	14,700	11,200
Wheat, Dryland	6,110	700	4,200	9,700	17,300	28,000	19,600	27,700	10,200	30,100	12,300
Peanuts											
Dryland	500	1,800	800	1,100	1,900	1,000	1,475	3,050	1,300	2,500	2,000
Irrigated	19,600	18,450	19,850	19,700	18,920	20,100	20,475	19,550	20,650	19,100	18,100
Vegetables											
Cabbage	3,200	3,600	2,100	2,700	2,300	2,200	2,100	1,800	2,150	1,450	1,330
Carrots	4,100	3,500	4,400	4,000	3,600	3,100	3,300	2,680	3,290	3,150	1,990
Spinach[b]	4,500	5,100	4,100	4,700	3,950	3,600	2,750	2,050	2,880	4,780	3,800
Hay											
Sorghum	1,490	17,600	4,000	2,300	4,600	3,500	6,000	5,600	2,600	3,500	6,100
Other Hay[c]	14,200	17,500	14,500	16,700	16,000	24,200	17,600	27,700	25,000	19,000	25,000

Source: Texas Crop and Livestock Reporting Service, 1981c.

[a] Reported acreages for Dimmit, Zavala, LaSalle, Frio, and Uvalde Counties.
[b] Fresh market spinach acreages, processing spinach acreage not available.
[c] Other hay excludes sorghum and alfalfa hay.

Table 28. Aggregation of Winter Garden Arable Soil Series, 1981.

Soil Name	Slope (Percent)	Soil Symbol	Major Soil (Acres)	Minor Soil (Acres)	Type[a]	Total (Acres)	Percentage of Major (Percent)
Amphion clay loam	0-1	AMA	20500	27571	1.	48071	42.6
Atco loam	0-1	ATA	14160	26632	2.	40792	34.7
Atco loam	1-3	ATB	8320	26030	3.	34350	24.2
Antosa-Bobillo	0-3	ABC	70420	6000	4.	76420	92.1
Bookout clay loam	0-1	BKA	60628			60628	100.0
Bookout clay loam	1-3	BKB	32622			32622	100.0
Brystal fine sandy loam	0-1	BSA	40924	36900	5.	77824	52.6
Brystal fine sandy loam	1-3	BSB	153056	27100	6.	180156	85.0
Caid sandy clay loam	0-1	CAA	41159			41159	100.0
Caid sandy clay loam	1-3	CAB	31615			31615	100.0
Chacon clay loam	0-1	CHA	70421			70421	100.0
Chacon clay loam	1-3	CHB	28779			28779	100.0
Cotulla clay	0-1	CTA	79584	16821	7.	96405	82.6
Cotulla clay	1-3	CTB	52196	8990	8.	61186	85.3
Dilley fine sandy loam	1-5	DLY	54930	33435	9.	88365	62.2
Divot silty clay loam	0-1	DIA	45900			45900	100.0
Duval fine sandy loam	0-1	DVA	62082			62082	100.0
Duval fine sandy loam	1-3	DVB	316239			316239	100.0
Duval loamy fine sand	0-3	DUC	29660			29660	100.0
Duval-Melon complex	0-5	DMX	110240	32723	10.	142963	77.1
Knippa clay	0-1	KNA	84491	14032	11.	98523	85.8
Knippa clay	1-3	KNB	16694	4993	12.	21687	77.0
Montell clay	0-1	MTA	124588	19396	13.	143984	86.5
Montell clay	1-3	MTB	23064	6000	14.	29064	79.4
Pryor sandy clay loam	0-1	PRA	27680	9000	15.	36680	75.5
Pryor sandy clay loam	1-3	PRB	84150	15000	16.	99150	84.9
Randado fine sandy loam	1-3	RNB	32038			32038	100.0
Tonio fine sandy loam	0-1	TOA	23920			23920	100.0
Tonio fine sandy loam	1-3	TOB	75390			75390	100.0
Uvalde silty clay loam	0-1	UVA	236864			236864	100.0
Uvalde silty clay loam	1-3	UVB	63879			63879	100.0
Valco clay loam	0-3	VLC	20533			20533	100.0
Webb fine sandy loam	0-1	WEA	40964			40964	100.0
Webb fine sandy loam	1-3	WEB	107665			107665	100.0
Winterhaven silty clay loam	0-1	WNA	48140			48140	100.0
Zavco sandy clay loam	0-1	ZVA	21807			21807	100.0
Zavco sandy clay loam	1-3	ZVB	14911	29100	17.	44011	33.9
Totals			2370213	339723		2709936	87.5

Source: Jack Stevens, Soil Conservation Service, personal communication; Stevens and Richmond.

[a] The name, slope, and acres of minor soil types are described in Table 29.

Table 29. Type and Minor Soils within Major Soil Groups, Winter Garden, 1981.

Type	Soil Name	Slope (Percent)	Minor Soil (Acres)
1.	Ramadero sandy clay loam	0-1	8171
	Laparita loam	0-1	8400
	Hanis sandy clay loam	0-1	6000
	Denhawkin-Elmendorf	0-1	5000
2.	Conalb loam	0-1	9419
	McAllen loam	0-1	4000
	Castroville clay loam	0-1	13213
3.	Conalb loam	1-3	4230
	McAllen loam	1-3	4000
	Castroville clay loam	1-3	2313
	Divot silty clay loam	1-3	5000
	Winterhaven silty clay loam	1-3	4730
	Sabenyo clay loam	1-5	5757
4.	Aluf-Hitilo	0-5	6000
5.	Miguel fine sandy loam	0-1	11900
	Delfina fine sandy loam	0-1	5000
	Poteet fine sandy loam	0-1	8000
	Brennan fine sandy loam	0-1	12000
6.	Miguel fine sandy loam	1-3	11100
	Delfina fine sandy loam	1-3	6000
	Brennan fine sandy loam	1-3	10000
7.	LaSalle clay	0-1	9500
	Tobosa clay	0-1	7321
8.	LaSalle clay	1-3	4500
	Tobosa clay	1-3	4490
9	Duval fine sandy loam	3-5	9000
	Brystal fine sandy loam	3-5	4000
	Randado fine sandy loam	3-5	15435
	Webb fine sandy loam	3-5	5000
10.	Comitas loamy fine sand	0-3	8723
	Poth loamy fine sand	0-3	13000
	Wilco loamy fine sand	0-5	11000
11.	Dant and Uvalde clay loam	0-1	2072
	Frio silty clay loam	0-1	10495
	Bosque loam	0-1	1465
12.	Dant and Uvalde clay loam	1-3	2594
	Frio silty clay loam	1-3	2399

Table 29. Continued.

Type	Soil Name	Slope (Percent)	Minor Soil (Acres)
13.	Mercedes clay	0-1	19396
14.	Mercedes clay	1-3	6000
15.	Mavco clay loam	0-1	7000
	Campbleton clay loam	0-1	2000
16.	Mavco clay loam	1-3	3000
	Campbleton clay loam	1-3	12000
17.	Amphion clay loam	1-3	11500
	Hanis sandy clay loam	1-3	7000
	Laparita loam	1-3	2600
	Denhawkin-Elmendorf	1-3	8000

Source: Jack Stevens, Soil Conservation Service, personal communication; Stevens and Richmond.

Table 30. Percent Brush Density by Range Site, Winter Garden, 1981.

Range Site	Symbol	Brush Density in Percent		
		Light	Medium	Heavy
Blackland	B	30	50	20
Clayey Bottomland	CB	20	60	20
Clay Flat	CF	30	40	30
Clay Loam	CL	20	40	40
Claypan Prairie	CP	20	40	40
Deep Sand	DS	80	20	
Gravelly Ridge	GR	10	40	50
Gray Sandy Loam	GSL	30	50	20
High Lime	HL	30	50	20
Lakebed	L	60	30	10
Loamy Bottomland	LB	20	60	20
Loamy Sand	LS	80	20	
Ramadero	R	20	60	20
Rolling Blackland	RB	20	50	30
Rolling Hardland	RH	20	60	20
Saline Clay	SC	40	50	10
Sandstone Hill	SSH	30	60	10
Sandy	S	70	30	
Sandy Loam	SL	30	50	20
Shallow	SH	30	60	10
Shallow Ridge	SR	30	55	15
Shallow Sandy Loam	SSL	30	55	15
Tight Sandy Loam	TSL	20	60	20
Adobe	A	20	60	20
Deep Upland	DU	20	40	40
Igneous Hill	IH	30	60	10
Redland	PL	20	40	40
Rocky Hill	KH	30	60	10
Low Stony Hill	LSH	30	60	10
Steep Rocky	STA	30	60	10

Source: Ken Starks, Soil Conservation Service, personal communication.

Table 31. Assignment of Non-Arable Range to Light, Medium, and Heavy Brush Density Categories, Winter Garden, 1981.

Range Site	Symbol	Non-Arable Range Total (Acres)	Brush Densities Light (Acres)	Medium (Acres)	Heavy (Acres)
Blackland	B	1,700	5,100	8,500	3,400
Clayey Bottomland	CB	146,000	29,200	87,600	29,200
Clay Flat	CF	2,000	600	800	600
Clay Loam	CL	10,290	2,058	4,116	4,116
Claypan Prairie	CP	200,650	40,130	80,260	80,260
Gravelly Ridge	GR	112,821	11,282	45,128	56,411
Gray Sandy Loam	GSL	62,240	18,762	31,120	12,448
Lakebed	L	6,930	4,158	2,079	693
Loamy Bottomland	LB	45,433	9,087	27,260	9,086
Rolling Hardland	RH	143,490	28,698	86,094	28,698
Saline Clay	SC	88,350	35,340	44,175	8,835
Sandstone Hill	SSH	7,000	2,100	4,200	700
Sandy Loam	SL	7,500	2,250	3,750	1,500
Shallow	SH	19,302	5,791	11,581	1,930
Shallow Ridge	SR	164,736	49,421	90,605	24,710
Shallow Sandy Loam	SSL	6,500	1,950	3,575	975
Tight Sandy Loam	TSL	50,350	10,070	30,210	10,070
Deep Upland	DU	7,737	1,547	3,095	3,095
Igneous Hill	IH	9,315	2,795	5,589	931
Redland	PL	21,293	4,259	8,517	8,517
Rocky Hill	KH	46,002	13,801	27,601	4,600
Steep Rocky[a]	STA	82,712	24,814	49,627	8,271
Total		1,242,351			

Source: Ken Starks and Jack Stevens, Soil Conservation Service, personal communication.

[a] Adobe, Low Stoney Hill, and Steep Rocky range sites were combined.

Table 32. Establishment Costs of Perennial Grasses for Hay and Grazing, Winter Garden, 1981.

	Unit Cost ($)	Dryland			Irrigated
		Buffel Grass[a]	Coastal Bermuda[a]	Bermuda Hay[b]	Bermuda Hay
1. Harvested Material		$15.00	$50.00	$132.34[c]	$264.68[c]
2. Variable Inputs					
Seed		5.00			
Sprigs and Sprigging			40.00	40.00	40.00
Nitrogen	.21	10.40	13.00	31.20	46.80
Phosphate	.32	12.80	9.60	19.20	19.20
Herbicide			3.50	3.50	3.50
Diesel	.98	1.92	2.12	2.43	2.75
Gasoline	1.15	.69	.69	.69	.69
Lubricants		.39	.42	.47	.52
Repairs		2.74	2.41	2.63	2.85
Labor	4.50	7.20	7.77	8.68	9.59
Irrigation (16 Ac. in.)[d]					21.50
Operating Capital	.08	1.65	3.18	4.35	5.90
Total Variable Costs		42.79	82.69	113.15	153.30
3. Custom Harvest				52.80	105.60
4. Fixed Costs					
Machinery and Equipment		16.92	16.60	25.33	27.65
Irrigation Equipment[d]					135.33
Total Fixed Costs		16.92	16.60	25.33	162.98
5. Total Establishment Cost		44.71	49.29	58.94	157.20
6. Prorated Estab. Cost	.08	3.58	3.94	4.72	12.58

Source: Extension Economists-Management, 1981b.

[a] One month of grazing for an animal unit valued at 50 cents.
[b] Dryland bermuda grass hay based on two cuttings versus four for irrigated bermuda grass hay.
[c] Bermuda grass hay valued at 66.17 dollars per ton.
[d] Sprinkler irrigated, Uvalde County, Water Resource Area 15.

Table 33. Annual Costs per Acre of Conversion of Light, Medium, and Heavy Brush Infested Range to Cropland, Winter Garden, 1981.

	Unit	Cost ($)	Level of Brush Infestation Light	Medium	Heavy
1. Variable Inputs					
Diesel	gal.	.98	5.35	4.17	4.17
Gasoline	gal.	1.15	.23	.23	.23
Lubricants	$		.84	.64	.64
Repairs	$		2.16	1.65	1.65
Labor, Machinery	hr.	4.50	4.64	3.74	3.74
Labor, Other	hr.	3.50		10.50	17.50
Chain, Custom	$				40.00
Rake and Stack, Custom	$			10.00	13.00
Burn, Custom	$			10.00	12.00
Root Plow, Custom	$			45.00	45.00
Operating Capital[a]	$	.08	.53	3.44	5.52
Total Variable Cost	$		13.75	89.37	143.45
2. Fixed Equipment	$		14.16	11.90	11.90
3. Total Cost	$		27.91	101.27	155.35
4. Annual Charge[a]	$		2.23	8.10	12.43

Source: Peña; Extension Economists-Management, 1981b.

[a] Assumes an 8 percent interest rate.

Table 34. Crop and Grazing Yields Under High Level Management by Soil Type, Winter Garden, 1981.[a]

Soils	Irrigated Crops: Vegetables: Cabbage (tons)	Carrots (tons)	Spinach (tons)	Cotton: Short Season (lbs)	Long Season (lbs)	Corn (bu)	Guayule (lbs)	Peanuts (cwt)	Sorghum (cwt)	Guar (cwt)	Bermuda Hay (tons)
ABC								30.0			4.0
AMA	18.0	15.0	7.0	794.0	907.0	120.0	590.0		70.0	18.5	10.0
ATA	14.0	10.0	7.0	722.0	825.0	80.0	470.0		50.0	14.7	9.0
ATB	10.0	8.0	6.0	613.0	701.0	70.0	350.0		45.0	13.3	8.0
BKA	16.0	12.0	8.0	722.0	825.0	90.0	530.0		53.0	14.0	10.0
BKB	15.0	10.0	7.0	650.0	742.0	85.0	500.0		50.0	13.2	9.0
BSA	16.0	12.0	7.0	722.0	825.0	95.0	530.0	32.0	48.0	13.3	10.0
BSB	15.0	10.0	6.0	650.0	742.0	90.0	500.0	30.0	45.0	12.5	9.0
CAA	17.0	14.0	7.0	722.0	825.0	90.0	560.0		60.0	16.0	10.0
CAB	14.0	10.0	6.0	650.0	742.0	80.0	470.0		50.0	13.3	9.0
CHA	15.0	10.0	6.0	722.0	825.0	90.0	385.0		62.0	16.4	10.0
CHB	14.0	8.0	5.0	650.0	742.0	85.0	335.0		53.0	14.0	9.0
CTA	15.0	10.0	6.0	722.0	825.0	85.0			50.0	9.3	14.0
CTB	14.0	8.0	5.0	577.0	660.0	80.0			45.0	8.4	12.0
DIA	18.0	15.0	8.0	902.0	1031.0	130.0			70.0	19.4	14.0
DLY						55.0	160.0	30.0	34.0	9.4	8.0
DMX				722.0	825.0	100.0	140.0	35.0	45.0	6.6	7.0
DUC				577.0	660.0	80.0	175.0	35.0	50.0	7.4	7.0
DVA				830.0	949.0	110.0	530.0	40.0	60.0	16.6	12.0
DVB				722.0	825.0	100.0	500.0	30.0	56.0	15.5	10.0
KNA	18.0	12.0	8.0	866.0	990.0	100.0	545.0		70.0	13.0	10.0
KNB	14.0	10.0	7.0	722.0	825.0	90.0	335.0		60.0	11.2	9.0
MTA	15.0	12.0	7.0	866.0	990.0	100.0			70.0	13.0	10.0
MTB	12.0	10.0	6.0	722.0	825.0	90.0			60.0	11.2	9.0
PRA	14.0	10.0	6.0	650.0	742.0	90.0			50.0	13.3	10.0
PRB	12.0	8.0	5.0	577.0	660.0	85.0			45.0	12.0	9.0
RNB	9.0	8.0	5.0	505.0	577.0	65.0	140.0		35.0	9.7	8.0
TOA				722.0	825.0	90.0	240.0		62.0	17.2	9.0
TOB				650.0	742.0	85.0	225.0		53.0	14.7	8.0
UVA	18.0	12.0	8.0	866.0	990.0	100.0	590.0		70.0	15.3	10.0
UVB	15.0	11.0	7.0	722.0	825.0	90.0	500.0		60.0	13.1	9.0
VLC	9.0	8.0	5.0	505.0	577.0	65.0	320.0		30.0	7.9	8.0
WEA	17.0		7.0	722.0	825.0	75.0	490.0	35.0	50.0	13.9	10.0
WEB	14.0		6.0	650.0	742.0	65.0	335.0	30.0	42.5	11.8	9.0
WNA	16.0	12.0	9.0	722.0	825.0	110.0			62.0	13.6	10.0
ZVA	15.0		7.0	722.0	825.0	90.0	500.0		60.0	16.0	10.0
ZVB	14.0		6.0	650.0	742.0	85.0	450.0		50.0	13.3	9.0

Table 34. Continued.

Soils	Dryland Activities							Oats for Grazing			Coastal Bermuda
	Cotton	Guayule	Sorghum	Wheat	Guar	Sorghum Hay	Peanuts	Peanuts (Dry)	Peanuts (Irig)	Oats (Only)	
	(lbs)	(lbs)	(cwt)	(bu)	(cwt)	(ton)	(cwt)	(aum)	(aum)	(aum)	(aum)
ABC							14.0	1.0	2.0	2.0	3.0
AMA	390.0	400.0	30.0	35.0	9.0	5.4				3.5	3.5
ATA	347.0	335.0	17.5	30.0	8.1	3.2				2.5	3.0
ATB	303.0	265.0	15.0	25.0	6.9	2.7				2.5	3.0
BKA	390.0	365.0	17.0	30.0	5.1	3.1				3.0	3.0
BKB	347.0	350.0	14.0	25.0	4.2	2.5				2.5	3.0
BSA	347.0	365.0	20.0	30.0	7.3	3.6	12.6	1.3	2.5	2.5	2.5
BSB	303.0	350.0	17.0	25.0	6.2	3.1	11.2	1.0	2.0	2.0	2.5
CAA	390.0	385.0	20.0	30.0	7.6	3.6				3.0	3.0
CAB	347.0	335.0	17.5	25.0	6.7	3.2				2.5	2.5
CHA	390.0	290.0	22.0	25.0	6.6	4.0				3.0	3.0
CHB	347.0	250.0	17.0	20.0	5.1	3.1				2.5	2.5
CTA	260.0		22.0	30.0	6.1	4.0				2.5	2.5
CTB	217.0		14.0	25.0	3.9	2.5				2.5	2.5
DIA	433.0		30.0	40.0	10.9	5.4				3.5	3.5
DLY		115.0		20.0			11.9	1.0	2.0	2.0	2.0
DMX	173.0		20.0	15.0	5.6	3.6	14.0	1.0	2.0	2.0	2.0
DUC	303.0		20.0	20.0	5.6	3.6	12.6	1.3	2.5	2.5	2.0
DVA	347.0	365.0	25.0	30.0	9.1	4.5	14.0	1.5	3.0	3.0	3.0
DVB	282.0	350.0	22.5	25.0	8.2	4.0	11.2	1.5	3.0	3.0	2.5
KNA	477.0	400.0	25.0	25.0	7.0	4.5				3.0	3.5
KNB	390.0	250.0	20.0	20.0	5.6	3.6				2.5	3.5
MTA	477.0		22.5	25.0	6.3	4.1				2.5	3.0
MTB	390.0		17.5	20.0	4.9	3.2				2.5	3.0
PRA	303.0		17.0	25.0	6.5	3.1				2.5	2.5
PRB	260.0		14.0	20.0	5.4	2.5				2.0	2.0
RNB		100.0	12.5	20.0	4.5	2.3				2.0	2.5
TOA	390.0	175.0	22.0	25.0	8.0	4.0				2.5	2.5
TOB	347.0	160.0	20.0	20.0	7.3	3.6				2.0	2.0
UVA	477.0	400.0	25.0	30.0	8.7	4.5				2.5	3.0
UVB	390.0	350.0	20.0	25.0	6.9	3.6				2.5	3.0
VLC	260.0	250.0	12.5	20.0	3.8	2.3				2.0	2.5
WEA	347.0	365.0	20.0	25.0	7.3	3.6	12.6	1.3	2.5	2.5	3.0
WEB	303.0	250.0	17.5	20.0	6.4	3.2	11.2	1.3	2.5	2.5	3.0
WNA	434.0		20.0	30.0	6.9	3.6				3.0	3.0
ZVA	390.0	350.0	20.0	25.0	7.6	3.6				2.5	2.5
ZVB	347.0	320.0	17.5	20.0	6.7	3.2				2.5	2.5

Source: Stevens and Richmond; U.S. Department of Agriculture, 1979; Smith and Huckabee; Cornforth, et al; Retzer and Mogen; Extension Economists-Mangagement, 1981b.

[a] Guayule yields represent typical management and wheat furnishes 1.5 AUM of grazing per acre.

Table 35. Fertilizer Recommendations for Cotton, Grain Sorghum, Corn, Bermuda Grass Hay, and Small Grains, Winter Garden, 1981.

Cotton

Yield		lb.	0-480	481-960	961-up
Nitrogen	low	lb.	.1042	.1042	.1042
Phosphate	low	lb.	.0625	.0556	.0521
Potash	low	lb.	.0625	.0556	.0521
	medium	lb.		.0417	.0417
	high	lb.			.0313

Grain Sorghum

Yield		cwt	0-30	30-60	60-up
Nitrogen	low	lb.	.0167	.0167	.0167
Phosphate	low	lb.	.0100	.0089	.0083
Potash	low	lb.	.0100	.0089	.0083
	medium	lb.	.0050	.0067	.0067
	high	lb.			.0050

Corn

Yield		bu.	0-60	61-90	91-up
Nitrogen	low	lb.	1.0000	1.0000	1.0000
Phosphate	low	lb.	.8333	.6667	.5833
Potash	low	lb.	1.0000	.7778	.6667
	medium	lb.	.8333	.6667	.5833
	high	lb.		.5556	.5000

Bermuda Grass Hay

Yield		ton	4	6	8	10	12
Nitrogen	all	lb.	120	220	320	410	560
Phospahte	medium	lb.		20	40	50	60
Potash	low	lb.	30	45	60	75	90
	medium	lb.		20	40	50	60
	high	lb.				18	35

Grazing

Crop			Oats	Wheat
Yield		aum	1.7-3.0	1.5
Nitrogen	med	lb.	60	60
Phosphate	med	lb.	30	30
Potash	low	lb.	30	30
	med	lb.	15	15

Source: Welch, et al.

Table 36. Fertilizer Recommendations per Unit of Output for Peanuts, Vegetables, Guayule, Coastal Bermuda Grass, Sorghum Hay, and Guar, Winter Garden, 1981.

Peanuts				
Yield	cwt	0-12.5[a]	12.5-32.7[a]	32.7-up
Nitrogen	lb.	1.2	.7273	.7273[a]
Phosphate	lb.	2.4	1.8182	(low) 1.2232[b]
Potash	lb.	1.6	1.0909	(low) 1.3761[b]
	lb.			(med) 1.0703[b]

Vegetables[a]		Cabbage	Spinach	Carrots
Yield	ton	13.8	9.3	7.2
Nitrogen (dry)	lb.	3.6364	5.3763	8.3333
Nitrogen (liquid)	lb.	3.6364	10.7527	8.3333
Phosphate	lb.	5.8182	17.2043	10.4167

Guar[a]		irrigated	dryland
Yield	cwt	17.5	8.0
Nitrogen	lb.	5.7143	6.2500
Phosphate	lb.	2.5714	1.8750

Other Crops				
Crop		Irrigated Guayule[c]	Coastal Bermuda[a]	Sorghum Hay[b]
Yield		500 (lb)	6.667 (aum)	(all)
Nitrogen	lb.	.02	13.50	80.0
Phosphate	lb.		4.50	(low) 30.0
Potash	lb.			(low) 35.0
	lb.			(med) 15.0

[a] Extension Economists-Management, 1981b..
[b] Welch, et al. (level of soil fertility in parenthesis).
[c] Cornforth, et al.

Table 37. Per Acre Five Year Total Guayule Harvest Costs, Dryland and Irrigated, Winter Garden, 1981.

Irrigated Guayule

	Unit	Windrow	Bale	Haul to Roadside	Transport	Dig	Total
Fixed	000$	17.97	58.12	46.33	22.13	09.87	154.40
Repairs	$	.60	9.85	4.30	8.54	2.21	25.50
Diesel	gal	1.18	3.58	6.38	.83	3.11	15.05
Gasoline	gal				14.82		14.82
Lube	$	.17	.53	.94	2.68	.46	4.75
Labor	hour	.24	3.92	2.13	3.84	.57	10.69
Twine	feet		4600				4600

Dryland Guayule

	Unit	Windrow	Bale	Haul to Roadside	Transport	Dig	Total
Fixed	$	17.97	40.75	32.43	20.51	9.87	121.55
Repairs	$	.60	6.90	3.01	8.40	2.21	21.10
Diesel	gal	1.18	3.38	4.46	.58	3.11	12.70
Gasoline	gal				15.56		15.56
Lube	$	.17	.50	.66	2.77	.46	4.55
Labor	hour	.24	3.04	1.49	3.84	.57	9.20
Twine	feet		3220				3220

Source: Cornforth, et al.; Purdue University; Extension Economists-Management, 1981b; Area Machinery Dealers, personal communication.

Table 38. Cow-Calf Enterprise Budget, Winter Garden, 1981.

Item	Units	Quantity
1. Beef	cwt	3.84
2. Variable Inputs		
Grazing	aum	12.00
Gasoline	gal	3.30
Machinery Repairs	$	1.73
Lubricants	$	1.37
Labor, Mechanical	hour	1.65
Labor, Other	hour	7.50
Minerals	head	1.00
Vet Medicine	head	1.00
Range Cubes	lb	60.00
Hay	bale	1.00
Selling Expense	head	1.00
Fence Repair	head	8.40
Water Facility Repair	head	1.00
3. Fixed Costs		
Equipment	$	13.70
Livestock	$	139.30

Source: Extension Economists-Management, 1981a, 1981b.

Table 39. Acre Feet of Groundwater Utilized for Irrigation, Winter Garden Study Area Counties, 1958, 1964, 1969, 1974, and 1979.

County	1958	1964	1969	1974	1979
Dimmit	18,303	14,873	20,785	18,781	11,839
Frio	30,373	56,300	74,300	72,767	76,013
LaSalle	5,539	13,820	11,744	10,900	9,060
Zavala	76,514	232,739	169,419	114,723	120,547
Total[a]	130,729	317,732	276,248	217,171	217,459
Uvalde	17,051	33,327	48,523	67,312	75,915
Grand Total	147,780	351,059	324,771	284,483	293,374

Source: Texas Department of Water Resources, 1981.

[a] Total for Counties served by the Carrizo Aquifer.

Table 40. Estimated Acre Feet of Groundwater Assigned to Non-Irrigation Uses by Water Resource Area, Winter Garden, 1981, 1986, 1991, 1996, and 2001.

Water Resource Area		1981	1986	1991	1996	2001
1	Batesville	180	223	267	311	356
2	La Pryor	39	48	58	68	77
3	Pearsall West	131	162	194	227	259
4	Pearsall East	2,333	2,583	2,832	3,107	3,381
5	Moore	90	112	133	156	178
6	Los Angeles	4	6	7	8	9
7	Asherton	506	607	708	816	923
8	Carrizo Springs	1,753	2,021	2,288	2,589	2,889
9	Crystal East	2,396	2,491	2,586	2,721	2,855
10	Crystal West	92	114	136	159	182
11	Zavala-Dimmit	1,771	2,088	2,407	2,748	3,088
12	Frio	1,525	1,782	2,040	2,313	2,585
13	LaSalle	136	168	201	235	269
15	Edwards	9,127	10,913	12,699	15,172	17,645

Source: U.S. Department of Commerce; Table 41.

Table 41. Acre Feet of Forecasted Groundwater Utilization, Winter Garden, 1980, 1990, 2000, 2010, and 2020.

Carrizo Aquifer Area[a]

Category	1980	1990	2000	2010	2020
Manufacturing	1,157	1,168	1,345	1,559	1,889
Municipal	9,671	11,706	13,984	16,572	19,329
Irrigation	206,174	150,088	94,000	72,999	52,001
Mining	991	755	522	552	582
Livestock	2,356	4,216	6,075	6,594	7,116
Steam Power	611	611	611	611	611
Total	220,960	168,544	116,537	98,887	81,528

Edwards Aquifer Area[b]

Category	1980	1990	2000	2010	2020
Manufacturing	645	758	1,064	1,432	1,980
Municipal	6,963	9,694	13,604	18,038	22,725
Irrigation	66,609	64,054	61,500	57,667	53,833
Mining	417	699	982	1,152	1,323
Livestock	1,102	1,548	1,995	2,165	2,336
Total	75,736	76,753	79,145	80,454	82,197

Source: William Moltz, Texas Department of Water Resources, personal communication.

[a] Carrizo Aquifer Area includes Dimmit, Zavala, Frio, and Zavala Counties.

[b] Edwards Aquifer Area is limited to Uvalde County.

Table 42. Aquifer Characteristics: Initial Depth to Water, Depth to Base of Aquifers, and Acre Feet Pumped to Increase Lift by One Foot, Winter Garden Water Resource Areas.

Water Resource Area		Initial Depth to Water[a] (feet)	Depth to Aquifer Base[b] (feet)	Acre Feet/ Foot Change in Lift[b] (Acre Feet)
1	Batesville	219	800	2,900.6
2	La Pryor	290	575	1,090.9
3	Pearsall West	145	1,715	3,078.4
4	Pearsall East	255	1,760	3,862.1
5	Moore	149	600	418.5
6	Los Angeles	89	3,090	78.9
7	Asherton	232	1,080	5,448.0
8	Carrizo Springs	194	280	1,771.8
9	Crystal East	344	900	19,732.1
10	Crystal West	288	950	3,303.6
11	Zavala-Dimmit	226	580	9,587.2
12	Frio	173	1,790	9,794.2
13	LaSalle	173	2,370	1,266.4
15	Edwards	119[c]	1,250[d]	31,344.8[d]

[a] Marquardt and Rodriguez; Texas Natural Resources Information System, personal communication, unless otherwise specified.

[b] Klemt, Duffin, and Elder, unless otherwise specified.

[c] Tommy Knowles, Texas Department of Water Resources, personal communication.

[d] Klemt, Knowles, Elder, and Sieh.

Table 43. Distribution of Arable Study Area Soils Among Water Resource Areas and Dryland, Winter Garden, 1981.

Soil Name	Slope (percent)	Soil Symbol	Batesville (acre)	La-Pryor (acre)	West Pearsall (acre)	Pearsall (acre)	Moore (acre)	Los Angeles (acre)	Asherton (acre)	Carrizo Springs (acre)
Amphion clay loam	0-1	AMA	65		509	485	1,157	750		
Atco loam	0-1	ATA	551	128	727	34	166	8	548	8
Atco loam	1-3	ATB	464	108	613	29	139	7	462	6
Antosa-Bobillo	0-3	ABC	354			2,385	5,864			27,434
Bookout clay loam	0-1	BKA	10,331	1,334	2,798		340		1,173	
Bookout clay loam	1-3	BKB	5,559	718	1,505		183		631	
Brystal fine sandy loam	0-1	BSA	295	10	520	489	967	87	1,280	2,333
Brystal fine sandy loam	1-3	BSB	684	23	1,205	1,131	2,239	201	2,964	5,401
Caid sandy clay loam	0-1	CAA	2,830	374	1,092	66	198	34	1,314	1,260
Caid sandy clay loam	1-3	CAB	2,174	287	839	50	152	26	1,010	968
Chacon clay loam	0-1	CHA	1,489	1,621	39				71	66
Chacon clay loam	1-3	CHB	609	662	16				29	27
Cotulla clay	0-1	CTA	1,448	929	100	100	174		16	
Cotulla clay	1-3	CTB	919	590	64	63	111		10	
Dilley fine sandy loam	1-5	DLY	1,166	116	767	6,266	987	40	1,677	5,586
Divot silty clay loam	0-1	DIA	262	193	1,916		166		813	13
Duval fine sandy loam	0-1	DVA	334		1,646	4,220	1,881	47	212	815
Duval fine sandy loam	1-3	DVB	1,704		8,386	21,494	9,583	239	1,081	4,150
Duval loamy fine sand	0-3	DUC	160		787	2,016	899	22	101	389
Duval-Melon complex	0-5	DMX	770		3 791	9,717	4,332	108	489	1,876
Knippa clay	0-1	KNA	416							
Knippa clay	1-3	KNB	92							
Montell clay	0-1	MTA	11,130	1,173	2,861		666		1,030	
Montell clay	1-3	MTB	2,247	237	577		134		208	
Pryor sandy clay loam	0-1	PRA	370	349	111	147	296		5,013	1,724
Pryor sandy clay loam	1-3	PRB	1,000	943	301	396	800		13,551	4,661
Randado fine sandy loam	1-3	RNB	764	60	178				798	2,713
Tonio fine sandy loam	0-1	TOA	72						2,777	3,545
Tonio fine sandy loam	1-3	TOB	226						8,751	11,173
Uvalde silty clay loam	0-1	UVA	23,504	2,690	6,128		1,133		2,364	
Uvalde silty clay loam	1-3	UVB	6,339	726	1,653		305		637	
Valco clay loam	0-3	VLC	1,448	78	1,184	426	442		68	
Webb fine sandy loam	0-1	WEA	380		1,245	862	1,254	102	217	831
Webb fine sandy loam	1-3	WEB	998		3,271	2,264	3,297	268	569	2,183
Winterhaven silty clay loam	0-1	WNA	1,397	1,164	4,050		329		5,037	60
Zavco sandy clay loam	0-1	ZVA	505	48	213	83	207	334	107	248
Zavco sandy clay loam	1-3	ZVB	1,020	96	429	167	417	673	215	500

Table 43. Continued.

Soil Name	Slope (percent)	Soil Symbol	East Crystal (acre)	West Crystal (acre)	Zavala-Dimmit (acre)	Frio (acre)	LaSalle (acre)	Dry-land (acre)	Uvalde-Edwards (acre)
Amphion clay loam	0-1	AMA				26,830	407	15,399	2,469
Atco loam	0-1	ATA	395	315	1,214	3,492	825	11,824	20,557
Atco loam	1-3	ATB	332	266	1,023	2,940	694	9,957	17,311
Antosa-Bobillo	0-3	ABC			30,910	5,397		4,076	
Bookout clay loam	0-1	BKA	8,402	1,173	22,625	5,800		6,653	
Bookout clay loam	1-3	BKB	4,521	631	12,174	3,121		3,580	
Brystal fine sandy loam	0-1	BSA	73	134	14,851	10,599	8,982	37,203	
Brystal fine sandy loam	1-3	BSB	169	310	34,378	24,536	20,793	86,123	
Caid sandy clay loam	0-1	CAA	2,363	437	9,346	2,993	3,505	15,067	279
Caid sandy clay loam	1-3	CAB	1,815	335	7,179	2,300	2,692	11,575	215
Chacon clay loam	0-1	CHA	4,154	9,909	31,558		97	21,417	
Chacon clay loam	1-3	CHB	1,697	4,049	12,897		40	8,753	
Cotulla clay	0-1	CTA	2,404	5,651	17,998	1,487		62,603	3,496
Cotulla clay	1-3	CTB	1,526	3,586	11,423	944		39,732	2,219
Dilley fine sandy loam	1-5	DLY	733	122	22,764	11,808	2,953	33,054	326
Divot silty clay loam	0-1	DIA	602	467	1,848	6,423		33,197	
Duval fine sandy loam	0-1	DVA		11	9,836	18,353	4,831	19,895	
Duval fine sandy loam	1-3	DVB		56	50,104	93,488	24,610	101,344	
Duval loamy fine sand	0-3	DUC		5	4,699	8,768	2,308	9,505	
Duval-Melon complex	0-5	DMX		25	22,651	42,263	11,126	45,815	
Knippa clay	0-1	KNA					21,404	76,703	
Knippa clay	1-3	KNB					4,711	16,884	
Montell clay	0-1	MTA	7,383	1,030	19,882	11,345	285	60,264	26,938
Montell clay	1-3	MTB	1,490	208	4,013	2,290	57	12,165	5,438
Pryor sandy clay loam	0-1	PRA	913	2,419	10,607	3,770		10,962	
Pryor sandy clay loam	1-3	PRB	2,469	6,538	28,671	10,190		29,630	
Randado fine sandy loam	1-3	RNB	382	58	9,928			16,481	676
Tonio fine sandy loam	0-1	TOA	30	305	8,476			8,716	
Tonio fine sandy loam	1-3	TOB	93	961	26,715			27,470	
Uvalde silty clay loam	0-1	UVA	16,933	2,363	45,596	19,307	217	49,922	66,708
Uvalde silty clay loam	1-3	UVB	4,567	637	12,297	5,207	58	13,463	17,990
Valco clay loam	0-3	VLC	491	68	1,323	5,011		4,508	5,486
Webb fine sandy loam	0-1	WEA		11	10,029	17,036	499	8,501	
Webb fine sandy loam	1-3	WEB		30	26,359	44,775	1,308	22,342	
Winterhaven silty clay loam	0-1	WNA	3,524	2,885	10,867	12,708		6,119	
Zavco sandy clay loam	0-1	ZVA	301	46	3,457	6,518	181	9,561	
Zavco sandy clay loam	1-3	ZVB	608	93	6,977	13,156	364	19,296	

Source: Klemt, Duffin, and Elder; Klemt, Knowles, Elder, and Sieh; U.S. Department of Agriculture, 1980b, 1980c; Jack Stevens, Soil Conservation Service, personal communication.

Table 44. Groundwater Utilization Assumptions and Cost and Life of Furrow and Sprinkler Irrigation Systems, Winter Garden, 1981.

Groundwater Utilization Assumptions

Parameter Description	Furrow	Sprinkler
Acres Covered	100	126
Gallons per Minute	1000	1000
Inches per Acre	22.5	18.3
Application Efficiency	.65	.80
Annual Hours of Use	1018.9	1043.1
Pounds per Square Inch at Discharge	15.0	40.0
Number of Sets per Year	3	3
Acre Inches per Set	7.5	6.1
Annual Acre Inches Pumped	2252.0	2305.0

Cost and Expected Life of Pump Components

Pump Component	Cost (dollars)	Life (Years)
First Bowl	1260.00	8.0[a]
Additional Bowls	368.00	8.0[a]
Column, 20 Foot Section	866.00	16.0
Pump Base	1350.00	20.0
Pump Slab	200.00	20.0
Strainer	420.00	16.0

Cost and Expected Life of Furrow Distribution System

System Component	(Unit)	(Dollars)	(Years)
Gated Aluminium Pipe, 30 ft. Section	70.0	90.00	15.0
Hydrants	3.0	200.00	20.0
End Plug	1.0	20.00	15.0
Gate Valve	1.0	450.00	20.0
Plastic Mainline, 10 in., 40 p.s.i.	2100.0	3.25	20.0

Table 44. Continued.

Cost and Estimated Life of Sprinkler Distribution System

System Component	(Unit)	(Dollars)	(Years)
Pivot System and Installation	1.0	37,700.00	15.0
Plastic Mainline, 10 in., 80 p.s.i.	1370.0	4.00	20.0
Gate Valve	1.0	450.00	20.0
Control Cable, Feet	1370.0	2.50	20.0

Furrow Irrigation: Motor and Pump Specifications and Costs

Lift	Interval (feet)	Column Length (feet)	Pumping Lift (feet)	Bowls	Brake Horse-power	Purchase Horse-power	Cost[b] (dollars)
1	100-149	200	150	3	64	75	4490
2	159-199	250	200	4	82	100	5440
3	200-249	300	250	5	99	100	5440
4	250-299	350	300	6	117	125	7430
5	300-349	400	350	7	134	150	8475
6	350-399	450	400	8	151	175	9730

Sprinkler Irrigation: Motor and Pump Specifications and Costs

Lift	Interval (feet)	Column Length (feet)	Pumping Lift (feet)	Bowls	Brake Horse-power	Purchase Horse-power	Cost[b] (dollars)
1	100-149	200	166	5	90	100	5440
2	159-199	250	216	6	107	125	7430
3	200-249	300	266	6	125	125	7430
4	250-299	350	316	7	142	150	8475
5	300-349	400	366	8	160	175	9730
6	350-399	450	416	9	177	200	10,780

Source: Kletke, Harris, and Mapp; Winter Garden area well drilling and service firms.

[a] Bowl life in the Carrizo Aquifer is one-half that of the Edwards (Joe Peña, personal communication).

[b] Price includes motor, control panel, and installation.

Table 45. Well Development Fixed Costs for Furrow and Sprinkler Systems, Winter Garden, 1981.

Water Resource Area		Depth to Base[a] (feet)	Drilling[b] ($)	Pipe[c] ($)	Casing[d] ($)	Total Cost ($)	Depreciation[e] ($)	Annual Interest ($)	Fixed Cost ($)	Furrow ($)	Sprinkler ($)
1	Batesville	800	12,800	7,200	15,000	35,000	1,400	1,400	2,800	28.00	22.22
2	LaPryor	575	12,800	7,200	15,000	35,000	1,400	1,400	2,800	28.00	22.22
3	West Pearsall	1,715	27,440	15,435	29,640	72,515	2,901	2,901	5,801	58.01	46.04
4	Pearsall	1,760	28,160	15,840	30,360	74,360	2,974	2,974	5,949	59.49	47.21
5	Moore	600	9,600	5,400	11,800	26,800	1,072	1,072	2,144	21.44	17.02
6	Los Angeles	3,090	49,440	27,810	51,640	128,890	5,156	5,156	10,311	103.11	81.83
7	Asherton	1,080	17,280	9,720	19,480	46,480	1,859	1,859	3,718	37.18	29.51
8	Carrizo Springs	280	4,480	2,520	6,680	13,680	547	547	1,094	10.94	8.69
9	East Crystal	900	14,400	8,100	16,600	39,100	1,564	1,564	3,128	31.28	24.83
10	West Crystal	950	15,200	8,550	17,400	41,150	1,646	1,646	3,292	32.92	26.13
11	Zavala-Dimmit	580	9,280	5,220	11,480	25,980	1,039	1,039	2,078	20.78	16.50
12	Frio	1,790	28,640	16,110	30,840	75,590	3,024	3,024	6,047	60.47	47.99
13	LaSalle	2,370	37,920	21,330	40,120	99,370	3,975	3,975	7,950	79.50	63.09
15	Uvalde	1,250	20,000	5,490	11,960	37,450	1,248	1,498	2,497	24.97	19.81

Source: Coefficients developed from data furnished by Winter Garden Area well drilling and service firms and computations outlined by Kletke, Harris, and Mapp.

[a] See Table 42.
[b] Drilling charge estimated at $16 per foot by Winter Garden Area well drilling and service firms.
[c] Steel pipe, 344 wall, 12 and three-fourths inch diameter (Winter Garden Area well drilling and service firms).
[d] Installation of Casing, first 50 feet, 1,500 dollars, and $16 per foot thereafter.
[e] Carrizo and Edwards well life assumed to be 25 and 30 years, respectively.

Table 46. Sprinkler and Furrow Irrigation System Fixed Costs per Acre, Winter Garden, 1981.

Sprinkler Irrigation System

Lift	Interval (feet)	Deprecia-tion ($)	Interest ($)	Tax ($)	Insurance ($)	Fixed Cost ($)
			Carrizo Aquifer			
1	100-149	37.08	21.03	1.05	2.62	61.78
2	159-199	39.68	22.48	1.12	2.81	66.09
3	200-249	40.75	23.15	1.16	2.89	67.95
4	250-299	42.97	24.30	1.21	3.04	71.52
5	300-349	45.27	25.49	1.27	3.19	75.22
6	350-399	47.49	26.62	1.33	3.32	78.76
			Edwards Aquifer			
2	159-199	36.24	22.46	1.12	2.81	62.63
3	200-249	37.31	23.15	1.16	2.89	64.51
4	250-299	39.16	24.28	1.21	3.04	67.69

Furrow Irrigation System

Lift	Interval (feet)	Deprecia-tion ($)	Interest ($)	Tax ($)	Insurance ($)	Fixed Cost ($)
			Carrizo Aquifer			
1	100-149	22.76	12.67	.63	1.58	37.64
2	159-199	25.50	14.07	.70	1.76	42.03
3	200-249	27.77	15.08	.75	1.88	45.48
4	250-299	31.04	16.89	.84	2.11	50.88
5	300-349	33.83	18.32	.92	2.29	55.36
6	350-399	36.74	19.83	.93	2.48	60.04
			Edwards Aquifer			
2	159-199	22.09	14.07	.70	1.76	38.62
3	200-249	23.90	15.08	.75	1.88	41.61
4	250-299	26.71	16.89	.84	2.11	46.55

Source: Kletke, Harris, and Mapp; Winter Garden price data furnished by area well drilling and service firms.

Table 47. Sprinkler and Furrow Irrigation System Variable Inputs per Acre Inch, Winter Garden, 1981.

Sprinkler Irrigation System

Lift	Interval (feet)	Lube ($)	Electric Power (kwh)	Labor (hour)	Repairs ($)	Maximum Demand (kw)
			Carrizo Aquifer			
1	100-149	.08	31.90	.023	1.05	.0229
2	159-199	.10	38.58	.023	1.10	.0277
3	200-249	.11	45.26	.023	1.13	.0325
4	250-299	.13	51.94	.023	1.18	.0373
5	300-349	.14	58.63	.023	1.21	.0421
6	350-399	.15	65.31	.023	1.26	.0470
			Edwards Aquifer			
2	159-199	.10	38.58	.023	.97	.0229
3	200-249	.11	45.26	.023	.99	.0325
4	250-299	.13	51.94	.023	1.01	.0373

Furrow Irrigation System

Lift	Interval (feet)	Lube ($)	Electric Power (kwh)	Labor (hour)	Repairs ($)	Maximum Demand (kw)
			Carrizo Aquifer			
1	100-149	.08	31.90	.023	1.05	.0229
1	100-149	.06	21.34	.079	.22	.0157
2	159-199	.08	28.02	.079	.25	.0206
3	200-249	.09	34.70	.079	.29	.0255
4	250-299	.12	41.39	.079	.34	.0305
5	300-349	.14	48.07	.079	.39	.0354
6	350-399	.16	54.75	.079	.42	.0403
			Edwards Aquifer			
2	159-199	.08	28.02	.079	.14	.0206
3	200-249	.09	34.70	.079	.16	.0255
4	250-299	.12	41.39	.079	.19	.0305

Source: Kletke, Harris, and Mapp; Central Power and Light Company.