TR- 74
1976

Adjustments Due to a Declining Groundwater Supply: High Plains of Northern Texas and Western Oklahoma

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Texas A&M University

RESEARCH PROJECT COMPLETION REPORT

Project Number B-179-TEX

(January 1, 1974 - June 30, 1976)

Agreement Number

14-31-0001-4165

ADJUSTMENTS DUE TO A DECLINING GROUNDWATER SUPPLY: HIGH PLAINS OF NORTHERN TEXAS AND WESTERN OKLAHOMA

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The work upon which this publication is based was supported in part by the Office of Water Research and Technology, Department of the Interior, as authorized under the Water Resources Research Act of 1964, P. L. 88-3797 through the Texas Water Resources Institute and in part by funds provided by the Texas Agricultural Experiment Station.

Technical Report No. 74
Texas Water Resources Institute
Texas A&M University

June, 1976

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ACKNOWLEDGEMENTS

This is a summary report of several studies conducted under a project involving Texas A&M University, Texas Tech University and Oklahoma State University. Sincere gratitude is expressed to Dr. J. R. Runkles, Director, Texas Water Resources Institute, for guidance, leadership and support in project development, research, fiscal accounting and publication processes.

This project involved several studies and phases. Different individuals assumed leadership for the different pieces. Without an outstanding effort on each phase, the many studies would not have fit together as a concise complete project. Therefore, our sincere appreciation is expressed to Clint Johnson (Texas Tech University), George Williford, Bruce Beattie and John Shipley (Texas A&M University), James Casey, Dean Schreiner and Gerald Doeksen (Oklahoma State University), Vernon Eidman (University of Minnesota) and Arthur Ekholm (Northern Arizona University). Of course, any errors, omissions or misinterpretations included in this report are the sole responsibility of the authors.

INTRODUCTION

The region north of the Canadian River in Texas and including the three western counties of Oklahoma have been rapidly developing the groundwater resource since the mid 1960's. This region, hereafter referred to as the Northern High Plains, is basically rural in nature with the principal agricultural products wheat, sorghum and cattle. Water is pumped from formations mainly for irrigating wheat and sorghum.

Since the Northern High Plains is a semi-arid region (average annual rainfall is about 21 inches), irrigation significantly increases crop yields. For wheat, irrigation increases yield from an expected 12 bushels per acre to 41 bushels per acre. Likewise, irrigated grain sorghum produces 5,300 pounds per acre compared to dryland production of 1,200 pounds per acre (Strickland and Harwell). Supplemental irrigation in agriculture results in a larger total use of agricultural inputs complementary with irrigation such as fertilizer, labor, chemicals for insect and weed control, steel, petroleum products and agricultural marketing facilities (Grubb). Larger total and individual farm incomes are a direct result of irrigation in the Northern High Plains which adds to the bundle of consumable agricultural products in the local, regional and national markets and in turn provides a demand for goods and services produced by non-agricultural sectors of the local, regional and national economies.

Water used for irrigation in the Northern High Plains is pumped from an aquifer, the Ogallala, with very little recharge; i.e., less than 1/2 inch per acre of surface area per year (Hughes and Harman). This means continued pumping will result in declining water levels and eventually economic exhaustion of the aquifer. As the water level decreases and the saturated thickness declines, pumping costs will increase and well yields will eventually decline. Beyond some peak or maximum number of irrigated acres the growth process will be reversed and irrigated acres will begin to decline.

Dependence of agricultural production on irrigation in the study area is emphasized by Osborn and Harris. It was estimated that the value of crop output in the Northern and Southern High Plains of Texas was $778.1 million in 1967. Of this total, $637.2 million was attributable to irrigated crops while dryland crops accounted for an output of $140.9 million. Total economic activity (direct and indirect) associated with the crop sectors was estimated to be $2.18 billion in 1967.

Agricultural output in the region can be expected to decline significantly as the transition from irrigated to dryland production occurs. Grubb has estimated that peak irrigated acreage in the Northern and Southern High Plains would occur in 1980. Using 1959 data and irrigated acreage projections to the year 2020, the primary benefits from irrigation in the High Plains was estimated to be $20 per acre irrigated with indirect benefits of $35.31. It was concluded that the resulting decline in output from reduced irrigated acreage would have a serious impact on the regional economy.

Relating the effect of declining irrigation to the region, Osborn and Harris estimated the value of irrigated production to decline from

$637 million in 1967 to $224 million in 2015, a decrease of 61.6 percent. Although it was estimated that the value of dryland production would increase 63.8 percent, the total value of crop production would be only 60.9 percent of the 1967 level. The total economic activity associated with crop sectors was estimated to decline from $2.18 billion in 1967 to $1.32 billion in 2015.

Another comprehensive study of the impact of a decline in groundwater was done by Hughes and Harman on a portion of the Southern High Plains. A 65 percent reduction in cotton production, a 91 percent reduction in sorghum production, and 22 percent increase in wheat production was estimated by the year 2015 as compared to 1966. This brought a decline in aggregate value of agricultural product from $432 million in 1966 to $128 million in 2015. These studies indicate a substantial reduction in agricultural income can be expected with reduced groundwater supplies.

Harman, Eidman, and Bekure have developed estimates of changes in aggregate agricultural output due to further development of irrigation and with a declining water supply for the Northern High Plains. Although these studies of expected adjustments to a declining water supply are complete for aggregate agricultural output, they do not extend to include expected adjustments within communities and impacts relative to individual producer profits, population and migration, public services and agriculturally related businesses.

In the developing stage, agricultural output increases resulting in associated increases in farm supplies and marketing facilities. This change provides an increasing tax base (based on the groundwater supply for irrigation) that can provide needed public services such as education, police and fire protection and other public services.

However, as the aquifer is dewatered, development may cease and cropland shift to dryland production. This results in a contraction of agricultural output and causes adjustments throughout the community and area that are related to the declining economic base of the area. The expected effect of reduced groundwater withdrawal on the regional economy and communities needs to be quantified with alternatives developed for slowing or reducing negative impacts.

STUDY AREA

This study of the effect of a declining groundwater supply covers 25 counties in the Northern High Plains of Texas and three counties of the Oklahoma Panhandle (see Figure 1). This region, referred to as the Northern High Plains, is a semi-arid region with long term mean annual precipitation of 21.12 inches. Annual fluctuations in rainfall range from about 10 inches up to nearly 40 inches (Alexander).

The growing season averages 201 days extending from mid-April until the first part of November. Although much of the land in the area is used for ranching, the amount of cultivated land has increased dramatically since 1900 when nearly all of it was used for grazing.

Irrigation from wells started in shallow water areas in the Hereford area in 1910 (Green). By 1937, there were 16 irrigation wells and about 2,000 acres under irrigation in the area. By 1971, this had increased to about 1.4 million acres. Currently, about 90 percent of the water used in the area is for irrigation.

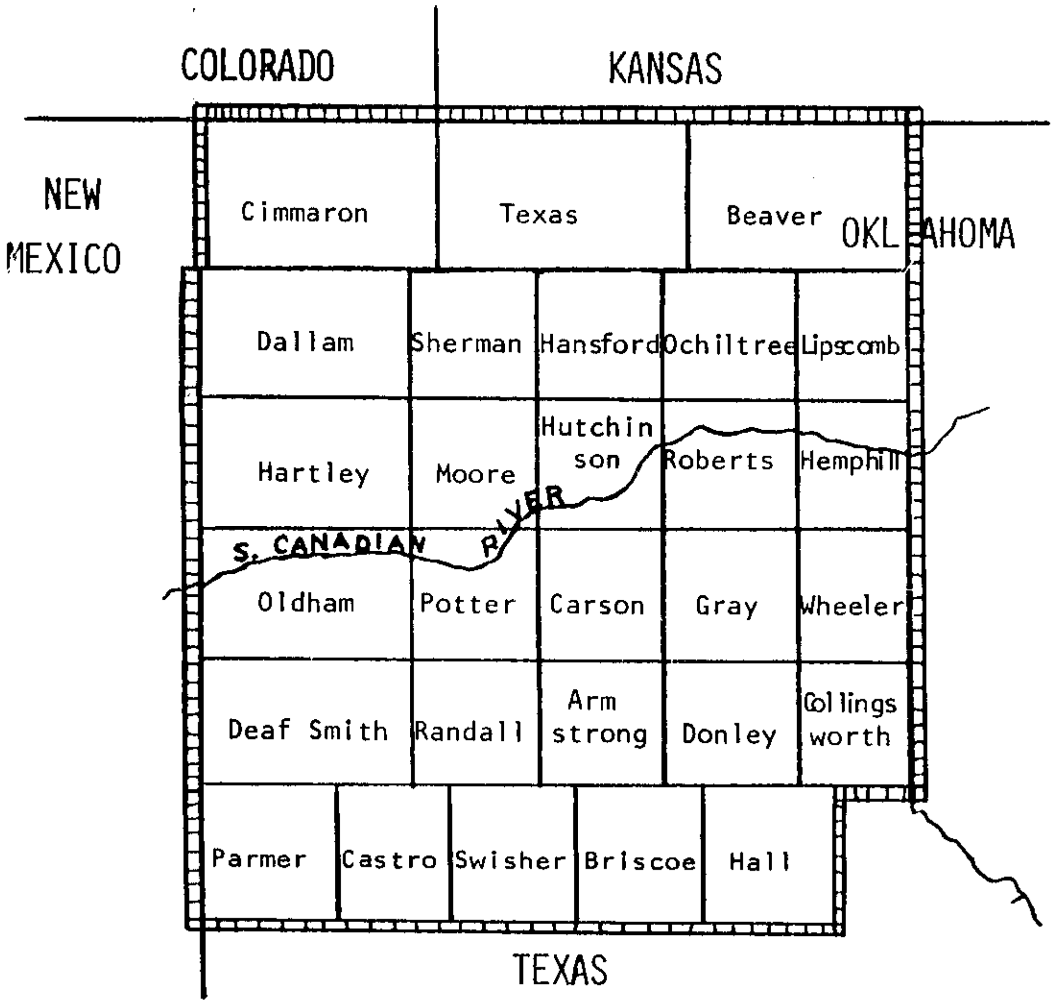

Figure 1. Northern High Plains of Texas and Oklahoma

Although there are some small areas within the study area where some fresh water is available in Cretoceous and Jurrassic rocks, the Ogallala formation is the principle source of fresh groundwater (North Plains Water Conservation District).

The Ogallala feathers from very shallow deposits along the western and southern boundaries to deposits of 900 feet in small bowl-like depressions. Sand, silt and clay are distributed irregularly throughout the formation. There is generally a gradual slope in an easterly direction in the aquifer which creates a slow water movement to the east of about 250 feet per year (North Plains Water Conservation District).

Prior to 1960, prices and yields of agricultural products in the area were marginal in justifying intensive irrigation development. However, the introduction of new varieties and more recent dramatic price increases have brought forth a rapid development of irrigation in the area.

Beyond some peak level of irrigated acreage the exhaustible nature of the groundwater supply will cause the process to reverse to dryland production. This trend is evident in the Southern High Plains where the number of irrigated acres increased from 460,804 in 1949 to 1,380,978 in 1959. However, by 1969 the number of irrigated acres had decreased to 1,324,224. In the Northern High Plains, where irrigation development is more recent, a decrease in irrigated acres has not yet occurred. From 1949 to 1969, the number of irrigated acres on the Northern High Plains increased from 12,591 to 1,230,435 (U. S. Department of Commerce, 1952, 1961, 1972).

A comparison of 1964 and 1969 agricultural production for the area indicates the continuing development of irrigation. Over this period, irrigated acres increased over 500,000 acres, from 680,000 to 1,231,000 acres (U. S. Department of Commerce, 1967, 1972). Similarly, acres of wheat and grain sorghum increased 22 percent from 1964 to 1969. Output of both wheat and sorghum increased proportionately more than acres produced. This is reflected in per acre yields which increased from 15.5 bushels to 23.2 bushels for wheat and from 46.2 bushels to 65.7 bushels for sorghum. The increase in yields can be attributed to increases in irrigation and improved varieties as well as increased use of complementary resources.

During this same five-year period, inventory of cows and calves in the Northern High Plains increased from 522 to 922 thousand head. Much of this increase was in confinement feeding, supported by the rapid increase in feed grain production in the region. The total value of farm product sales for this area shows the increased output and favorable prices in that they increased nearly three-fold or from 104 million dollars to 298 million dollars.

In a period when farm consolidation and increased farm size was the norm in most areas of the United States, average farm size in the study area decreased from 2,432 acres in 1959 to 2,016 acres in 1969. This implies that the development of irrigation requires more intensive production of crops and that some land division is occurring. The average value of sales per farm increased from $37,527 to $75,459, comparing 1964 to 1969, respectively. To produce much of the agricultural output of 1969, some 1,914,666 acre feet of water were pumped from the underground reservoir.

The impact of increases in number of acres irrigated is shown in data relative to the Ogallala formation. From 1961 to 1971 average decline in the water table was a little over 2 feet per year. In some areas of sparse water-well development, the decline was less than 1 foot per year while in areas of intense development, the decline was greater than 5 feet per year (Wyatt, 1971). As expected, areas with the greater quantity of water are the ones with the greatest degree of irrigation development and hence, greater decline in saturated water level.

Well yields in this area range from 200 to 1,200 gallons per minute averaging about 700 gallons per minute (Alexander). Depth to water is around 100 feet or less in area designated as the "breaks" (North Plains Water Conservation District). This is primarily range land not suitable for cultivation. For the "plains" areas (regions under cultivation or readily adaptable to cultivation), typically depth to the static water level increases substantially ranging from 150 feet to over 300 feet. There are exceptions to these depths to the water level in both the breaks and plains. Thickness of the Ogallala ranges from 200 to 400 feet. There are exceptions along the edges of the aquifer and in some cones of depression.

There is a recognition of the need to plan and manage the use of water from the Ogallala in the region. This is reflected in the creation of groundwater conservation districts in Texas. In the Northern Plains of Texas there are three such districts--the Northern Plains Ground Water Conservation District No. 2 the Dallam County Underground Water Conservation District No. 1 and the Panhandle Water District (Alexander). Each of these conservation districts have been validated by the Texas Legislature. The general nature of the work done by the districts is the conservation, protection, recharging, and prevention of waste of the underground water within the boundaries of the districts. The North Plains Ground Water Conservation District No. 2 requirements on the spacing of wells promotes the efficient development of its water resources; and its records of well-completion data, well logs and well measurements are important sources of information.

This region is basically a rural area with Amarillo as the only Standard Metropolitan Statistical Area (SMSA). The Amarillo SMSA serves as a regional trade center, and in the decade of 1960 to 1970 accounted for 40 percent of the region's population. Other principal cities of the area are Dumas, Dalhart, Perryton and Spearman, the largest of which is Dumas with a 1970 population of 9,780 (U. S. Department of Commerce, 1973). Population in these four cities increased 10,463 from 1960 to 1970 (from 16,618 to 27,081). Approximately thirty communities have populations between 1,000 and 5,000 with only eight communities exceeding 5,000 persons. There are numerous communities with less than 1,000 persons. Total regional population was 357,095 in 1970, which represented a 4.4 percent decline from 1960 (U. S. Department of Commerce 1963, 1973). With the numerous small towns that are heavily oriented to surrounding agricultural production, changes in agricultural output will immediately and directly affect the economy and provision of community services due to changes in farm supplies demanded and changes in agricultural output.

As pumping continues, the declining static water level will result in increased pumping costs and ultimately in declining well yields. It is projected that annual pumpage of groundwater in the Northern High Plains of Texas and Western Oklahoma will increase from 1967 to 1990 or 1995, after which it will decline (Wyatt, 1975). As the water decline continues, producer profits are affected and eventually aggregate agricultural output declines due to a reduction in water use and shifting to dryland production. These changes have significant implications for the communities serving agriculture.

OBJECTIVES

The primary objective of this project was to estimate the regional, community and farm firm effects resulting from a declining water supply in the Northern High Plains. Specific objectives were as follows:

1. Determine the regional impact of a declining water supply in terms of
    a. value and quantity of agricultural output
    b. aggregate value of all related products and services
    c. farm and non-farm employment
2. Determine the expected community adjustment to a declining water supply with regard to examples of the relation to adjustments in
    a. tax base
    b. population
    c. public services

PROCEDURES

The declining groundwater supply in the Northern High Plains is a regional problem affecting the regional economy and state and economies in Texas and Oklahoma. A study of the economic, agricultural and industrial production and community service effects of a declining resource requires a large effort and the input of several scientists. This study was developed as a regional project involving participation by Texas A&M University, Texas Tech University and Oklahoma State University. Project participants from each University had specific objectives and, in addition, were actively involved in the development and conduct of research at the other institutions.

Coordination was achieved through a series of project participant meetings to formalize vital research procedures. A total of seven such meetings occurred over the project period.

Interdependence of the Universities' research was critical to completing all phases of the work. For example, a model developed at Texas Tech University (Osborn, 1974) was modified and applied in the Oklahoma State University phase of the work. The projections from the Oklahoma State University study were input data to the community services analysis done at Texas A&M University. This continuous and free exchange of analytical techniques and research results was a strong part of the research and brought forth close cooperation, mutual admiration, and total fulfillment of project objectives.

For this project, there are four distinct and separate pieces that can be defined. The methodology applied in each was different. Therefore, a brief discussion of methods applied for each is described here. Complete details are presented in reports, publications and/or theses for each of the four major thrusts of the project.

Simulated Regional Adjustments

The work at Oklahoma State University was directed to simulating the regional economy based on groundwater withdrawal. This research is an estimate of what can be expected to occur in this regional economy to 2010, given that conditions or assumptions of the study do not change substantially.

Basically the analytical technique used was an economic information system and a dynamic simulation model which estimate the impact of declining groundwater and petroleum resources in the study region. The information system was estimated from secondary sources and consists of a 42 sector interindustry transactions matrix, a capital account and a human resources account. The regional economy from 1967 to 2010 is simulated by a system of difference equations arranged in recursive sequence. Empirical output of the simulation model includes sector and regional output, employment, income and regional population. These measures of the regional economy are estimated within the constraint of a projected groundwater and petroleum supply. Several scenarios of the regional economy were generated. Sensitivity of the economy to changes in assumptions about resource supplies and selected parameters was investigated. Complete details of the model are presented in Ekholm and in Ekholm, Schreiner, Eidman and Doeksen.

Projecting Optimum Agricultural Adjustments

A part of the Texas A&M University research was developing a model whereby an optimum (profit maximizing) organization of agricultural production could be estimated for the projected groundwater withdrawal rates.

In addition, alternative groundwater withdrawal rates can be assumed to evaluate effect of rate of withdrawal on present value of the groundwater.

The unique aspect of this model is that it includes both optimizing and input-output components. A basic linear programming model of agriculture production for the region was formulated that included input-output linkages among the sectors of the High Plains economy.

This model was designed to complement the Oklahoma State University model described above. The Oklahoma State University model projects economic activity given the 1967 structure of the High Plains economy. The Texas A&M model is designed to estimate changes in cropping patterns or feedlot activity which could more effectively utilize water available annually and thereby sustain regional growth for an extended period.

More specifically, the input-output component provides a technical description of the economy necessary to estimate the effects on non-agricultural output of changes in the agricultural sector. Linear programming (a mathematical optimizing technique) allocates the groundwater resource among agricultural production activities.

The model was applied for the years 1975 to 2010 at five year intervals. Three alternative groundwater withdrawal projections were evaluated in terms of discounted returns to agricultural producers and the regional economy. The model was developed in a recursive framework so that a groundwater withdrawal projection from 1975 to 2010 could be evaluated in a single computer run with appropriate discounting calculations made. Complete details of the model and procedure are presented in Casey and in Casey, Jones and Lacewell.

Identifying Economic Growth Sectors

A third phase of the project conducted at Texas Tech University was directed toward identifying sectors in the economy of the Northern High Plains that could be expected to replace the declining economic activity from irrigated agriculture. Sectors in the regional economy were selected on the basis of employment potentials, interindustry impacts and import-export considerations.

An interindustry model for a 56 county area in West Texas was available (Osborn and McCray). The study was developed for 1967 and was based on surveys of many of the major industries in West Texas. The study included 94 processing sectors in the model.

The location quotient technique was used to delineate a 94 sector input-output model for the Northern High Plains. This model was resentative of the economic activity and effects of the economic effects within the regional economy. Economic effects (direct, indirect and induced) as well as employment multipliers (Type I and II) were estimated from the input-output model. The results from Ekholm were used to estimate the impact of declining groundwater on employment as well as identifying economic growth sectors. Other considerations in the process were import-export balances and interindustry impacts. Complete details of the model and methods applied are presented in Osborn and Johnson.

Community Services Model

The final major part of the project was estimating the effect of the declining groundwater resource on provisions of community services. Reduced availability of groundwater in the Northern High Plains of Oklahoma and Texas is expected to have repercussions throughout the regional economy due to the reduction in agricultural income. This decline in the economic base should lead to an out migration of people and thus a diminishing population over time. It is presumed that the decrease in population and available income will result in a curtailment of expenditures for community services.

This study established some theoretical concepts for empirical analysis and measurement of service expenditures. Initially, time series data and cross-sectional data were considered in attempts to specify the expenditure functions for selected public services. Due to the failure of relationships developed using the time series data to meet statistical criteria, all estimates of service expenditure functions were developed using a cross-sectional data sample.

Linear and power model forms were applied to provide alternative estimates of community service expenditure functions. Expenditure functions were developed for water and sewer, streets, police, fire, and the total of all four services. Projections of future expenditure levels for selected community sizes were made using both the linear and power models. The results of the Oklahoma State University simulation model provided population and expenditure projections for input into the community services model from 1968 to 2010. Complete details of the community services models are presented in Williford and in Williford, Beattie and Lacewell (1976b).

RESULTS

This project has been prolific in producing relevant research results. These results have been published separately and in considerable detail. Therefore, only a very brief discussion of findings for each of the four major thrusts of the project are included in this report. By referring to referenced publications, additional details can be obtained.

Simulated Regional Adjustments

Ekholm, Schreiner, Eidman and Doeksen projected several regional economic factors, by year, for the period 1967-2010. The analysis included several alternatives for rate of groundwater and petroleum development. For this summary report, only the "base" projections are reported. The base might be considered best estimates of rate of development and use of exhaustible resources.

Table 1 shows projected population, employment and per capita disposable income from 1967 to 2010. The results indicate that population can be expected to increase until 1981. A continuous decline thereafter is projected with population in 2008 back to approximately the 1967 level.

Employment follows a similar trend as population. Alternatively, for per capita disposable income a continuous increase from $3,010 in 1967 to $4,511 in 2010 is estimated.

Table 2 presents projected gross output by sector for 1967, 1995 and 2010. Forty-two sectors are included. Basically, the projections show an increase from 1967 to 1995 then a decline in gross output from 1995 to 2010. Notable exceptions are irrigated cotton, petroleum and chemicals which decline throughout and dryland agricultural crops, range livestock, and meat products which increase over the period.

Table 1. Population, Total Employment, and Disposable Income per Capita, Northern High Plains, 1967-2010.[a]

Year	Population	Total Employment	Disposable Income per Capita
	Number	Number	1967 Dollars
1967	362,361	153,295	3,010
1968	363,084	155,074	3,081
1969	365,099	157,677	3,157
1970	370,857	161,086	3,219
1971	378,455	164,756	3,270
1972	386,732	169,347	3,333
1973	397,111	173,975	3,372
1974	407,135	177,748	3,411
1975	415,977	181,826	3,462
1976	425,097	185,623	3,486
1977	433,541	188,255	3,497
1978	439,177	189,769	3,510
1979	442,337	190,489	3,528
1980	443,570	190,846	3,553
1981	443,958	190,904	3,579
1982	443,649	190,437	3,602
1983	442,120	189,824	3,633
1984	440,256	189,236	3,666
1985	438,455	188,773	3,702
1986	436,943	188,740	3,739
1987	436,430	188,912	3,772
1988	436,393	189,182	3,804
1989	436,477	189,488	3,835
1990	436,755	189,660	3,865
1991	436,806	189,646	3,893
1992	436,388	189,471	3,922
1993	435,498	189,204	3,953
1994	434,449	188,909	3,985
1995	433,340	188-628	4,019
1996	432,263	187,697	4,043
1997	429,699	185,983	4,061
1998	425,348	183,624	4,082
1999	419,532	180,956	4,110
2000	413,050	178,304	4,144
2001	406,563	175,740	4,181
2002	400,317	173,031	4,213
2003	393,751	170,172	4,244
2004	386,859	167,271	4,279
2005	379,884	164,431	4,315
2006	373,060	161,702	4,354
2007	366,502	159,124	4,394
2008	360,297	156,655	4,433
2009	354,352	154,279	4,473
2010	358,629	151,954	4,511

[a]Source: Ekholm, Schreiner, Eidman and Doeksen, Table 4, p. 46.

Table 2. Gross Output by Sector, Northern High Plains, 1967, 1995 and 2010.[a]

Sector	Gross Output in Thousands of 1967 Dollars		
	1967	1995	2010
Irri. Cotton	27,656	21,772	16,589
Irri. Food Grain	71,096	148,653	129,866
Irri. Feed Grain	165,867	333,867	292,980
Other Irri. Crop	44,419	46,221	39,597
Dry Cotton	7,098	12,991	16,287
Dry Food Grain	23,237	24,367	33,174
Dry Feed Grain	21,935	17,594	35,249
Other Dry Crop	5,259	9,961	14,498
Range Livestock	68,848	133,518	161,931
Feedlot Livestock	218,414	2,127,854	2,013,090
Ag. Services	19,460	44,600	43,337
Crude Oil & Gas	397,398	237,705	168,081
Natl. Gas Liq.	134,035	80,173	56,669
Oil & Gas Ser.	32,943	36,096	31,352
Construction	164,773	215,576	191,018
Meat Products	49,242	471,717	457,064
Food Process	50,149	166,632	109,435
Textile Prod.	5,349	8,933	8,330
Milling & Feeds	14,774	115,274	111,065
Beverages	10,624	16,187	14,515
Wood & Paper & Pri.	15,545	24,867	22,563
Chemicals	100,873	93,318	77,753
Petro. Product	173,220	159,419	137,275
Soil & Rock Prod.	13,294	19,362	17,629
Metal Product	14,927	21,292	19,121
Machinery	20,695	28,007	24,358
Other Mfg.	11,306	16,224	14,690
Transportation	39,541	71,042	64,404
Communication	32,213	61,760	58,506
Gas Service	141,989	125,332	104,861
Electric Service	61,178	102,010	93,063
Water & San. Ser.	11,149	18,365	16,445
Whl. Agr. Prod.	11,586	66,178	63,224
Whl. Petro. Prod.	37,146	59,551	53,746
Other Wholesale	157,569	266,833	243,827
Agr. Supplies	2,822	4,945	4,447
Gas. Serv. Stat.	15,015	24,704	23,118
Other Retail	167,016	261,900	235,986
Finance	68,373	176,700	164,742
Insur. & R. E.	32,479	60,430	45,481
Education Serv.	84,219	143,623	131,874
Other Serv.	149,814	262,707	239,147

[a]Source: Ekholm, Schreiner, Eidman and Doeksen, Table 5, p. 48.

Table 3 presents projections of employment by industry and as a percent of total employment for 1967, 1995 and 2010. Total employment increases and then decreases for agriculture, manufacturing, trade, finance, insurance, real estate, services and other. For mining, construction, transportation and utilities, employment declines throughout.

About 33 percent of total employment is projected in agriculture with near 20 percent in trade and 20 percent in services. Each of the other industries comprises less than 10 percent of total employment.

This provides only a brief overview of this comprehensive study. The publication by Ekholm, Schreiner, Eidman and Doeksen provides several alternative situations with projections. In addition, a discussion of planning and policy implications of the study are included.

Optimum Agricultural Adjustments

Estimates of agriculture output, cropping patterns, and a comparison of net returns are presented for the three strategies of irrigation development by Casey, Jones and Lacewell. Output estimates for each of the non-agriculture sectors are given for the three strategies. Model results are reported at 5 year intervals with the groundwater resource changing at each interval.

The trend in physical output reflects an increase until 1990, then a decrease or slowing of the rate of increase. Corn and wheat output increase until 2010, but the rate of increase is slower after 1990. Output of these crops continue to increase due to their interdependence with feedlots and the remainder of the regional economy. These crops are grown predominately for utilization within the region.

Table 3. Base Projection of Employment by Industry and Percent of Total Employment, Northern High Plains, 1967, 1995 and 2010.[a]

Industry	Employment			% of Total Employment		
	1967	1995	2010	1967	1995	2010
Agriculture	49,112	62,266	50,296	32.0	33.0	33.1
Mining	3,799	1,294	770	2.5	0.7	0.5
Construction	6,578	6,143	4,843	4.3	3.2	3.2
Manufacturing	9,610	12,725	9,494	6.3	6.7	6.2
Transportation & Utilities	6,866	5,481	3,959	4.5	2.9	2.6
Trade	34,215	36,523	27,083	22.3	19.4	17.8
Finance, Insurance & Real Estate	4,226	8,055	7,025	2.7	4.3	4.6
Services	24,240	34,705	29,682	15.8	18.4	19.6
Other	14,649	21,436	18,802	9.6	11.4	12.4
Total	153,295	188,628	151,954	100.0	100.0	100.0

[a]Source: Ekholm, Schreiner, Eidman and Doeksen, Table 6, p. 51.

Similarly, cotton output increases to a point and remains constant until 2010. The total physical output of cotton, corn and wheat follows the same trend for all three strategies of irrigation developments. Production trends of these crops is largely affected by the interdependencies that exist among the sectors of the High Plains economy.

The production of grain sorghum in the Northern High Plains was the most responsive to changing groundwater levels. Grain sorghum is utilized in the High Plains feedlots. Model results indicate that a significant amount of grain sorghum is also exported from the region. Under the current projected rate of groundwater development, grain sorghum output in the High Plains is estimated to increase by 21 percent by 1990 and then decrease 17 percent by 2010. Under a faster rate of groundwater withdrawal, grain sorghum output increases 23 percent by 1985 and decreases 18 percent from 1985 to 2010. Under the slower rate of groundwater withdrawal, the output of grain sorghum increases only 2 percent by 1985 and decreases 4 percent by 2010.

Regional employment necessary to support the output of the agriculture sectors is estimated from sectoral output and employment-output ratios. If groundwater withdrawal in the Northern High Plains continues along the present trend, employment is expected to increase from 129,500 in 1975 to 150,600 in 1990 and then decrease to 141,400 in 2010. These employment figures are estimates of total regional employment necessary to support the agricultural output. They are less than those estimated by Ekholm (Table 1) because they do not include employment unrelated to agriculture and other differences in assumptions of the two models.

If the slower rate of groundwater withdrawal is assumed, employment increases from 1975 to 2010. However, the rate of change in employment is less than under the other two rates. Regional employment increases from 129,500 in 1975 to 139,500 in 2010.

With the faster rate of groundwater withdrawal, total employment necessary to support agriculture output increases from 129,500 in 1975 to 150,600 in 1988 and then decreases to 141,400 in 2008. Employment increases 15.5 percent from 1975 to 1985 under the faster groundwater use rate compared to 10 percent under the current projected rate. The changes in regional employment are due to changes in agricultural activity.

As annual groundwater availability increases in the region, total irrigated acres increase from 1.95 million acres in 1975 to 2.71 million acres in 1990, and decreases to 2.1 million acres in 2010 due to dewatering of the aquifer. Total cropland remains constant throughout, thus the increase (decrease) in irrigated acres corresponds to an equal decrease (increase) of dryland production. The reduction in irrigated acres causes a reduction in producers net returns.

Net returns to High Plains producers increase from $256.0 million in 1975 to $298.60 in 1990 assuming the current rate of irrigation development. Net returns decrease as dryland production is substituted for irrigated production in the region. Total producer net returns decrease to $271.3 million by 2010. Under the faster rate of irrigation development in the Northern High Plains, net returns increase from $256.0 million in 1975 to $298.3 million by 2008. If groundwater withdrawal is restricted to the slower rate, producers net returns increase from $256.0 million in 1975 to $267.0 million in 2010.

The producers' net returns are discounted at a rate of 8 percent to compare the strategies of groundwater withdrawal. Total discounted returns are highest for the faster rate of development of groundwater. This thus indicates that producers would have incentive to not reduce their rate of water use but rather increase it. Eight percent is assumed as a typical internal rate of return for producers. The producers' net returns are also discounted at an assumed social discount rate of 3.25 percent. At a low discount rate the present value of the groundwater supply is greatest for the slower rate of development and use.

These results indicate that a significant discrepancy exists between the preferences of society and producers. The internal rate of return would need to fall to less than 5 percent before producers would change strategies. Similarly, the social discount rate would have to exceed 5 percent before society would change strategies. With such a gap between the two groups, considerable attention needs to be given to policies of groundwater withdrawal that form a compromise between the two interests.

The input-output segments of the model estimate the non-agriculture output necessary to support the economic activity level of the agricultural sector. Under the current rate of irrigation development, non-agricultural output in the High Plains increases from $391.89 million in 1975 to $473.59 million in 1980 and decreases to $435.3 million in 2010. Maximum output necessary to support agriculture under the rapid groundwater development rate is reached in 1988 as opposed to 1990 under the current rate. The sectors that are most affected include agriculture services, milling and feeds, chemicals, petroleum products, and finance.

The output of the services sector is expected to increase from $29.1 million in 1975 to $33.6 million in 1990 and decline to $31.0 million in 2010. The milling and feeds sector shows a gradual increase in output until 2010. The chemicals sector is tied closely to irrigated production, thus the chemicals sector increases output until 1990 and decreases output thereafter. The same trend is apparent for the petroleum sector as it is also shows high relative dependence on irrigated production. The finance sector shows increasing output until 2000 and a gradual decline from 2000 to 2010.

This study provides insight to the possible effects of depleting the groundwater inventories of the region. Model results indicate that agriculture output increases for a few years and then begins a steady decline. For the years of increase, gross regional product increases, thus providing markets for secondary and tertiary industries. The sectoral output increases of the non-agriculture sectors show how the economy is expected to expand. The expanding regional product leads to increasing employment opportunities.

However, a reversal is expected when annual groundwater pumpage begins to decrease. As sectoral output diminishes, some of the industries are forced to reduce production. This, in turn, leads to decreasing employment. Details of the study are presented by Casey, Jones and Lacewell.

Economic Growth Sectors

An interindustry model was developed for the study area with 94 processing sectors (Table 4). Sectors one through eight were crop sectors which are directly related to availability of groundwater for irrigation. That is, as availability of groundwater for irrigation is increased, the total value of output by the irrigated crop sectors would increase (Sectors one through four).

Results of the work by Ekholm provided information regarding growth in the irrigated crop sectors (Table 5). Expansion was projected for the dryland crop sectors since a trend was included in the economic model for technological advances. Likewise, the reduction in value of production for the irrigated crop sectors was less since the trend for technology was included.

Estimated losses in employment from decline in groundwater for irrigation were 5802 people from 1995 to 2010 (Table 6). These estimates are based on constant direct employment coefficients which do not assume changes in labor productivity. This estimate included direct employment, indirect employment, and induced employment effects. Reduction in employment would have impacts on many other industries through income losses which would reduce the effective demand for goods and services.

Economic sectors with a potential for economic growth can be classified as agricultural related and nonrelated to agriculture (Table 7). Over 50 percent of the value of production of each crop sector is exported from the area. A potential for growth in the agricultural related sectors for processing of these raw materials does exist. (Sectors 23, 24, 25, 26, and 28).

The Milling and Feeds Sector has a Type II multiplier for employment of 6.05. That is, for each new employee in the sector, additional employ-

Table 4. Input-Output Model, Northern High Plains

Sector Code Number	Sector Name	Standard Industrial Classification Components
		Agriculture
1	Irrigated Cotton	Irrigated part of 0112
2	Irrigated Food Grains	Irrigated food grain part of 0113
3	Irrigated Feed Grains	Irrigated feed grain part of 0113
4	All Other Irrigated Crops	Parts of 0119, 0122, and 0123
5	Dryland Cotton	Dryland part of 0112
6	Dryland Food Grains	Dryland food grain part of 0113
7	Dryland Feed Grains	Dryland feed grain part of 0113
8	All Other Dryland Crops	Parts of 0119, 0122, and 0123
9	Range Livestock	Parts of 0135, 0136, and 0139
10	Feedlot Livestock	Parts of 0135, 0136, and 0139
11	Swine	Parts of 0136
12	Dairy and Poultry	0132 and 0134
13	Ginning and Compressing	0712
14	Agricultural Services	0713 through 0731
		Mining
15	Crude Petroleum	1311
16	Natural Gas	1321
17	Oil and Gas Field Services and Other Mining	1011 through 1099, 1381 through 1389, and 1411 through 1499
		Construction
18	Residential	Parts of 1511 and 1611 as well as associated special trade contractors
19	Commercial, Educational and Instructional	Parts of 1511 and 1611 as well as associated special trade contractors
20	Industrial	Parts of 1511 and 1611 as well as associated special trade contractors
21	Facility	Parts of 1511, 1611, and 1621 as well as associated special trade contractors
22	Maintenance and Repairs	Parts of all SIC in construction that are involved in this activity
		Manufacturing
23	Meat Products	2011 through 2013
24	Dairies	2021 through 2026
25	Milling and Feeds	2041 through 2047
26	Food Processing	2031 through 2036, 2051 through 2073, and 2091 through 2099
27	Beverages	2082 through 2087
28	Textile Products	2211 through 2399
29	Wood Products	2411 through 2599
30	Paper Products and Printing	2611 through 2794
31	Chemicals	2812 through 2899
32	Petroleum Products and Plastics	2911 through 3231

Table 4 (Continued)

Sector Code Number	Sector Name	Standard Industrial Classification Components
	Manufacturing (cont.)	
33	Soil and Rock Products	3251 through 3299
34	Metal Products	3312 through 3429, 3441 through 3449, 3471 through 3493, and 3499
35	Plumbing and Related Products	3431 through 3433, 3451 through 3461, and 3494 through 3498
36	Machinery	3511 through 3599
37	Electronic Equipment	3611 through 3699
38	Transportation Equipment	3711 through 3799
39	Other Manufacturing	3811 through 3999
	Transportation	
40	Railroad	4011 through 4041
41	Intercity Rural Highway	4131 and 4132
42	Motor Freight	4213 and 4231
43	Other Warehousing	4222 through 4226
44	Air	4511 through 4583
45	Local and Suburban	4111 through 4121
46	Other Transportation Services	4141 through 4172, 4712, 4713, and 4742 through 4789
	Communications	
47	Telephone	4811 and 4821
48	Radio and TV	4832 and 4833
49	Other Communications	4899
	Utilities	
50	Gas Services	4922 through 4925, and part of 4931 through 4939
51	Electric Services	4911 and part of 4931
52	Water and Sanitary Service	4941 through 4953
	Wholesale Trade	
53	Auto Parts and Services	5012 through 5013
54	Groceries	5041 through 5049
55	Farm Products	4221, 5052, 5053, and 5059
56	Livestock	4731 and 5054
57	Non-Farm Machinery, Equipment and Supplies	5081, 5082, and 5084 through 5089
58	Farm Machinery, Equipment and Supplies	5083
59	Petroleum and Petroleum Products	5092

Table 4 (Continued)

Sector Code Number	Sector Name	Standard Industrial Classification Components
	Wholesale Trade (cont.)	
60	General Wholesale	5022, 5028, 5029, 5033 through 5039, 5063 through 5077, and 5093 through 5099
	Retail Trade	
61	Lumber Yards	5211
62	Farm Equipment	5252
63	Agricultural Supplies	5962 and 5969
64	Hardware, Heating, Electrical, Paint and Wallpaper	5221 through 5251
65	Department and Variety	5311, 5331, and 5399
66	Food	5411 through 5499
67	Automobile Dealers and Repair Shops	5511 through 5531, and 7531 through 7539
68	Gasoline Service Stations	5541
69	Apparel and Accessory	5611 through 5699
70	Furniture, Home Furnishings, and Equipment	5712 through 5733
71	Eating and Drinking Places	5812 and 5813
72	Other Retail	5591 through 5599 and 5912 through 5999
	Finance, Insurance, and Real Estate (F.I.R.E.)	
73	Banking and Credit Agencies	6011 through 6161
74	Insurance Carriers	6312 through 6399
75	F.I.R.E., NEC	6211 through 6281 and 6411 through 6799
	Services	
76	Legal	8111
77	Lodging	7011 through 7041
78	Personal	7211 through 7299
79	Advertising	7311 through 7319
80	Research and Development	7391 and 8921
81	Other Business Services	7221, 7331 through 7351, 7361, 7392 through 7399, 7813 through 7815, and 7821
82	Motion Picture, Amusement, and Recreation	7816 through 7833, and 7911 and 7849
83	Automobile Rental and Parking	7512 through 7525
84	Miscellaneous Repair	7622 through 7699
85	Physicians and Dentists	8011 through 8041
86	Hospital and Laboratory	8061 through 8072
87	Other Medical	8092 and 8099
88	Elementary and Secondary Schools	8211

Table 4. (Continued)

Sector Code Number	Sector Name	Standard Industrial Classification Components
	Services (cont.)	
89	Colleges and Universities	8221 and 8222
90	All Other Education	8231 through 8299
91	Accounting, Auditing and Bookkeeping	8931
92	Other Professional	8911 and 8999
93	Other Services	8411 through 8811
	Other	
94	Ordnance	1911 through 1999
	Final Payment	
95	Households[a]	
96	Federal Government	
97	State Government	
98	Local Government	
99	Imports	
100	Depreciation	
	Final Demand	
101	Households[a]	
102	Net Change in Inventory	
103	Federal Government	
104	State Government	
105	Local Government	
106	Exports	
107	Capital Formation	

[a] Although the High Plains model was closed when the Households Sector was included in the processing section, it is generally included in the final payments section.

Table 5. Projected Value of Production for Irrigated and Dryland Crop Sectors, Northern High Plains, 1967, 1990, 1995, and 2010[a]

Sector Number	Sector Name	1976	1990	1995	2010
			($1,000,000)		
1	Irrigated Cotton	24.6	23.3	21.8	16.6
2	Irrigated Food Grains	71.1	136.6	148.6	129.9
3	Irrigated Feed Grains	165.9	309.2	333.9	293.0
4	All Other Irrigated Crops	44.4	46.6	46.2	39.6
	Total	306.0	515.7	550.5	479.1
5	Dryland Cotton	7.1	12.0	13.0	16.3
6	Dryland Food Grains	23.2	24.1	24.4	33.2
7	Dryland Feed Grains	21.9	15.8	17.6	35.2
8	All Other Dryland Crops	5.2	8.8	10.0	14.5
	Total	57.4	60.7	65.0	99.2

[a]Source Ekholm

Table 6. Estimated Changes in Employment from Declines in Value of Production from Crop Sectors, Northern High Plains

Sector Number	Sector Name	Changes in Value of Production 1995-2010	Direct Employment Per $10,000	Direct Employment Total from Change	Type II Employment Multiplier	Total Employment Changes
		($10,000)				
1	Irrigated Cotton	-520	.8769	-456	1.50	-684
2	Irrigated Food Grains	-1870	1.7547	-3281	1.24	-4068
3	Irrigated Feed Grains	-4090	.9367	-3831	1.44	-5517
4	All Other Irrigated Crops	-660	.8054	-532	1.50	-798
5	Dryland Cotton	330	.4953	163	1.91	311
6	Dryland Food Grains	880	1.1979	1054	1.34	1412
7	Dryland Feed Grains	1760	1.1198	1971	1.39	2740
8	All Other Dryland Crops	450	1.3320	599	1.34	802
	Total	3720	----	4313	----	5802

Table 7. Potential Economic Growth Sectors for the Northern High Plains

Sector		Employment		Type
Number	Name	Per $10,000	Type II Multiplier	
23	Meat Products	.8030	1.57	Agricultural Related
24	Dairies	.2285	3.88	Agricultural Related
25	Milling and Feeds	.1645	6.05	Agricultural Related
26	Food Processing	.1598	4.26	Agricultural Related
28	Textile Products	.4516	1.83	Agricultural Related
36	Machinery	.5012	1.51	Nonrelated to Agriculture
37	Electronic Equipment	.3742	1.39	Nonrelated to Agriculture

ment is generated for 5.05 other people. The multiplier is high since several other sectors use the product from the Milling and Feeds Sector.

Some processing of output from Sectors 1, 4, and 5 is being conducted at the present time by the Food Processing Sector. Processing of production from Sectors 2, 3, 6, 7, and 8 is possible. The employment multiplier is high (4.26). Potential expansion of this sector would be limited by the level of availability of groundwater for irrigation.

Locational advantages in regards to raw product is available for Sector 28 (Textile Products). Some expansion is being experienced by this sector at present. However, the potential expansion is large.

Manufacturing of Machinery (Sector 36) has a potential for growth as a nonrelated agricultural sector. Although the Type II employment multiplier is low per $10,000 when compared to other sectors, the value of output could be high. Transportation, labor, weather, and natural resource availability would provide an environment for expansion.

Stability in the regional economy would be increased by expanding the Electronic Equipment Sector. This sector is relatively unrelated to agriculture with minimum requirements for natural resources. However, a supply of labor and transportation facilities are necessary for the sector. These services and resources are available in the regional economy. Details of the study are presented by Osborn and Johnson.

Projected Community Services

Williford, Beattie and Lacewell describe in detail the expected effect of a declining resource base on provision of community services.

Model For analysis, a community service expenditure function was specified as a linear additive model and fitted using least squares regression analysis. Total operating expenditures for all services was the dependent variable while independent variables were 1970 community population, county per capita income in 1970, and percent change in community population from 1960 to 1970. A cross sectional data set composed of observations from 47 communities was used in building the model. The variable values from the smallest community, largest community, and the range over all sample sizes are shown in Table 8.

A number of alternative equation specifications were used. These included power and quadratic forms as well as various combinations of the independent variables. The model that provided the best fit of the sample data was

$$1)\quad TE = -177734.73 + \underset{(29.96)}{49.103P} + \underset{(2.044)}{56.146Y} - \underset{(-2.929)}{1312.050C}$$

$$R^2 = .9244 \qquad F = 175.312$$

where

TE = total community service expenditures

P = 1970 community population

Y = county per capita income in 1970

C = percent change in community population 1960-1970

The "T" values below each coefficient are all significant at the 95 percent probability level.

Table 8. Values of principle community service variables for 47 communities in the Texas High Plains

Variable	Unit	Smallest Community	Largest Community	Range over all communities
Community population	persons	578	21,726	578 to 21,726
Percent change in community population (1960-1970)	percent	31.96	-11.91	-31.12 to 75.30
County per capita income	dollars	3,071	3,655	2,442 to 3,952
Total service expenditures	dollars	5,271	1,088,812	5,271 to 1,088,812

Each of the coefficients has the expected sign. The percent change in community population has a negative coefficient which indicates that a community experiencing a great deal of growth over a decade should have to expand the services offered and in turn expenditures made on these services. Conversely, a community whose population has declined in the decade should have a greater amount of capital facilities and equipment than would be currently needed. In attempting to maintain these facilities, the expenditures could be expected to be disproportional to community size.

Projected Community Service Expenditures In projecting the level of service expenditures over time, equation (1) was used. The values of the independent variables were computed from the results of the Oklahoma State University regional simulation model. Per capita income was assumed to be at the same level as that projected by Ekholm, Schreiner, Eidman and Doeksen, for the region. Community population was assumed to be at a given level in 1968 and change by the same rate as total regional population in the simulation model.

The projected levels of expenditures over time for five communities of a given population in 1968 are shown in Table 9. Although these figures are not purported to represent the case for any individual community, they should illustrate the path of service expenditures over time for "average" area communities of approximately the same size.

Examination of Table 9 shows that expenditures in a community with an initial population of 2,500 are projected to rise steadily by approximately 53 percent from 1978 to 2010. This was caused by the continuous increase in per capita income diminishing the effect of declining population in the smaller communities.

In a community with a 1968 population of 20,000, service expenditures are estimated to increase 3.6 percent from 1978 to 1990, and decline 15 percent by 2010. These results indicate that larger communities will be able to respond more rapidly in reducing service output with a decline in population and economic activities while smaller communities may be less able to do so.

Perhaps of greatest interest in examining the effects of an overall community decline stemming from a diminishing resource base is per capita service expenditures. The projected levels of per capita total service

Table 9. Projections of total service expenditures through 2010 for five Northern High Plains communities of a given population in 1968

			1968 Population									
			2,500		5,000		10,000		15,000		20,000	
Year	Per Capita Income[a] (1967 $)	Change in population (%)[b]	Population	Total Service Expenditures	Population	Total Service Expenditures	Population	Total Service Expenditures	Population	Total Service Expenditures	Population	Total Service Expenditures
1978	3,510	21	3,025	140,321	6,049	288,809	12,097	585,784	18,145	882,759	24,191	1,179,635
1980	3,553	19.6	3,056	145,963	6,110	295,924	12,218	595,845	18,327	895,815	24,433	1,195,638
1985	3,702	5.4	3,022	171,291	6,039	319,435	12,077	615,918	18,116	912,451	24,151	1,208,788
1990	3,865	-1.5	3,011	189,087	6,017	336,690	12,030	631,947	18,046	927,350	24,058	1,222,558
1995	4,019	-1.2	2,987	196,161	5,971	342,685	11,937	635,633	17,905	928,680	23,870	1,221,579
2000	4,144	-5.5	2,847	201,816	5,692	341,514	11,378	620,713	17,066	900,011	22,753	1,179,260
2005	4,315	-12.3	2,619	209,274	5,236	337,777	10,464	594,487	15,696	851,394	20,926	1,108,203
2010	4,511	-15.6	2,404	214,051	4,806	331,997	9,602	567,495	14,405	803,337	19,205	1,039,031

[a]Source: Ekholm [2]

[b]Calculated over 10 year period

expenditures for the selected community sizes are given in Table 10. These values indicate that slight increases in per capita expenditures over larger communities exist throughout the study period while rather large increases are projected for smaller communities.

In summary the estimations show the effects of the projected economic and demographic decline due to the declining groundwater supply in the Northern High Plains to be much more serious for smaller communities, under 5,000 population. The projections of this study show that smaller towns will be required to proportionately increase total expenditures at a greater rate over time than will larger communities. The smaller communities are also shown to face a disadvantage in per capita costs of service provision. Since the majority of the area towns fit into this category, it can be concluded that the area as a whole will be adversely affected in providing public services.

Table 10. Projections of per capita total service expenditures through 2010 for five Northern High Plains communities of a given population in 1968

Year	1968 Population				
	2,500	5,000	10,000	15,000	20,000
1978	43.39	47.75	48.42	48.65	48.76
1980	47.76	48.43	48.77	48.88	48.94
1985	56.68	52.90	51.00	50.37	50.05
1990	62.80	55.96	52.53	51.39	50.82
1995	65.67	57.39	53.25	51.87	51.18
2000	70.89	60.00	54.55	52.74	51.83
2005	79.91	64.51	56.81	54.24	52.96
2010	89.04	69.08	59.10	55.77	54.10

CONCLUSIONS

The different thrusts of this project all support a central conclusion, that reduced annual withdrawals of groundwater for irrigating agricultural crops due to a progressively declining water supply will exert significant downward pressure on the economy of the region. The reduced agricultural output will be reflected throughout the region in terms of population, employment and gross output of non-agricultural sectors. The declining groundwater supply effects costs of providing community services. Of particular significance is the expected effect on smaller communities (less than 5,000) where rather dramatic increases in costs of community services are indicated.

Through this study, the structure of the Northern High Plains Economy has been quantified. Data have been developed relative to expected changes in population, employment, per capita disposable income and agriculture and non-agricultural output. This provides information to planners in developing policy for regional development. Further the models are available for estimating the impact of alternative policies such as water importation or encouragement toward rapid growth in specific industries.

A last major conclusion brought about by this project is the verification that regional projects crossing university and state lines can be most successful. For a major problem as the declining groundwater in the Northern High Plains, there are several affected communities and two states. By cooperating and joining in a single project a much superior product evolved that than could be expected from each university operating independently.

A note on study limitations is appropriate. Several models with a brief overview of results have been presented in this report. It must be understood that underlying the models are certain assumptions and any project of this magnitude certainly has limitations associated with the results. The limitations of each study are explicitly defined in the respective reports.

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