Nebraska
Natural
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Commission

State Water
Planning
and Review
Process

Report on the
South-Central Area Ground Water Planning Study

State of Nebraska
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Dayle E. Williamson, Director of Natural Resources

Natural Resources Commission

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Problem Analysis and Area Planning Acitivity

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Table of Contents

List of Figures

List of Tables

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Chapter 1
INTRODUCTION

The South-Central Area Ground Water Planning Study was a cooperative study of the water and related land resources of parts of the Platte, Little Blue, and Republican river basins. It was conducted by the Natural Resources Commission (NRC) with the cooperation of the Lower Republican, Central Platte, and Tri-Basin natural resources districts, and the Central Nebraska Public Power and Irrigation District. It was based on work done by the same agencies, in cooperation with the U.S. Geological Survey, on the South-Central Nebraska Hydrogeology Study.

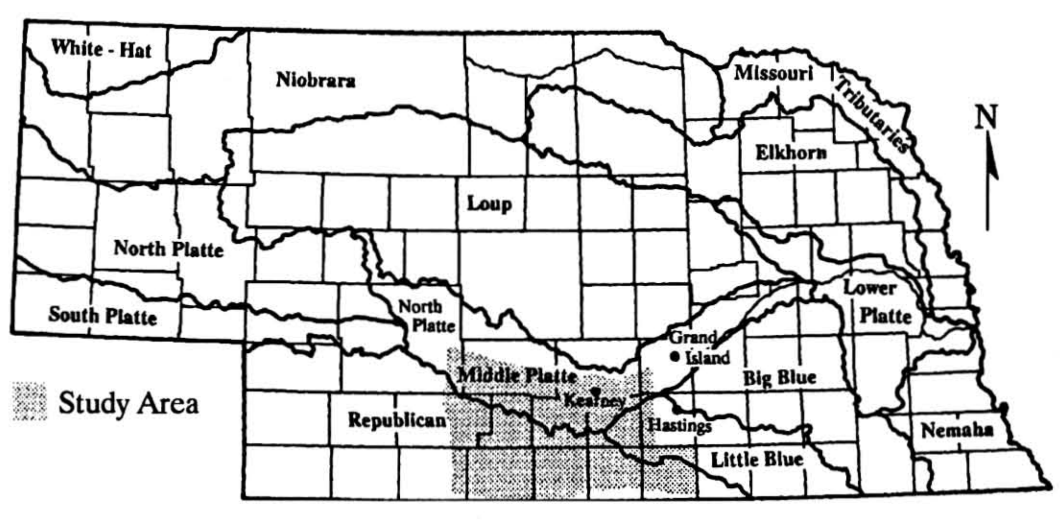
This report is a product of the State Water Planning and Review Process for which the NRC is responsible. The design of the process, prepared in 1978 at the direction of the Legislature, set up a continuing process comprised of five activities: Policy Issue Analysis, Problem Analysis and Area Planning, Project and Program Review, Project Planning and Design, and Basic Planning.

Prior to 1978, the NRC had been working on a basin planning study of the Big and Little Blue river basins. Although it was phased out after the new process was implemented, the work that was completed showed that ground water conditions in the adjoining Platte River Basin had a significant effect on the western end of the Little Blue River Basin. It was evident that the existence and use of the surface water and ground water resources in any river basin in the south-central area could have an impact on other basins.

Extensive water resources development in the Middle Platte River Basin had changed both the surface water and ground water supplies in that basin and adjacent areas. Seepage losses from the storage and distribution systems of several irrigation projects caused ground water levels to rise more than 10 feet in an area of nearly 1,000 square miles. They had risen as much as 80 to 90 feet in some places.

Extensive ground water development in the 1970s that was dispersed throughout the projects' service areas, and around them, also had significant effects on ground water re-

Nebraska's River Basins



sources. In some places outside the area of ground water rise, water table declines of five feet or more were measured.

Much better knowledge of the south-central area from the Platte River to the Republican River was needed, so the NRC decided to conduct a study of the geology and hydrology of the area. In April 1979 the NRC approved a proposal to contract with the U.S. Geological Survey (USGS) for a cooperative study to prepare for further planning. It became one of the first Problem Analysis and Area Planning studies in the Planning and Review Process.

STUDY DESCRIPTION

The South-Central Area Ground Water Planning Study evolved from the hydrogeology study. The role of that study was the collection of data and development and testing of a digital computer ground water model. The role of the planning study was to use the ground water model with an economic model to project future conditions under a wide variety of assumptions to evaluate planning and management alternatives.

STUDY PARTICIPANTS

The USGS was primarily responsible for the hydrogeology study. They organized and supervised the field work to collect data and led the work on the development of the computer model. The natural resources districts (NRDs), Central Nebraska Public Power and Irrigation District (CNPPID), and the NRC contributed to data collection efforts. The NRC also participated in the preparation of the computer model.

The NRC led the planning study. The NRDs and CNPPID helped define current trends in land and water use, and specified different conditions that might control future water use in simulations with the models.

PURPOSE AND SCOPE OF THE STUDY

The South-Central Area Ground Water Planning Study originated during the hydrogeology study. It was designed to extend that study and address some needs the first study did not fulfill. The purpose of the planning study was to utilize the computer models and knowledge gained from previous studies to simulate future conditions specified by study participants. These simulations were intended to be used to evaluate the effects of various management and development alternatives on the ground water resource, and some of the attendant impacts.

The objectives of the study were to:

1. use the results of the hydrogeology study to give participants and the public better understanding of the water and related land resources of the area,
2. inform the districts of the capabilities and constraints of the model and other analytical systems,
3. identify trends and future conditions considered likely to occur and reach agreement on alternative development and management activities needing evaluation,
4. simulate future ground water storage and water table levels under selected conditions, and
5. evaluate the effectiveness of alternatives and identify some of their impacts.

This detailed study of the ground water resources of the south-central area also considered related water resources, including precipitation, soil moisture, surface water used for irrigation and power production, and streamflow affected by ground water. Land resources and uses affecting water resources were also studied in detail. The study of economic and social impacts of land and water use was limited to examination of area-wide impacts of ground water management on farming and ranching production and returns.

Ground water studies were sufficiently detailed to construct a regional, digital computer model capable of representing average water table conditions in sub-areas, called elements, ranging in size from 179.4 acres to 13,765.8 acres, and averaging 3,475.8 acres. Model computations were based on average conditions for two periods each year: the irrigation season in June, July and August, and the non-irrigation season. Land use data, especially cropland data, were based on county statistics reported by the Nebraska Agricultural Statistics Service. The data were distributed according to a land use map prepared for this study and irrigation well registration records from the Department of Water Resources.

CONTENTS OF REPORTS

The first two reports by the USGS on the south-central Nebraska hydrogeology study contain detailed data collected during the geologic drilling program, and other hydrologic data. The third USGS report, Hydrogeology of the Tri-Basin and Parts of the Lower Republican and Central Platte Natural Resources Districts, Nebraska, Water-Resources Investigations Report 87-4176, presents a detailed description of the area and its hydrogeologic system, and a description of the computer model. It also includes the results of the model's simulation of historic conditions and future conditions with artificial constraints on development.

This NRC report presents the results of many ground water model simulations of future conditions or hypothetical conditions without existing projects. For some situations, it also presents information on potential economic impacts projected by the economic model. It contains enough background information on the area modeled, and the study participants, conditions, methods and procedures to provide an understanding of those results.

PROCEDURES AND METHODOLOGY

The purposes of the two studies were related but different, so the procedures and methods used were also different. The USGS had primary responsibility for the development of the model in the first study, so an explanation of their procedures is not represented in this report. In the hydrogeology study, the NRC had primary responsibility only for determining land use in the study area. The NRC was the leader in the planning study, which focused primarily on applications of the ground water model. The modeling procedures used in the hydrogeology study were changed slightly for the planning study.

LAND USE MAPPING

Land use information was essential to the development of the ground water model and the simulation of future ground water conditions. Detailed land use data were provided for one year by mapping land use, and estimates were made for other years by modifying data from that map with information from other sources.

In preparing the land use map, some on-site data were collected to improve identification by remote sensing techniques. Aerial photographs were used to delineate field patterns, and land use in those fields was identified from a combination of sources, including aerial photographs, satellite imagery, field notes, and Agricultural Stabilization and Conservation Service files.

GROUND WATER MODELING

To simulate the ground water system of the south-central area, RAQSIM (Regional AQuifer SImulation Model) was selected. It is a two-dimensional finite-element model that allows considerable flexibility in choosing boundaries and representing streams in the study area. It utilizes an irregular node pattern, so smaller cells can be used in areas where streams or geologic features are more complex. Larger cells can be used where conditions are more homogeneous.

RAQSIM does not model the vertical component of ground water flow. Instead, it accounts for vertical variations in the saturated layers by recomputing several aquifer characteristics if the water level changes between time steps exceed a limit specified by the modeler. More information on the program may be obtained from Documentation of a Regional Aquifer Simulation Model, RAQSIM, and a Description of Support Programs Applied in the Twin Platte - Middle Republican Study Area, USGS Water-Resources Investigations Report 85-4168.

ECONOMIC MODELING

The Farm and Ranch Economics (FARE) model was used to simulate the agricultural economy of the study area. The FARE model is a revised and updated version of the model constructed for the Six-State High Plains Ogallala Aquifer Study. It divides the state into 20 regions. The area covered by two of these regions corresponds closely with the study area.

The model is a recursive linear program which determines the combination of cropping alternatives for a region that maximizes net returns to agriculture, depending upon the availability of natural resources and the price-cost situation for agricultural production. The model generates a solution for eight periods beginning in 1985 and ending in 2020. Actions taken in any time period can modify what happens in the next time period. For example, pumping ground water may cause water tables to decline and increase the depth from which water must be pumped during succeeding time periods; this changes pumping costs.

A measure of the availability of land and water resources in a region is also needed for the model. The land resources are determined using secondary sources such as agricultural statistics and data from the Soil Conservation Service concerning land capabilities. The water resources available, particularly ground water, are calculated within the model using mathematical equations that were derived from data generated by the ground water model.

The output of the FARE model can be divided into economic and physical categories. The economic output is information on net income. Net farm income is approximated with estimates of returns to land and management. These returns are the residual of income that remains after charges for all production costs except charges for land (rent or mortgage) and for the operator's management have been deducted. This value can be reported on a per acre basis or as a total for the region.

The outputs in the physical category provide information on resource use or commodity production. The model keeps track of the amount and use of the land resources in a region. The amount of land that is irrigated with ground water or surface water, the amount that is farmed without irrigation, and the amount of pasture or range in a region can be reported. The model also can report the amount of ground water used for irrigation and estimates of the effect that this pumping has on the aquifer. Reports can be extracted from the model output that show how many acres of each crop are grown during a solution year and the total production of each commodity.

The cropping alternatives include the major crops: corn, grain sorghum, soybeans, wheat, and alfalfa. Other crops, such as wild or tame hay, small grains other than wheat, sugar beets, and dry edible beans may also be included among the alternatives. Each crop can be dryland, or irrigated with either surface water or ground water. The irrigated production alternatives include gravity and sprinkler systems and various levels of water application. Sixty-five possible combinations can be considered, in addition to the pasture/rangeland alternative.

Chapter 2
THE SOUTH-CENTRAL AREA

The study area, shown in Figure 1, covers more than 5,600 square miles, including all or part of 14 counties in south-central Nebraska. It lies within three river basins: Middle Platte, Republican, and Little Blue. The three NRDs that cooperated in the study: Central Platte, Lower Republican, and Tri-Basin, cover most of the study area, but it extends slightly into the three adjacent NRDs.

GEOGRAPHY AND GEOLOGY OF THE AREA

The south-central area has evolved physically into a region which supports intensive agriculture and a small population. Its climate, soils, and physical geography help support the population and agricultural base, but the continued availability of irrigation water from streams and aquifers is one of the keys to the future of the area.

PHYSICAL FEATURES

The land surface in the study area was formed primarily by wind blown deposits of silt and clay, called loess. These deposits formed a relatively flat upland plain which still exists in the central portion of the area. This plain covers most of Phelps and Kearney counties and northern Franklin County. It is an area of low relief with nearly level to gentle slopes, shallow, poorly defined drainageways, and many closed drainage basins. When rainfall is sufficient, numerous irregularly distributed fresh water wetlands are formed in the closed basins. These basins caused this region, with another region to the east, to be called the "rainwater basin" area.

Many wetlands in both regions have been drained for agricultural purposes. Most of the remaining "rainwater basin" wetlands are now in the region that lies outside the study area.

In the remainder of the study area, the plain has been eroded by water and wind, producing landforms with moderate to steep slopes, sharp ridge crests, and remnants of the old plain. These dissected plains can be found both north and south of the flat, upland plains area.

Two major streams cross the study area, as shown in Figure 2. The Platte River flows near the north boundary of the area, and the Republican River flows across the southern portion. Both streams cross the study area from west to east and are characterized by wide, shallow channels with low banks, numerous sand bars, and many small islands. The numerous tributaries of the Republican River are typically narrow and deeply incised, whereas the broad Platte River valley lowlands have drainage patterns that are less well developed.

The CNPPID diverts water from the Platte River west of the study area. This water is conveyed through supply canals and reservoirs to the study area for power generation and irrigation. Johnson Reservoir, the Midway Lakes, and Elwood Reservoir are the largest reservoirs in the CNPPID system within the study area. Johnson Reservoir covers approximately 2,500 acres. Midway Lakes, a group of eight lakes near the western edge of the study area, were formed by the Tri-County Supply canal. They have a total surface area of approximately 615 acres. Elwood Reservoir, the latest addition to the CNPPID system, covers approximately 1,150 acres when full.

South-Central Ground Water Planning Study Area

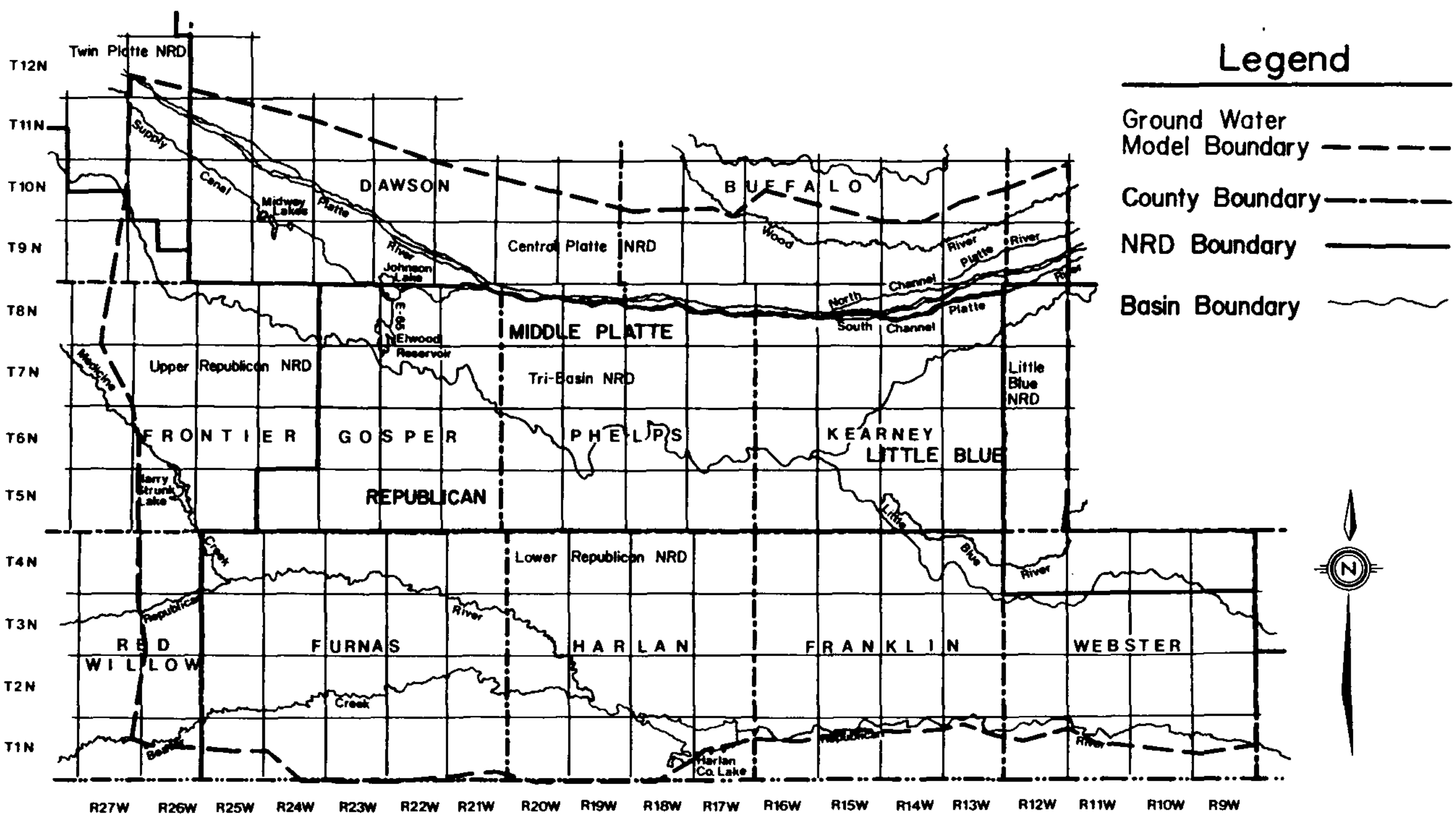
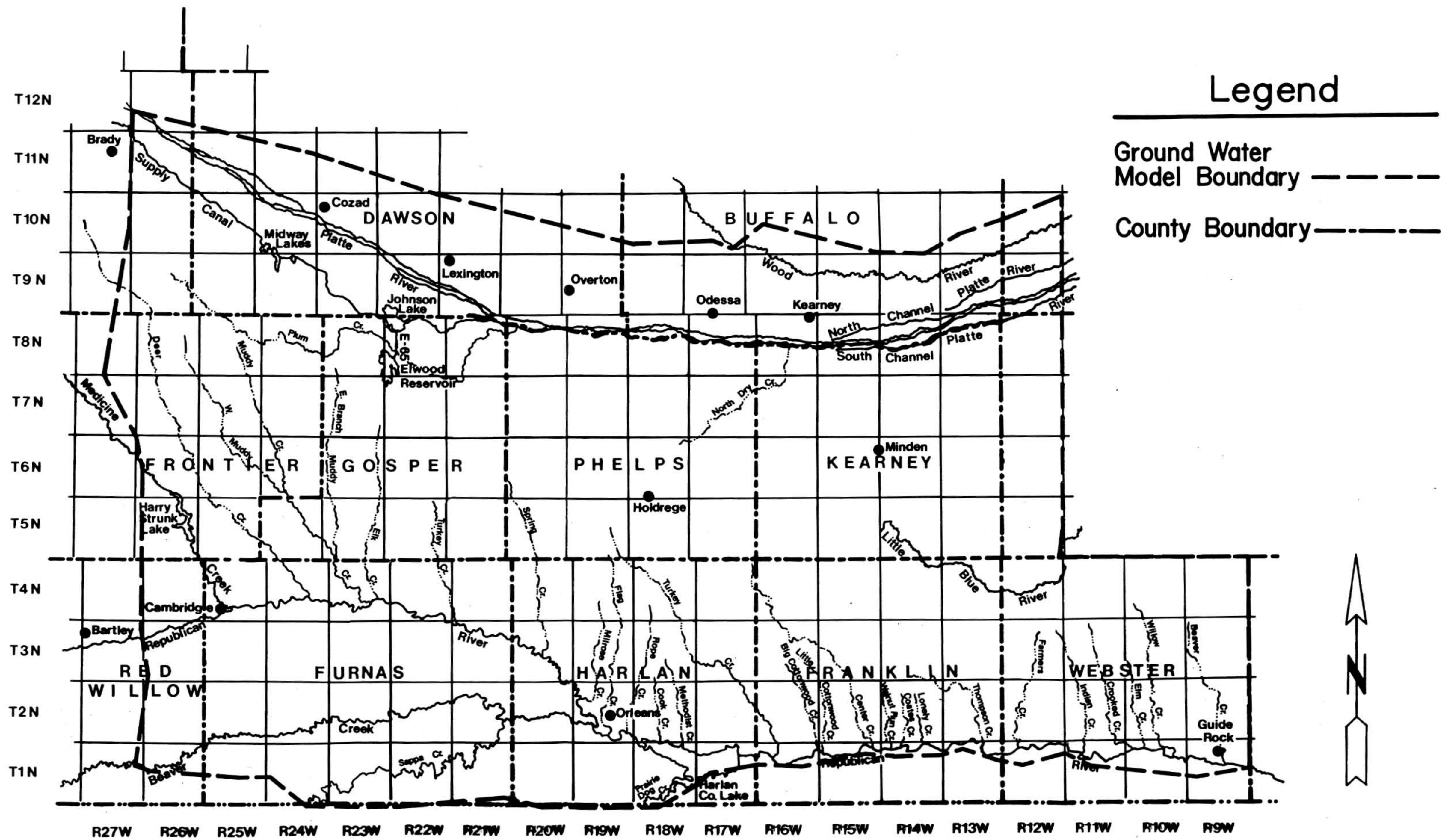


Figure 1

Streams in the Study Area



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Harlan County Lake is the largest reservoir in the study area. It is located on the Republican River in the southeast corner of Harlan County. With its conservation pool filled to capacity (350,000 acre-feet), Harlan County's surface area measures 13,200 acres. Harry Strunk Lake, created by Medicine Creek Dam, lies on the western boundary of the south-central area. Its surface area measures 1,840 acres, and it provides water for irrigation in Furnas and Harlan counties.

COMMUNITIES

Population centers in the study area vary widely in population and area. Many of the larger cities developed along the major transportation corridor provided by the Platte River. Most of the towns in this corridor originally developed with the construction of the first transcontinental railroad.

Six cities have 2,500 or more inhabitants, so they are considered urban areas according to the 1980 Census of Population. Kearney is the largest with 21,751 people, followed by Lexington (7,040), Holdrege (5,624), Cozad (4,453), Gothenburg (3,479), and Minden (2,939). All except Holdrege and Minden are located in the Platte River valley, and those two are located on another major railroad.

There are eight other cities in the study area that fall in the 2,500 to 1,000 population range. The largest group of population centers includes incorporated and unincorporated communities of less than 1,000 population. They range in population from nearly 1,000 to less than 100.

CLIMATE

The study area is characterized by a continental-type climate prone to extremes. It typically experiences a wide range in monthly and seasonal temperatures with cold winters and short hot summers. Kearney, for example, has experienced extremes of -34 degrees and 114 degrees for record low and high temperatures. January is normally the coldest month and July is normally the warmest.

Average annual rainfall in the study area varies from approximately 20 inches in the west to 24 inches in the east. Kearney's average annual precipitation is 22.6 inches. Gothenburg, which is farther west, annually averages 19.9 inches of precipitation. During the winter months, precipitation is generally snow. Average annual snowfall ranges from 21 to 32 inches across the area.

Rainfall in the study area is unevenly distributed throughout the year. However, nearly two-thirds of the average annual rainfall generally occurs during the growing season. Summer rainfall is usually in the form of localized thunderstorms, so precipitation patterns can vary considerably during the growing season. The normal growing season of 150 to 180 days extends from the second week in April through the second or third week of October.

Climatic data from 31 weather stations under the administration of the National Weather Service and 8 weather stations maintained by the CNPPID in or near the study area were used to estimate water-use data for the ground water model. Monthly precipitation data for the years 1931 through 1981 were compiled from the National Weather Service and CNPPID weather station data. Temperature data, including the average monthly temperature and average high and low temperature for the warmest month of the year, were compiled for nine of the National Weather Service stations. The percent of possible sunshine recorded at the North Platte weather station, located outside the study area, was used because it was the closest source of this type of data.

SOILS

Soils in the model area vary from loamy sands along river bottoms to silty clay loams on upland sites. Some of the prominent upland soils in the model area include the Coly-Uly, Hastings-Holder, and Holdrege associations. The flood plain soils are in the McCook-

Munjor-Inavale and Gothenburg-Platte associations.

Irrigability of the soils in the model area varies widely, depending on slope, drainage, water-holding characteristics, and depth to the water table. The level, moderately well drained Hastings, Holder, and Holdrege soils are the best suited for irrigation, followed by the level, well to somewhat excessively drained McCook-Munjor-Inavale association. Steep slopes (30-60 percent) and excessive drainage rates make the Coly-Uly association poorly suited to irrigation. While the Gothenburg-Platte association is nearly level, its shallow, poorly drained soils and high water table make it unsuitable for irrigation.

LAND USE

Land use data came from two sources: land use maps by NRC and historical county agricultural statistics from the Nebraska Agricultural Statistics Service. Land use was mapped by NRC from conditions that existed in 1980. This land use map covered all of seven counties and parts of two counties north of the Platte River.

Land uses identified were agricultural use, including row crops, small grain, alfalfa, pasture and rangeland; major water areas; and other miscellaneous areas (urban areas, feedlots, Game and Parks Commission Wildlife Management Areas). The identification of irrigated crops was an important part of the mapping. Irrigated row crops identified included corn, sorghum, and beans. Other irrigated areas identified were alfalfa, small grains, crops for silage, and irrigated pasture. This information is shown on two land use maps included in the back of this report: "Irrigated Cropland in South Central Nebraska in 1980" and "Non-Irrigated Cropland in South Central Nebraska in 1980." It has been supplemented with a land use map of Webster County, also included in the back of the report, that shows the same information.

To provide the required historical record of land use, the amount of land in 11 categories of agricultural land use was compiled for each county from 1940 through 1980. This information, taken from annual reports of the Nebraska Agricultural Statistics Service, was used in the study's ground water model.

Over the period for which land use data were collected, several trends in agriculture were apparent. The most apparent change was the rapid increase in irrigated row crops. In Gosper, Phelps, and Kearney counties the amount of surface water irrigated row crops increased with the development of the CNPPID system during the 1940s. Furnas, Harlan, Franklin, and Webster counties experienced increases in surface water irrigated row crops during the mid-1950s and early 1960s as water became available from the Frenchman-Cambridge and Nebraska Bostwick irrigation systems.

Surface water irrigated row crops in Buffalo and Dawson counties grew relatively little during the same period. However, those counties also experienced increases in irrigated acres as the development of ground water irrigation in the latter half of the 1960s expanded irrigated row crop acreages throughout the study area. The development of center pivots contributed significantly to this expansion.

The trend in dryland row crops was not as clear as that in irrigated row crops. Two general patterns are apparent. In Franklin, Harlan, Furnas, Gosper, and Webster counties dryland row crop acreage peaked prior to 1945 and declined to a low point during the mid-1960s. There was a gradual increase after that time, but the total remained far below the peak reached earlier.

The dryland row crop trend in Buffalo, Dawson, Phelps, and Kearney counties was similar. A peak was reached prior to 1945, followed by a decline to a low point in the mid-1960s. Increases in acreage since then generally equalled or surpassed the peaks reached prior to 1945.

The general trend in the acreage of small grain crops in the study area was one of gradual declines. Totals in most counties peaked during the 1940s and early 1950s and declined since then. Only Furnas and Webster counties had relatively stable small grain acreage totals throughout the study period. Alfalfa acreage totals have fluctuated throughout the 1940-1981 period of record. There does not appear to be any consistent trend among the counties in the study area.

GEOLOGY

The entire south-central area is underlain by 3,000 to 5,000 feet of sedimentary material resting on a layer of igneous and metamorphic rocks. Most of the older, more deeply buried, sedimentary rocks are not considered a suitable source of ground water since they are too dense to contain much water in their pore spaces or fractures. If they do contain water, it often contains high concentrations of dissolved solids. This has little impact on water use in the area, because an enormous supply of high quality water is available in the sedimentary materials overlying these older formations. The deposits containing this supply constitute the principal ground water reservoir in this area. The geologic time scale in Figure 3 shows the relative ages of different geologic units.

Formations comprising the ground water reservoir are all of the Cenozoic Era. During the Tertiary Period of this era, the Rocky Mountains were being uplifted, and much material was removed by erosion and deposited in the south-central area. Other material came from volcanic eruptions that sent clouds of debris into the air. This debris was then carried eastward by the prevailing winds and deposited in the High Plains region. These sediments accumulated during the Oligocene, Miocene, and Pliocene Epochs of the Tertiary Period. In the south-central area they include the Arikaree Group and Ogallala Formation, from oldest to youngest.

During the more recent Quaternary Period, glaciers entered eastern Nebraska from the northeast, damming the predominantly eastward flowing streams that existed at that time. This forced the streams to deposit the sediment they carried in eastern and central Nebraska. Quaternary age deposits of the south-central area consist of sand and gravel layers, which probably correspond to times when glaciers extended into eastern Nebraska, and finer textured sediments deposited by wind and water, which probably correspond to times when glaciers had retreated to some extent.

More recent sediments were formed on the flood plains of the drainageways that currently exist in the study area. In the south-central area, these consist of the water-deposited sands and silts along the numerous drainageways, and windblown sand dunes found just south of the Platte River in Phelps and Kearney counties.

The materials that form the ground water reservoir lie on bedrock of Cretaceous age, including the Pierre Shale and the Niobrara formation. The Pierre Shale is not an aquifer, but water has been obtained from the Niobrara Formation in some parts of Nebraska. Due to the great depth of this formation in the south-central area, it is not regarded as part of the ground water reservoir.

GROUND WATER RESOURCES

Ground water within the south-central area played a significant role in the settlement and development of this area. The ground water reservoir, developed over millions of years, yields good quality water in most places. This water is available for municipal, industrial, domestic, agricultural, and other uses.

DESCRIPTION OF THE GROUND WATER RESERVOIR

The ground water reservoir in the study area consists of sediments of the Ogallala Formation and the overlying sands and gravels of Pleistocene age. The Ogallala Formation consists of sandstone, sands, silts, clayey silts, and

Geologic Time Scale and Description of Sediments

Figure 3

ERA	PERIOD	EPOCH	DESCRIPTION OF SEDIMENTS IN SOUTH CENTRAL AREA	ESTIMATED YEARS SINCE BEGINNING (in millions of years)
CENOZOIC	QUATERNARY	HOLOCENE	Fluvial silts and clays Some windblown sands	0.01
		PLEISTOCENE	Fluvial silts and clays Windblown loess (silt) Sand and gravels in cycles that correspond to glacial advances and retreats	1
	TERTIARY	PLIOCENE	Ogallala Formation, sands, silts, sandstones, clays and clayey silts	13
		MIOCENE	Siltstone, clayey silts, silts	25
		OLIGOCENE EOCENE AND PALEOCENE	Not found in the study area	63
MESOZOIC	CRETACEOUS	UNDIFFERENTIATED	Marine deposited shales, chalks, limestones and sandstones	135
	JURASSIC		Shales and limestones	181
	TRIASSIC		Sediments of this age not found in study area	230
PALEOZOIC	UNDIFFERENTIATED	UNDIFFERENTIATED	Shales, limestones, dolomites and sandstones of marine origin	600
PRECAMBRIAN BASEMENT COMPLEX			Igneous and Metamorphic rocks	

silty sands in varying amounts. The dominant texture is a very fine to fine sandstone that is very slightly compacted. Variations in texture occur both in the lateral and vertical direction. Thickness of the formation is variable, ranging from zero to over 350 feet. In general the Ogallala Formation is thickest in the northwest part of the study area and gradually thins toward the east and south. In the southeastern part of the study area, this formation was completely stripped away prior to the deposition of younger sediments.

The Pleistocene sand and gravel layers overlying the Ogallala Formation range in texture from very fine sand to coarse gravel. The predominant grain size ranges from coarse sand to medium gravel. These layers range in thickness from zero to over 100 feet. Generally, the gravels are thickest in the northern part of the study area and thin or absent in the area just north of the Republican River. Where they exist, these gravels are an excellent source of high quality water.

Water Table

The water table is the upper boundary of the ground water reservoir. It is defined as the surface at which the fluid pressure in the pores of a porous medium is exactly atmospheric. It is also the level at which water stands in shallow wells and other wells in unconfined aquifers.

The 1940, or predevelopment, water table map for the south-central area, Figure 4, shows a gently southeastward sloping surface ranging from around 2,600 feet in northwestern Dawson County to around 1,700 feet in Webster County. In the southern part of the study area, the contours bow upstream conspicuously along the Republican River and Beaver Creek. The contours also extend eastward along the northern boundary of Webster County to enclose a ridge of ground water under the divide between the Republican and Little Blue river basins.

The 1981 water table map, Figure 5, has this same basic configuration except where the water table contours bow eastward in an area extending from northern Gosper County to central Kearney County. In this area the water table has risen as much as 80 feet beneath the CNPPID's power and irrigation facilities, creating a ground water divide between the Platte and Republican river basins.

This divide is not present in the 1941 water table map because none existed prior to construction and operation of the CNPPID project. Creation of this ground water mound changed the flow of ground water north of the divide, providing ground water contributions to the base flow of the Platte River in this reach. On the south side of the divide, it has increased the gradient of the water table toward the Republican River and its tributaries. This has increased the base flow in those streams.

Ground water declines as great as 25 feet have occurred in isolated areas along the northern boundaries of Furnas, Harlan, and Franklin counties in response to irrigation well pumpage. In these areas, the shape of the water table contours has changed slightly, but not enough to alter the basic configuration.

Base of the Ground Water Reservoir

Throughout much of the study area, the base of the ground water reservoir is the lower boundary of the Ogallala Formation. This surface corresponds to the upper surface of Cretaceous age sediments in most of the study area, or to the upper surface of the Arikaree Group sediments where they were deposited in Dawson County. At some locations, the base of the ground water reservoir is defined by the top of fine-textured or consolidated sediments that are found at the base of the Ogallala Formation.

The Cretaceous surface is mapped in Figure 6. This surface has been extensively dissected by ancient drainageways (paleovalleys) since these formations were uplifted above sea level. Several prominent paleovalleys cross the study area from northwest to southeast. They are separated by higher areas that probably formed drainage divides prior to deposition of post-Cretaceous sediments. The most prominent paleovalley enters the study area

Predevelopment Water Table

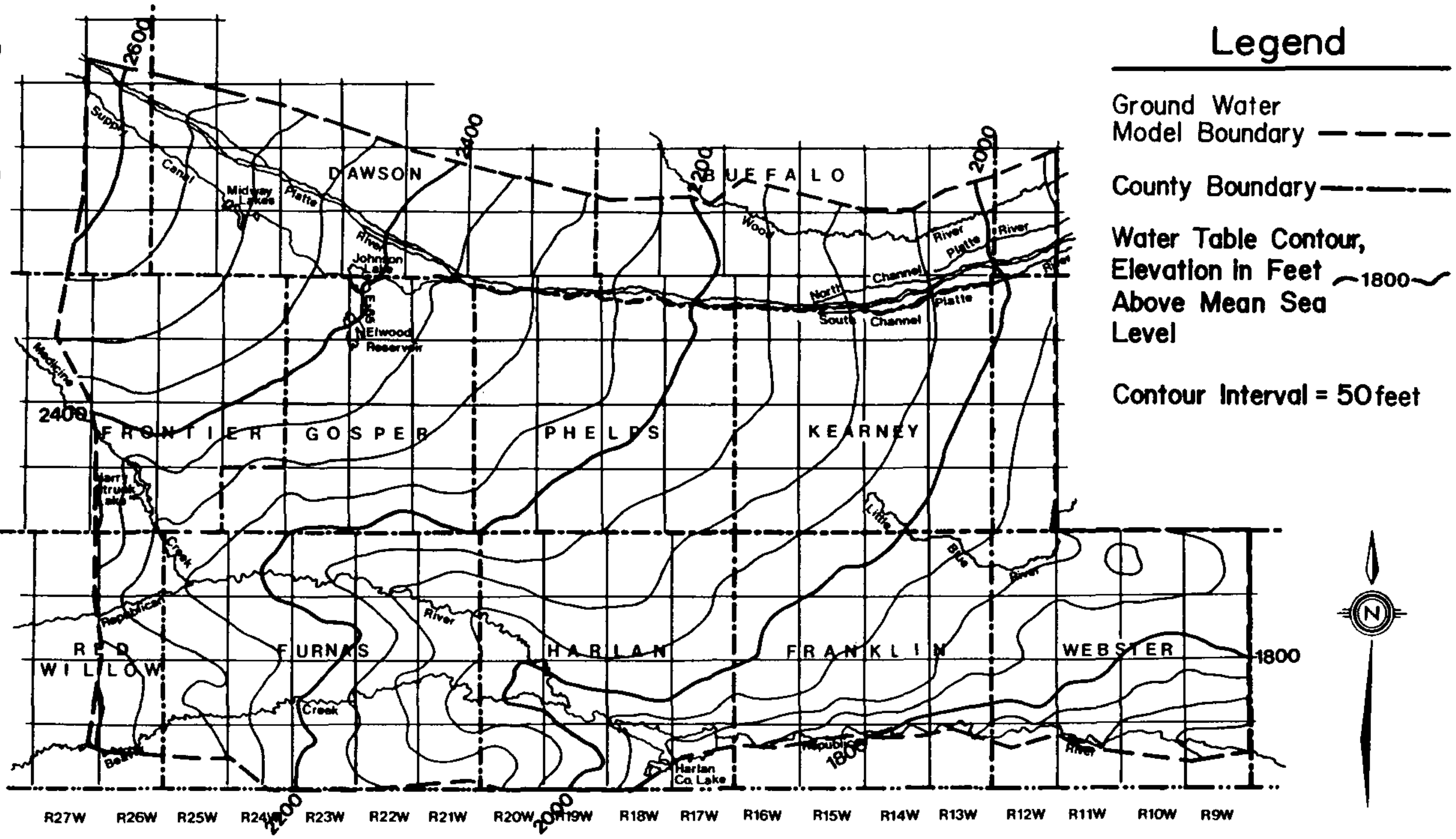


Figure 4

1981 Water Table

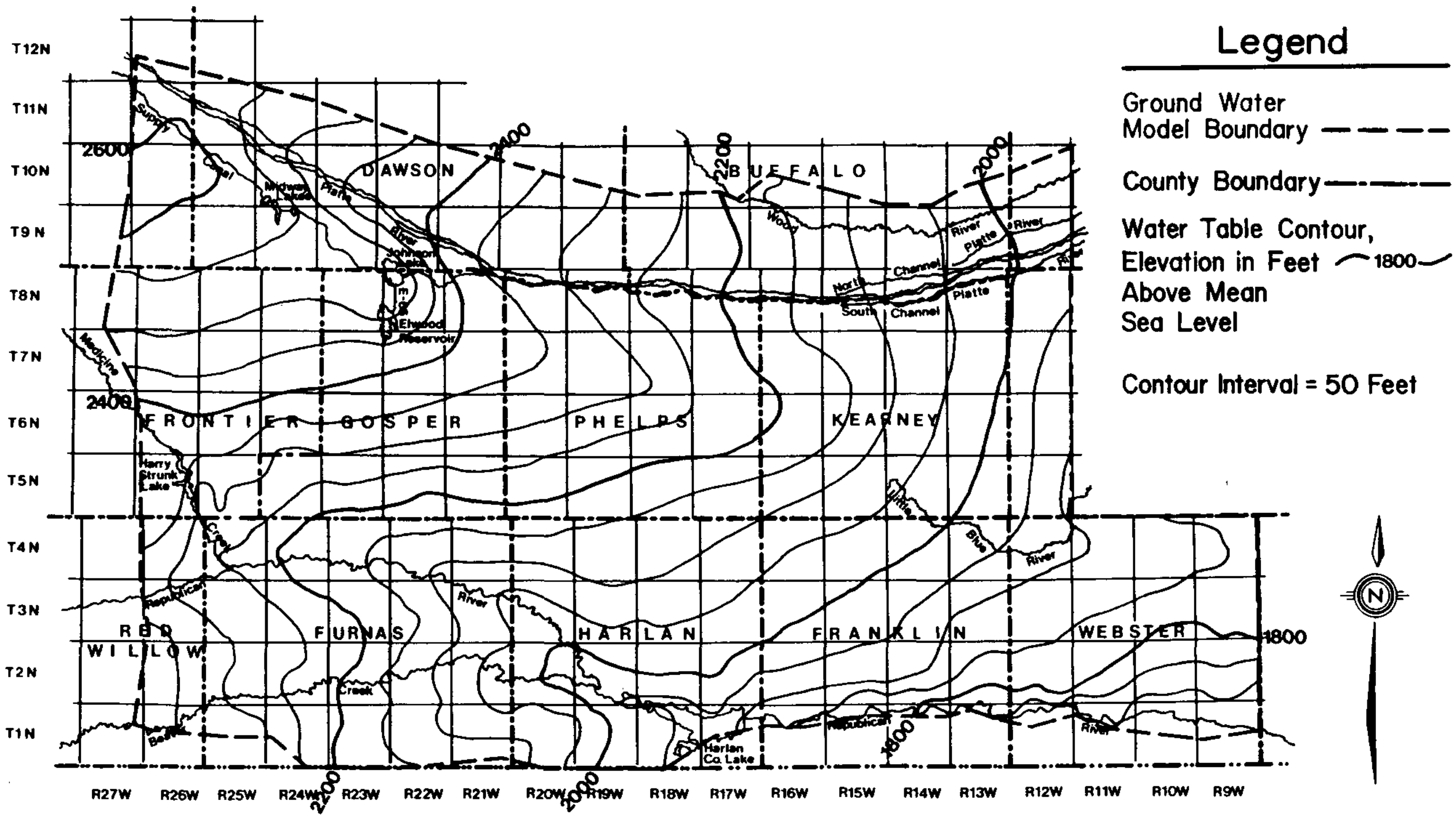
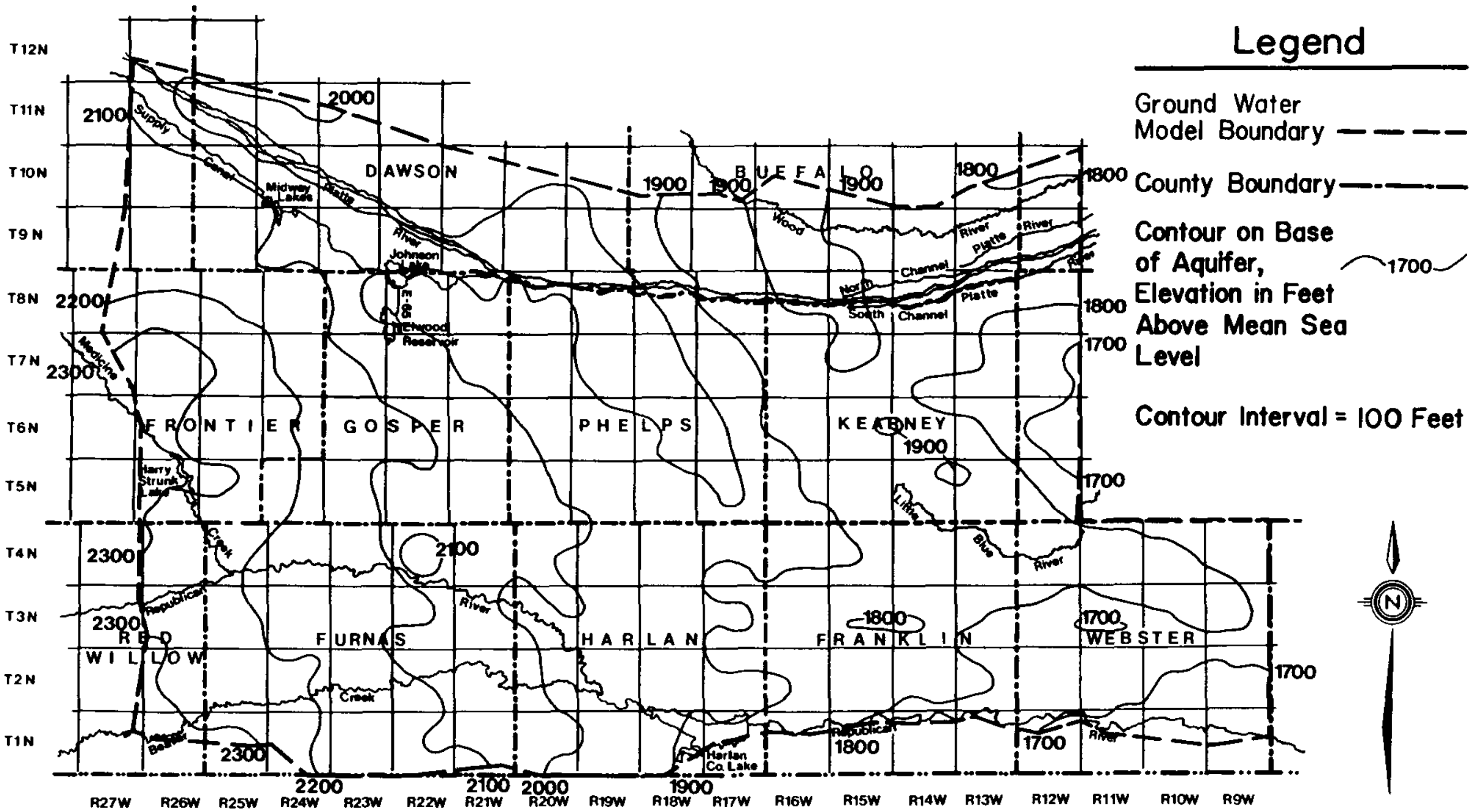


Figure 5

Figure 6

Configuration of the Base of the Modeled Aquifer



near northwestern Gosper County, runs southeastward into western Franklin County, then bends eastward to exit in southeastern Webster County. Another paleovalley enters the study area near the northeast corner of Phelps County and exits in eastern Kearney County. Other buried depressions follow the Republican River, and Beaver and Sappa creeks. High bedrock areas occur between these drainageways in southeastern Gosper County, northcentral Phelps County, central Kearney County, and northern Webster County.

Aquifer Characteristics

Two characteristics are very important when describing a ground water reservoir. The first, transmissivity, is a measure of an aquifer's capacity to transmit water. It is the rate at which an aquifer will transmit water through a one foot wide strip extending vertically through the entire aquifer. Figure 7 shows transmissivity rates in the south-central area in 1981. Areas with transmissivity less than 20,000 gallons per day per foot generally do not yield enough water to wells to make irrigation economically feasible.

The areas of highest transmissivity generally occur on a diagonal line extending across the study area from northwest to southeast. There is another area with high transmissivity in northern and east-central Kearney County. The areas of lowest transmissivity are generally near or south of the Republican River, from Furnas County to Webster County.

The storage factor is another important characteristic of an aquifer or ground water reservoir. It is the amount of water taken into storage in an aquifer per unit rise in water level, or the amount withdrawn from an aquifer per unit decline in water level. For unconfined aquifers, the storage factor is equal to the drainable porosity, or specific yield, of the materials of the aquifer. Some materials, like clay, store little water; their specific yield (0.03) is low. Other materials, such as dune sand, store large amounts of water; their specific yield (0.38) is high. Specific yield values within the study area range from 0.08 in northern Webster County and southern Harlan County, to 0.24 in several places, including central Webster and Franklin counties, and northern Furnas County. Most aquifer materials in the study area have a specific yield that falls between 0.18 and 0.24.

Ground Water Flow

Water moves at much slower rates beneath the land surface than it does in streams and rivers. Typical rates of flow in the types of porous materials found in the south-central area range from 0.002 feet per day for clayey silts to 5 feet per day in the gravel layers. The estimated rate for gravel is based on a water table sloping 10 feet per mile.

Ground water flow is always from areas of greater potential to areas of lower potential. For flow in the horizontal direction, lines of equal potential are equivalent to the water table contours. Consequently, the horizontal direction of ground water flow in the study area is perpendicular to the water table contours. The general direction of flow in the study area is therefore from northwest to southeast. Variations in this pattern occur where contours bend upstream near rivers and eastward beneath the CNPPID system. Figure 5 shows the 1981 water table contours. Flow lines are at right angles to these contours.

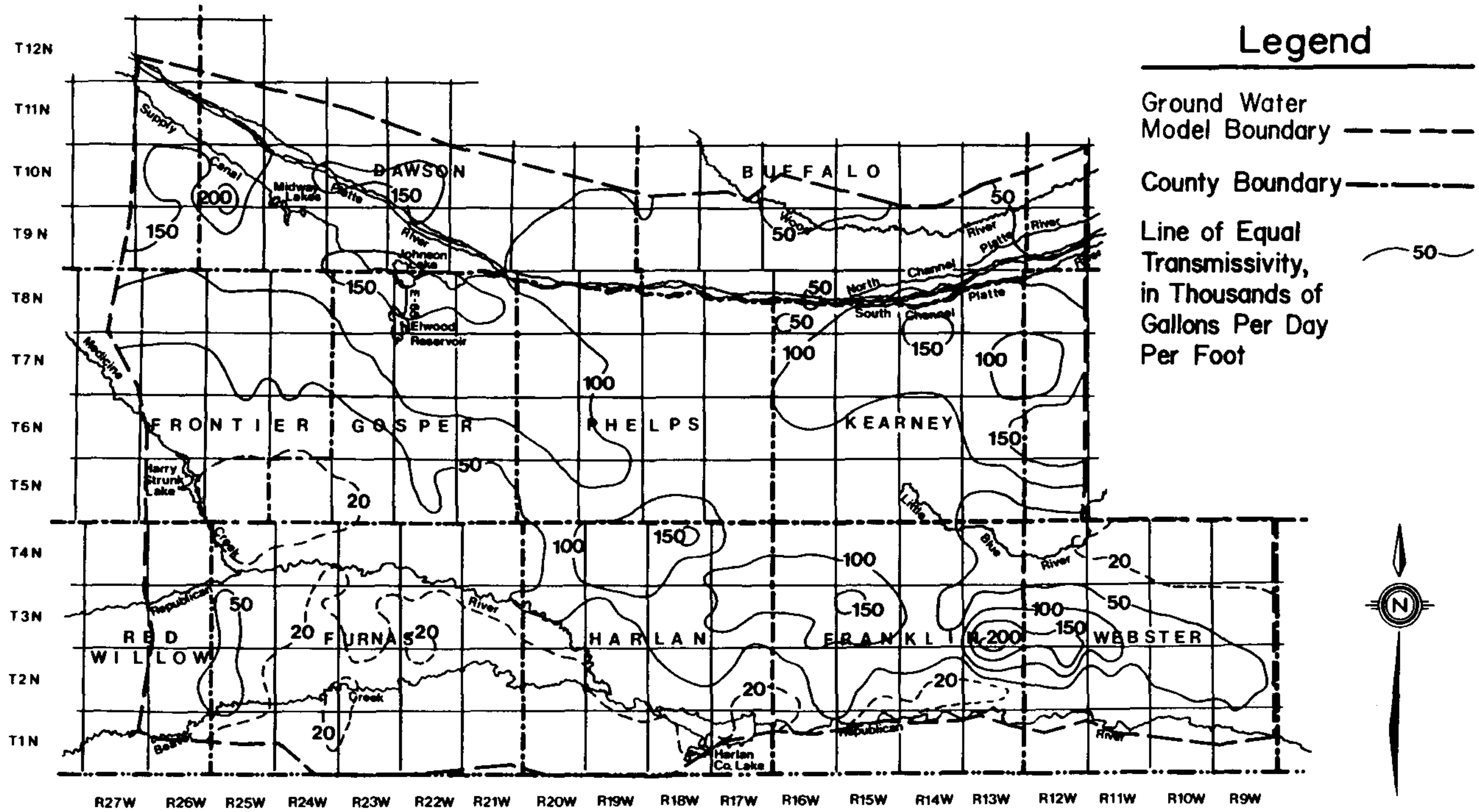
RECHARGE

Recharge to the ground water reservoir occurs from several sources, including: infiltration of precipitation, seepage from canals and lakes, deep percolation from irrigation, and ground water inflow from adjacent areas.

The first source of recharge, infiltration from precipitation, is determined by a soil's ability to absorb rainwater. The soil's slope, texture, surface roughness, and the amount of vegetative cover all affect infiltration. The rate at which water can be absorbed at the soil surface is called the infiltration rate. Any excess water not absorbed will pond in lowland areas, evaporate, or be lost as runoff. Sandy

Figure 7

Transmissivity of the Modeled Aquifer in 1981



soils have high infiltration rates, while clayey soils allow only limited infiltration.

Once the water has penetrated the soil surface, it moves downward through the spaces, or "pores", in the soil. Large grained sands have large pore spaces which can allow rapid downward movement, ranging from twelve to eighteen inches per hour. Clay particles, and their corresponding pore spaces, are much smaller than sand particles, so water moves more slowly through clay layers, often at rates as low as one to six inches per hour. The process by which water moves from the root zone to the water table to recharge the ground water reservoir is not well understood.

Seepage of surface wate,r primarily from canals and reservoirs, also contributes significantly to recharge. Seepage of this type is partly responsible for the rise of the water table in Gosper, Phelps, and Kearney counties. The shape of the ground water "mound" produced by this rise generally centers on the CNPPID Supply Canal and the E-65, E-67 and Phelps County canal systems.

Output from the computer model indicates that the volume of water that seeped to the aquifer in the study area from 1940 through 1981 was approximately 28 million acre-feet. This is an average of 0.6 million acre-feet per year that was added to the ground water flow system. Total seepage from the area's canals and lakes was probably even greater, but some of the water returned to rivers and streams.

A third major source of ground water recharge is deep percolation of irrigation water. Rainfall during or shortly after an irrigation application is a common cause of deep percolation which cannot be controlled. Even when irrigation is carefully scheduled, excess irrigation applications can occur during flood or furrow irrigation. Sometimes it is necessary to overapply water at the top of a field to ensure complete irrigation at the bottom of the field. Some of this excess water is intercepted by plant roots, but most will move out of the soil profile and ultimately reach the water table.

A fourth type of recharge to the study area occurs through ground water inflow. This occurs principally along the study area's western boundary. It also occurs along the northwestern boundary north of the Platte River, and along the southwestern boundary near the Republican River. Figure 8 shows the portions of the model area where significant ground water inflow occurs. Output from the ground water model indicates that average ground water inflow from 1940 to 1981 was approximately 82,800 acre-feet per year.

DISCHARGE

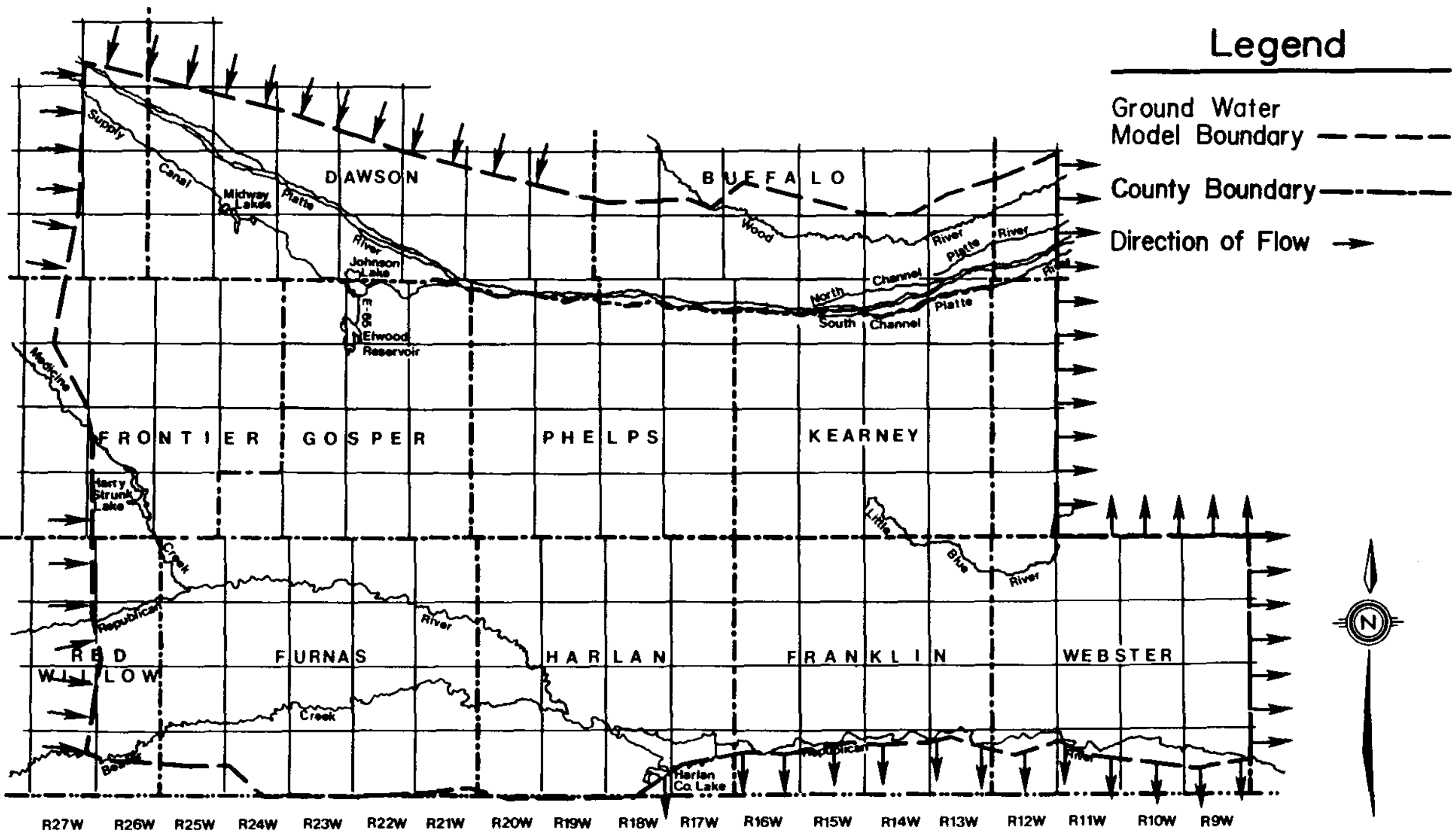
Ground water is discharged from ground water reservoirs in three ways. The first, outflow to adjacent areas, occurs along the eastern boundary of the model area, and along the southern boundary between Alma and Guide Rock. Figure 8 shows the portions of the model with significant outflow across the boundary. The amount of outflow is dependent on the hydraulic gradient, cross-sectional area over which flow is occurring, and the hydraulic conductivity of the aquifer material. Output from the model indicates that ground water outflow for an average year was approximately 44,970 acre-feet.

The second method of ground water discharge is by pumping. Of all the wells in the study area, only irrigation wells remove enough water from the ground water reservoir to affect the model. The number of irrigation wells in the study area is estimated to have gradually increased from about 1,050 in 1940 to about 12,740 in 1981. Other, less significant quantities of water are pumped by several high capacity municipal wells, and low capacity domestic wells scattered throughout the area.

Ground water may also be discharged from the ground water reservoir where a stream or river is incised into the water table. If the adjacent water table is higher than the surface of the stream and slopes toward it, water will be discharged from the ground water reservoir to the stream. This is termed a gaining stream reach. During a 12 month period in 1980 and 1981 the Republican River gained an average of 139 cfs in this manner; during the same period, the Platte River gained an average of 286 cfs.

Figure 8

Areas of Significant Ground Water Inflow and Outflow



GROUND WATER QUALITY

Ground water in the study area has historically been of very good quality. In most parts of the study area, it is good enough to be used without treatment. Recent human activities, however, have affected water quality enough in some locations so it does not meet state criteria for some uses.

Extensive irrigation development in the upper Platte and Republican River valleys affects water quality in the study area. Dissolved solids become concentrated in irrigation return flows which drain to the Platte and Republican rivers. This water recharges the upper aquifers in the study area as it seeps from river channels, canals, and reservoirs. Surface and ground water irrigation in the study area also contribute to mineralization of the upper aquifers.

Concentrations of dissolved solids in the ground water of the Platte River and Republican River valleys are in the range of 750 to 2,250 milligrams per liter (mg/l). This is considerably greater than in other parts of the study area, and in most areas of the state. Higher concentrations of sulfate are also found in these river valleys and in the CNPPID service area in Gosper, Phelps, and Kearney counties. Sulfate is one of the principal constituents of irrigation return flows. Nitrate in relatively high concentrations is found in the ground water of some parts of the study area, most extensively north of the Platte River. The drinking water standard, or maximum contaminant level, for nitrate is 10 mg/l as nitrogen. Department of Health records show that five municipal water supplies in the study area have had nitrate concentrations at or above 10 mg/l. Concentrations are usually highest in the upper parts of the saturated zone.

In 1980 and 1981, the USGS sampled 73 wells in the study area to obtain representative water quality data. Most were irrigation wells; a few public water supply wells were also sampled. Samples from three wells had nitrate concentrations above 10 mg/l, and four other samples were above 7 mg/l. The results of these water quality analyses are published in USGS Water Resources Data-Nebraska, 1980 and 1981.

SURFACE WATER RESOURCES

The surface water resources of the study area are of two types: those that occur naturally, and those that are created by human activity. Natural surface waters include streams and wetlands in undrained areas. Surface water resources created by humans include reservoirs, sandpit lakes, and canals.

NATURAL STREAMS AND WETLANDS

Surface water drainage varies widely throughout the study area. In the central, relatively flat, upland plain, drainage is poorly defined and channels are shallow. In many cases drainage basins are closed. Rainfall collects in the basins, forming wetlands. The majority of these closed rainwater basin areas were excluded from the Platte River Basin to insure there was no transbasin diversion when the CNPPID project was developed. Most were later assigned to the Republican River Basin.

To the north and south of the upland plain, drainage patterns range from poorly to well developed. Runoff from these drainage areas flows to three rivers: the Platte, Republican, and Little Blue.

Republican River Basin

Outside of the rainwater basin area, drainage patterns in this river basin are normal. Moderate to steep slopes and sharp ridge crests have developed; only remnants of the former plain remain. Runoff to the Republican River has created narrow, deeply incised drainageways and canyons. Water carried by this well-defined drainage flows onto level or gently sloping, well drained soils on lowland terraces and footslopes. It then flows onto Republican valley bottom lands which are nearly level, yet well drained, and prone to lowland flooding.

The major tributaries of the Republican River in the study area are listed in Table 1. Included in the table are high and low flows and drainage areas for each stream, and the length and slope for several of the streams.

The Republican River enters the study area near Bartley and flows about 150 miles across it before exiting near Guide Rock. The river flows through a loess plain, and its valley gradually broadens as it flows eastward. Its flows are regulated by reservoir releases and irrigation diversions. The numerous reservoirs on the Republican and its tributaries not only regulate flows for irrigation, but provide flood control benefits. A devastating flood in the Republican River in 1935 caused the deaths of 150 people, and caused over $1 million in private property damages. Other significant floods in the basin occurred in 1876, 1915, 1923, 1947, 1957, 1982, and 1983.

Historically, the Republican River's base flow was not extensive. There was little seepage to the river or its tributaries from underlying aquifers. Recently, however, ground water recharge from irrigation projects has increased seepage to the Republican and its tributaries. This seepage has created continuous flow in the lower reaches of many tributaries.

The Republican's flow is highly regulated between Harlan County Dam and Guide Rock, near the edge of the study area. When no lands are being irrigated, Republican River flows are impounded by Harlan County Dam and flows below the dam are very low. During the irrigation season, large releases are made, and more water is available in the river for instream uses, such as recreation. Table 2 lists the average annual flows, base flows, record flows, and drainage areas for four gaged sites on the Republican.

Table 1

Major Tributaries of the Republican River in the South-Central Study Area

Name	Base Flow	Record Flood Flow	Drainage Area	Length	Slope
	----------(cfs [1])---------		(sq.mi.)	(miles)	(ft/mile)
Perennial Streams					
Elm Creek	15.60	7,800	39	28.5	12.4
Thompson Creek	21.00	12,200	279	58.1	8.5
Center Creek	5.52	3,150	177	--	--
Turkey Creek	2.44	940	75	--	--
Muddy Creek	5.56	7,280	246	55.8	8.4
Medicine Creek	5.52	1,300	880	--	--
Sappa Creek[2]	2.85	43,400	3,740	--	--
Beaver Creek[2]	.91	9,510	1,950	--	--
Intermittent Stream					
Prairie Dog Creek	--	15,000	1,007	--	--

[1]cubic feet per second
[2]These streams occassionally have periods with no flow.

Platte River Basin

Drainage to the Platte River is similar to the Republican. Runoff from loess hills and dissected plains flows through a well developed drainage pattern. Unlike the Republican, however, these overland flows discharge onto poorly drained valley lands. The Platte River valley varies considerably in width. At Brady and Odessa, it is about five miles wide; between these points it widens to as much as 18 miles. The Platte's broad valley lowlands generally consist of flat terraces with steep slopes between the terraces. Flooding is not unusual when runoff from the steeper hills drains onto the valley lands.

There are no major tributaries to the Platte River within the study area. Plum Creek and Dry Creek flow into the Platte from the south, each contributing a small amount of base flow. The Wood River flows through southern Buffalo and Hall counties north of the Platte. It flows parallel to the Platte for 60 miles, eventually joining it about 40 miles east of the study area. Table 3 lists available data on these tributaries to the Platte.

Much of the flow in this reach of the Platte River originates in the Rocky Mountains. It enters Nebraska in the North Platte and South Platte rivers, which join near the city of North Platte. A substantial portion of the flow of the Platte River is diverted into the Tri-County Supply Canal just downstream from North Platte. The water left in the river flows on a bed of sand or sandy gravel, often in two or more channels. Table 4 shows the range of flows and drainage areas at four gaged sites in or near the study area.

SURFACE WATER QUALITY

The 1986 Nebraska Water Quality Report prepared by the Department of Environmental Control (DEC) provides an assessment of surface water quality. The assessments are based on data for 1984 and 1985, and are limited to the Platte River and Republican River.

Water quality in the Platte River was generally good throughout the study area. No water quality concerns were identified by DEC for this reach of the river. Nonpoint sources had only a minor effect on surface water quality. A number of domestic and industrial facilities in this area discharged waste water to the Platte River but adequate treatment was provided.

The assigned beneficial uses of the Platte River within the study area were secondary contact recreation, warmwater aquatic life, and agricultural water supply. An assessment of water quality data indicated the river fully supported these assigned beneficial uses. The

Table 2

Characteristics of the Republican River in the Study Area

Gage Location	Average Annual Flow	Base Flow	Record Flood Flow	Drainage Area	Slope
	(cfs)			(sq. mi.)	(ft/mile)
at Cambridge	312	123.0	280,000 [1]	14,520	7.3
near Orleans	303	129.0	40,600	15,640	7.3
below Harlan Co. Dam	264	12.1	260,000 [1]	20,760	3.4
near Guide Rock	339	95.5	29,200	22,040	3.4

[1]Estimated flow in the 1935 flood. These were the only two gages at that time.

Table 3

Tributaries of the Platte River in the South-Central Study Area

Stream	Average Discharge	Drainage Area	Length	Slope
	(cfs)	(sq. mi.)	(miles)	(ft/mile)
Wood River	10.8	700 [1]	112	8.5
Plum Creek	10.0	N/A	75	5.8

[1] At Grand Island.

quality was nearly good enough to support primary contact recreation, although it was not an assigned use in this reach.

A number of toxic pollutants have been measured in Platte River water quality samples. Levels of these pollutants were below Environmental Protection Agency (EPA) criteria for freshwater aquatic life. Toxic pollutants were also found in fish tissue samples; some recommended pesticide levels were exceeded.

The water in the Republican River was of fairly good quality. Some segments were assigned primary contact recreation use, but the more recent water quality assessment indicated this use was not supported. Secondary contact recreation assigned to other segments was only partially supported or not supported. Warmwater aquatic life and agricultural water supply uses were fully supported.

Because assigned recreation uses were not supported in the Republican River below Medicine Creek, DEC identified water quality concerns for this area. Nonpoint source pollution was suspected to cause the impairment in this entire reach. Domestic wastewater discharges probably contributed to the problem in Webster County.

Low levels of toxic metals and inorganics were measured in some water quality samples from the Republican River. Toxic pollutants were found in fish tissue samples, several in concentrations above recommended guidelines.

Table 4

Platte River Flows and Drainage Areas

Gage Location	Average Annual Flow	Base Flow	Record Flood Flow	Drainage Area
	(cfs)			(sq. miles)
at Brady	603	147	23,500	56,200
near Cozad	520	197	21,500	56,500
near Overton	1,383	1,007	37,600	57,700
near Odessa	1,286	874	22,900	58,100

IRRIGATION AND ELECTRIC POWER PROJECTS

Many projects have been built to take advantage of the surface water resources in the study area. The major reservoirs and canals in these projects are shown in Figure 9. In the Platte River Basin, many projects have been built by local districts or private organizations. Most are for irrigation, but two also produce hydroelectric power. In the Republican River Basin, several large irrigation and flood control projects have been built by federal agencies.

The CNPPID project is the largest in the Platte River Basin. Kingsley Dam on the North Platte River provides most of the storage for the system in Lake McConaughy. Water released from Lake McConaughy is used by others before it is diverted from the Platte River just below the confluence of the North Platte and South Platte rivers. This water is diverted into the Tri-County Supply Canal and used to generate hydroelectric power at a plant west of the study area. Water can be returned to the river below this plant or it can flow on through the Supply Canal.

The Tri-County Supply Canal continues eastward to the Tri-County area of the district, creating 26 lakes by damming canyons along the route with the canal embankment. In northern Gosper County, it connects with two additional storage facilities, Johnson Lake and Elwood Reservoir. These reservoirs store water when there is surplus over irrigation demand, and deliver water to the system when needed. From Johnson Lake, the canal delivers water to two more hydroelectric power plants before it reaches the headgates of the Phelps County Canal, near the Platte River. The Phelps County Canal and the E-65 and E-67 canals are the major canals. The system includes 120 miles of irrigation canals and 590 miles of distribution laterals. Construction of most of the structures in the CNPPID system was completed in 1941. Elwood Reservoir was added in 1979.

The Tri-County Supply Canal and power facilities operate all year. When irrigation water is not needed in the Phelps County Canal, the water used in the last two hydropower plants is returned to the river.

Other projects in the Platte basin are smaller and many are privately owned. All were built to provide irrigation service, and several were built to produce hydroelectric power as well. The Kearney Canal, operated by Nebraska Public Power District, is the only one that still has a power plant. The Gothenburg Canal ceased producing power over 20 years ago. The Thirty-Mile, Six-Mile, Orchard-Alfalfa, Cozad, and Dawson County canals were built to provide irrigation service.

In most of the irrigation service areas in the Platte valley, it was also necessary to construct drainage ditches to carry surface return flows and excess ground water to the Platte River. These drains contribute to the base flow of the river all year.

In the Republican River Basin, the U.S. Army, Corps of Engineers (COE) and the Bureau of Reclamation (USBR) have built several projects in the study area. Parts of the Frenchman-Cambridge and Bostwick Divisions, constructed by the USBR, are in the area. In addition, the Harlan County Dam is managed jointly by the COE and USBR to provide flood control and irrigation storage for the Bostwick Division. Another reservoir built by the USBR to serve the Frenchman-Cambridge Division is located on the western edge of the study area on Medicine Creek.

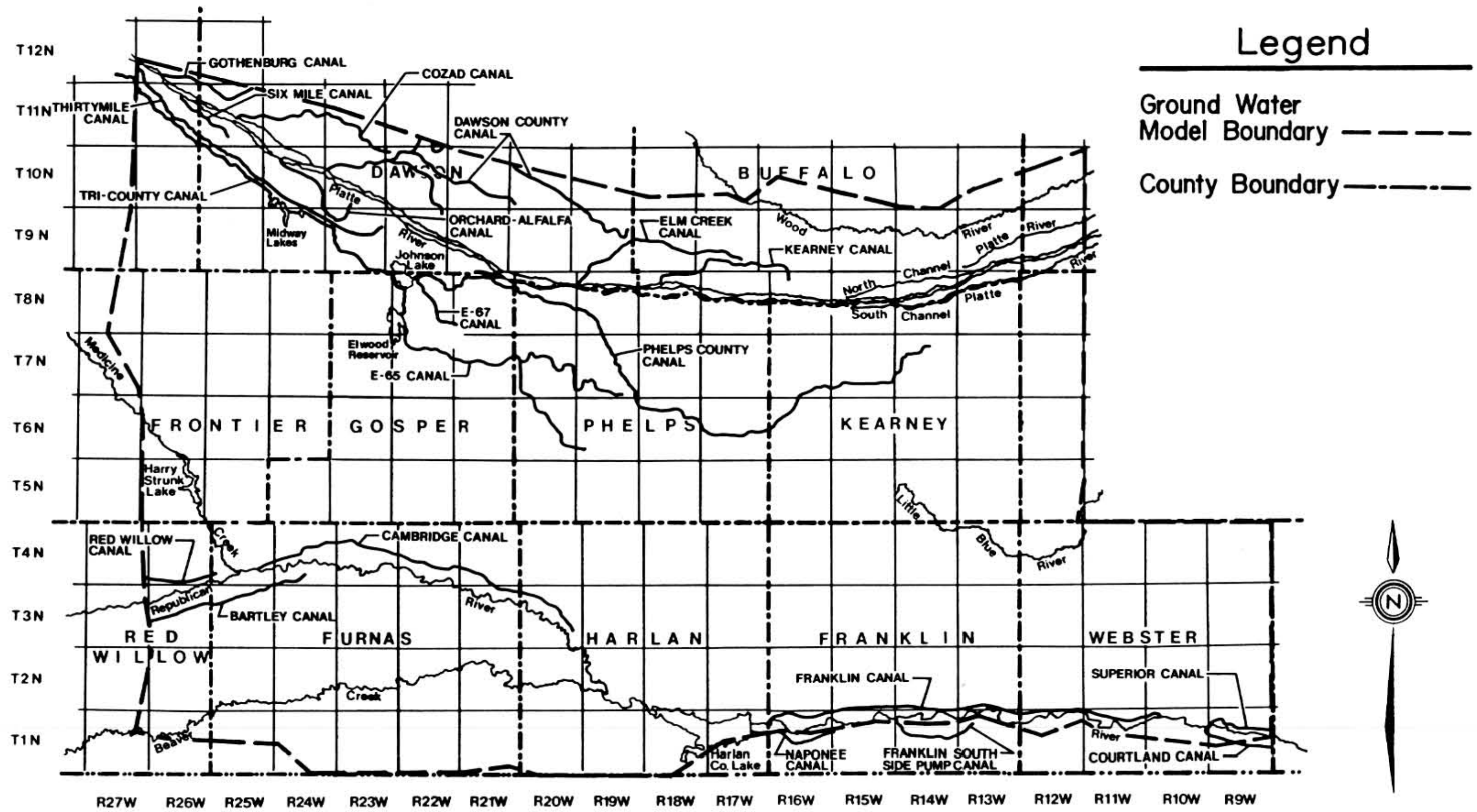
Platte River Basin Canals and Service Systems

Eight major canals divert water from the Platte River for use within the study area. In downstream order of diversion, these canals are: Tri-County Supply, Thirty-Mile, Gothenburg, Six-Mile, Cozad, Orchard-Alfalfa, Dawson County, and Kearney. A ninth canal, Elm Creek, was abandoned in 1963.

The Tri-County Supply Canal, the largest of the canals, is part of the CNPPID system. It is 76 miles long, and 40 miles are within the study area. It has a capacity of 2,200 cfs, and a slope of 0.5 feet per mile. Some water is re-

Figure 9

Major South-Central Area Irrigation and Electric Power Facilities



moved for irrigation along its 76 mile route, but most is delivered to the Phelps County Canal and two other irrigation canals. The first, the E-65 Canal, serves about 43,000 acres. It is 55 miles long, and has 194 miles of laterals. The second, the E-67 Canal, was completed in 1954. It is 9 miles long, has 16 miles of laterals, and serves about 6,000 acres.

The Phelps County Canal is the district's main irrigation canal. It supplies water to 64,000 acres in Gosper, Phelps, and Kearney counties. It is 57 miles long, and has 380 miles of laterals.

The efficiency of much of the CNPPID system was recently improved. Draglines were used to clean sediment and debris from some canals and laterals. In addition, pipelines and compacted earth or concrete linings were used to improve or replace many unlined portions of the system. As a result, seepages losses for the system were reduced from 65 percent to 45 percent of water diverted by 1981.

The remaining canals diverting Platte River water within the study area were developed between the 1880s and 1930s. The Gothenburg, Cozad, Dawson County, and Kearney canals divert water to irrigate lands north of the river. The Elm Creek canal also supplied irrigation water to lands north of the Platte. The Thirty-Mile, Six-Mile, and Orchard-Alfalfa canals divert water to land south of the river. All of these canals formerly relied on natural flow, but now have storage rights to water in either Lake McConaughy or Sutherland Reservoir. Water for all except the Kearney Canal is released from Lake McConaughy or the Sutherland Reservoir, and carried through the CNPPID system. It is returned to the river below the power plant just west of the study area. Storage water for the Elm Creek canal was returned to the river below the power plants near Johnson Lake. The Kearney Canal also retains rights to water returned below the Johnson plants, but generally does not use this water, relying instead on natural flow to satisfy its irrigation requirements.

All the smaller canals diverting water for irrigation from the Platte are unlined. In the development of the model, seepage losses were estimated to be 50 percent of all water diverted. Periods of flow and maximum diversions in 1985 are listed in Table 5 for each canal. Table 6 lists the average annual diversions for irrigation and power, average annual return, and average area irrigated for each Platte River canal, including the CNPPID system.

Republican River Basin Canals and Service Systems

Eight major canals within the study area divert water from the Republican or one of its

Table 5

Periods of Flow and Maximum Diversion for Platte River Canals in South-Central Study Area - 1985

Canal	Initial Diversion	End of Diversion	Maximum Flow
			(cfs)
Thirtymile	May 13	September 11	347
Gothenburg	April 9	October 19	332
Sixmile	May 30	September 6	39
Cozad	May 8	September 2	262
Orchard-Alfalfa	April 24	September 7	78
Dawson County	May 15	September 12	509
Kearney	April 15	November 19	356

Table 6

Platte River Canal Diversions, Returns and Area Irrigated

Canal	Average Annual Diversion 1940-1980 Irrigation	Power	Average Annual Return (Power Only)	Average Area Irrigated
	(acre-feet)			(acres)
Tri-County Supply	4,815 [1]	---	---	5,694
Phelps	59,032	---	---	[2]
E-65	35,961	---	---	[2]
E-67	4,369	---	---	[2]
Jeffrey Power Return	---	---	46,840	---
Gothenburg	35,220	80,000 [3]	68,580	2,295
Thirtymile	37,834	---	---	10,665
Sixmile	1,471	---	---	1,135
Cozad	24,621	---	---	7,776
Orchard - Alfalfa	8,333	---	---	1,535
Dawson County	54,358	---	---	7,794
Johnson Power Return	---	---	573,400	---
Elm Creek [4]	6,850	---	---	3,000
Kearney	12,922	74,990	74,990	2,405

[1] 1981 only.
[2] Acres are combined for these three canals. Average acres irrigated are: 1941 - 26,320; 1946 - 74,434; 1955 -104,261; 1965 - 122,058; 1974 - 122,628; and 1981 - 129,375.
[3] Prior to 1979, when power right was cancelled.
[4] Abandoned in 1963.

Source: Hydrologic Data for the South-Central Area, Nebraska, U.S Geological Survey, 1986.

tributaries. Three of the canals are located in the USBR's Frenchman-Cambridge Division. The Red Willow Canal receives water from Hugh Butler Lake outside the study area. The Bartley Diversion Dam on the Republican River outside the study area diverts to the Bartley Canal, and the Cambridge Diversion Dam on the Republican diverts water to the Cambridge Canal. The other five canals are located in the USBR's Nebraska-Bostwick Division. These canals and their points of diversion are the Franklin and Naponee canals from Harlan County Lake on the Republican River, and the Franklin Southside Pump, Superior, and Courtland canals directly from the Republican River.

All of these canals were constructed by the USBR during the late 1940s and 1950s. All are open, earth bottom canals subject to seepage losses. Table 7 lists the length, initial capacity, average diversion, and acres irrigated for each canal. Table 8 lists periods of flow and maximum diversions for Republican River Basin canals in 1985.

Platte River Basin Reservoirs

The reservoirs and lakes in the study area are all important in meeting the water needs of this area. Within the study area, the CNPPID operates two reservoirs. Johnson Lake in

Table 7

Republican River Basin Canal Capacities, Diversions and Area Irrigated

Canal	Length[1]	Average Annual Diversion	Average Area Irrigated[1]	Initital Capacity
	(miles)	(acre-feet)	(acres)	(cfs)
Bartley	15	3,313	6,219	130
Red Willow	7	2,502	1,991	85
Cambridge	48	8,670	12,762	325
Naponee	4	1,107	1,199	36
Franklin	45	7,971	10,915	230
Franklin Southside	1	1,152	1,478	42
Superior	6	4,280	560	139
Courtland	6	1,658	384	751

[1]Lengths and average acres irrigated are within South-Central Study area only.

Gosper County is the largest in the CNPPID system after Lake McConaughy. It has a storage capacity of 92,000 acre-feet. Johnson Lake's annual loss to seepage was about 40,000 acre-feet.

Elwood Reservoir, in Gosper County south of Johnson Lake, is supplied by the E-65 canal during the off-season. When it was first filled, the lower part of the reservoir was filled by gravity flow. Only the upper part, which is filled by pumping and drained by gravity is used in normal operations. Approximately 25,000 acre-feet are delivered to Elwood Reservoir each year and later released during the irrigation season. It has a storage capacity of approximately 38,000 acre-feet; its average annual loss to seepage was about 29,000 acre-feet.

Table 8

Diversion Periods and Maximum Diversion for Republican River Canals in South-Central Study Area - 1985

Canal	Initial Diversion	End of Diversion	Maximum Flow
			(cfs)
Red Willow	June 10	September 9	96
Bartley	June 10	September 13	116
Cambridge	June 3	September 13	313
Naponee	June 21	September 10	37
Franklin	June 21	September 13	252
Franklin Pump	June 27	September 4	44
Courtland	June 1	September 12	596
Superior	June 25	September 6	139

The Midway Lakes, located in southwest Dawson County, provide storage for the CNPPID system on the supply canal itself. The three main lakes, West, Central, and East, provide about 8,000 acre-feet of storage.

Republican River Basin Reservoirs

Harlan County Lake is the largest reservoir within the study area. It is jointly maintained by the USBR and COE as a flood control and irrigation reservoir. It was completed and began impounding water in 1952. The reservoir has a storage capacity of 850,000 acre-feet, of which 200,000 are reserved for sedimentation; 150,000 for irrigation storage; and 500,000 for flood control. Releases for irrigation vary from year to year, so the amount of water in storage varies widely. For example, storage in the reservoir peaked in May 1985 at 316,579 acre-feet. Following the irrigation season, storage was down to 247,773 acre-feet in September. Harlan County Lake's average annual loss to seepage was about 24,000 acre-feet.

Harry Strunk Lake was created by the construction of Medicine Creek Dam in 1949. It is located in the southeast corner of Frontier County, and is maintained by the USBR as a flood control and irrigation structure. Harry Strunk Lake has a storage capacity of 32,200 acre-feet; another 57,000 acre-feet are available for flood control storage. In 1985, the lake peaked in April at 38,123 acre-feet. Following the irrigation season, the lake reached its low for 1985 in September at 21,968 acre-feet. Average annual loss to seepage from this lake was 7,600 acre-feet.

WATER BUDGET

Water enters the study area in many ways, including precipitation, stream inflow, canal inflow, and ground water inflow. It exits by evaporation and transpiration, stream flow, canal outflow and ground water outflow. The balance is stored in the area for varying lengths of time.

The entire study area continually loses water from its land surface and from ground water aquifers through evapotranspiration. This loss includes water which evaporates from the soil surface, and water which is drawn up through plant root systems and transpired into the atmosphere. During the 1980-81 period, the study area lost approximately 89,700 acre-feet to evapotranspiration.

Evapotranspiration is increased by ground water pumpage for irrigation. In 1981, there were 12,740 irrigation wells in the study area pumping water from the ground water reservoir. Part of this water was lost to evaporation before it reached the crops, part was transpired by the growing crops, and only a small percentage moved through the root zone and returned to the aquifer.

PLATTE RIVER BASIN

Platte River flows into the study area near Brady averaged 735 cfs from June 1980 to May 1981. During the same period, an average of 1,218 cfs flowed out of the study area in the Platte River near Grand Island.

Between Brady and Kearney, seven canals remove water from the Platte each irrigation season. Table 9 shows the amount diverted into each canal from June 1980 through May 1981. This table also includes the approximate amount of each diversion which the canal lost to seepage and the amount lost to deep percolation from irrigated fields. Those irrigated croplands lost approximately 20,450 acre-feet to seepage during the 1980-81 period.

Some irrigation water runs off the fields to which it is applied and eventually returns to

Table 9

Diversions and Seepage Losses for Seven Platte River Canals June 1980 - May 1981

Canal	Canal Diversion	Seepage Loss from Canals	Seepage Loss from Irrigation
	(acre-feet)		
Gothenburg	53,310	2,568	2,041
Cozad	37,017	15,090	2,301
Dawson	74,856	33,495	12,776
Kearney	9,230	4,615	[1]
Thirtymile	39,060	19,530	1,666
Sixmile	1,260	630	[1]
Orchard-Alfalfa	9,540	4,770	1,666

[1]Crop needs exceeded deliveries for these canals.

streams and to the river. This return flow was considered insignificant and was not included in the ground water model.

The Tri-County Supply Canal enters the study area south of the Platte River near Brady. Its average flow during 1980-81 was 1,466 cfs. Johnson Lake, which is on the supply canal, averaged 43,400 acre-feet of storage during 1980-81, and lost 24,400 acre-feet to seepage during the same period. Part of the flow of the supply canal is diverted into the E-65 canal before it reaches Johnson Lake to supply Elwood Reservoir. Elwood Reservoir's average impoundment was 12,972 acre-feet during 1980-81. It lost about 24,400 acre-feet to seepage during the same period.

The Tri-County Supply Canal continues beyond Johnson Reservoir, supplying water to the E-67 lateral, two hydroelectric power plants, and to the district's main irrigation canal, the Phelps County Canal. During the off-irrigation season, flows are diverted back to the Platte River through the Johnson Return, rather than to the Phelps County Canal. These returns averaged 604 cfs during 1980-81.

All along its route, the supply canal loses flow to seepage. These losses during 1980-81 were estimated at 260,673 acre-feet. During the same period, there was little or no loss to deep percolation from irrigated lands supplied directly by this canal.

The ground water reservoir is recharged by deep percolation from precipitation. The Platte River basin within the study area averaged 3 inches of recharge from this source in 1980-81.

Aquifers in the Platte River Basin discharge ground water to this reach of the Platte River and several of its tributaries. In 1980-81, this discharge averaged 286 cfs. In addition, an average of 14 cfs was discharged into Wood River by ground water seepage during 1980-81. Despite this discharge, Wood River carried little or no flow out of the study area during the same period.

REPUBLICAN RIVER BASIN

The Republican River enters the study area near Bartley in Red Willow County. Its flow averaged 143 cfs during 1980-81 immediately downstream at Cambridge. Two irrigation canals also enter the study area near Bartley. Both canals divert water from the Republican River or a tributary outside the study area. Soon after entering Furnas County, some of the Republican's flow is di-

Table 10

Diversions and Seepage Losses for Republican Basin Canals June 1980 - May 1981

Canal	Diversion	Canal Seepage Loss[1]
	(acre-feet)	
Bartley[2]	9,840	1,189
Red Willow[2]	7,473	304
Cambridge	32,577	8,624
Franklin	29,730	11,205
Naponee	3,999	1,113
Franklin South Side Pump	3,667	919
Superior	15,440	1,210
Courtland	2,524	5

[1]Includes deep percolation losses from irrigated lands. All losses are within the study area.
[2]Diversion point is outside study area.

verted into the Cambridge Canal. Table 10 shows the amount diverted into each of these canals during the 1980-81 study period. It also shows the amount of seepage lost from each canal combined with deep percolation losses from lands irrigated by each canal.

A major tributary to the Republican, Medicine Creek, is impounded by the Medicine Creek Dam soon after entering the study area in Frontier County. This reservoir, Harry Strunk Lake, averaged 22,725 acre-feet of storage during 1980-81, while losing 8,900 acre feet to seepage.

Republican River flows are impounded by the Harlan County Dam. This reservoir averaged 229,092 acre-feet of storage, and lost 32,200 acre-feet to seepage, during the 1980-81 period. The Franklin and Naponee canals divert water from the Harlan County reservoir. Diversions and losses from these two canals are also shown in Table 10.

Three canals divert Republican River flows for irrigation below Harlan County Dam within the study area. The Franklin South Side Pump Canal supplies water to irrigate lands south of the river. The Superior-Courtland Diversion Dam provides water to the Superior and Courtland canals. The Courtland Canal delivers water south of the river, and the Superior Canal delivers water north of the river. Both canals extend beyond the study boundary, and carry some water out of the study area. Diversions and losses for 1980-81 are listed in Table 10.

Some irrigation water runs off the fields to which it is applied and eventually returns to the Republican River through ditches and streams. In recent years, the USBR has constructed several projects to improve efficiency and drain high ground water that increase return flows. These return flows were considered too small to affect the model, so they were not included.

Within the Republican basin portion of the study area, surface water is lost to deep percolation from irrigated acres, but figures on the amount of this loss are not available. Ground water aquifers in the Republican basin are also recharged by deep percolation from precipitation. This type of recharge averaged 2.5 inches over the entire basin in 1980-81. Aquifers also discharge ground water to the Republican and many of its tributaries. In 1980-81, this discharge averaged 139 cfs. The Republican exits the study area east of Guide Rock. Its flow averaged 85 cfs during 1980-81.

Chapter 3

SIMULATIONS OF ALTERNATIVE ACTIONS AND POLICIES

The effects of alternative policies, projects, and independent actions that might occur in the future were simulated with the economic and ground water models for the NRDs and the NRC. Selected hypothetical conditions were also modeled to estimate the effects of existing projects.

First, a baseline projection of future conditions was made to serve as the basis for comparing the effects of alternative actions and policies. The NRC and its consultants selected projected crop yields, demand, and interest rates for the baseline projection. The NRDs advised the modelers on potential shifts in crops such as the conversion from corn to soybeans.

The NRDs requested an evaluation of the ground water effects that could be attributed to seepage from surface water projects. They also asked for projections of ground water impacts due to changes in water use, ranging from a rate of growth of 10 percent per year to a 10 percent rate of reduction from 1981 ground water irrigated acres. The criteria for choosing the locations of the additions and deletions were selected by the NRC with the concurrence of the NRDs. Changes were restricted to existing areas with irrigated acres.

The NRC established the criteria for the other simulations. The objective of these projections was to begin to define the magnitude of the problems faced by NRDs in implementing their ground water management plans. The Lower Republican NRD's aquifer life goal of infinity and criteria for establishing management areas were selected as representative conditions. Criteria for locating future irrigation development was changed to allow more economic growth by making it more likely that an area would be developed if there is little or no irrigation and irrigable acres are available.

The results of these simulations can be used to judge the effects of a proposed policy or project compared to other policies or projects, but not for predicting the future. They simply demonstrate the economic activity and aquifer response under the given set of conditions imposed on the model.

The results of all simulations are highly dependent on the conditions selected. For instance, the use of long-term average crop prices and yields will not project the short-term effects of droughts on production, or periodic low prices on farm stability, but they will produce a balanced projection of the economic situation in the long run.

Projections of future water table declines are dependent on the amount and location of future irrigated acres. Since future development cannot be predicted accurately, a range of development from positive to negative was used. If future development occurs in places other than the location selected for these model runs, the results of the simulations will be erroneous for a small area but the overall trend should be the same.

BASELINE PROJECTIONS

Computer models are often used to simulate the effects of conditions that might have occurred in the past or could occur in the future. The results of these simulations are most useful when compared to some situation that is familiar or easily understood. If the existing situation will not provide a useful comparison, some acceptable projection of future conditions, often called a baseline, may prove to be more meaningful. For example, if a dam has recently been constructed on a stream, historical records of streamflow would not be useful for planning future irrigation below it. It would be more meaningful to compare the results of alternative plans to a baseline projection of flows with planned dam operations than to compare them with historical flows.

Baseline projections of farm and ranch economics and ground water conditions were made for this study. The area covered by the economic model differed from the ground water model area. The FARE model is based on county data aggregated to regions, so its regions 11 and 12 were used in this study. The seven counties that comprise these regions are shown in Figure 10. Projections of economic conditions were made from current trends and projections of future water use. These were then adjusted to cover the entire ground water model area before being used as the basis for projections of ground water conditions.

BASELINE CONDITIONS

The results of any simulation are greatly influenced by the conditions imposed on the model or the criteria selected for the actions to be modeled. Two types of actions were selected for the baseline: independent actions by private individuals or organizations, and public programs or projects. It was assumed that current trends in water use and development would continue if there was no new governmental action. This included assumptions that any projects currently underway would be completed, federal and state programs would be continued, and no new controls would be initiated.

Ground Water Model Conditions

The most important independent action modeled was the future development of ground water irrigation. The amount of projected development was determined by the FARE model. The location of new irrigated acres, a task of the ground water model, was based on the number of undeveloped acres remaining in each area. Total irrigable acres in any cell were calculated by multiplying the number of acres of each soil association in the cell by the percentage of the association estimated to be irrigable. Remaining irrigable acres were calculated by subtracting the number of acres already irrigated. New development was assigned to cells according to the percentage of remaining irrigable acres in the cell.

No other potential independent actions to develop ground water were considered significant enough to affect the baseline. No new municipal or industrial well development was modeled.

The only public project that was included in the model was the rehabilitation and improvement project of CNPPID. It appeared that water tables around Elwood Reservoir had not stabilized, and might continue to rise. In addition, CNPPID recently improved many of their canals and laterals so that seepage losses were reduced by about 30 percent. This could have a significant impact on water levels in the surface water irrigated areas and adjacent ground water irrigated lands.

To provide the basis for comparisons of the effects of public policies, no new regulatory programs were imposed in the baseline. It was assumed that the conservation provisions of the 1985 farm bill would still allow irrigation development under approved conservation plans. It was also assumed there would be no NRD control or management areas. The number of surface irrigated acres was projected to remain constant, but changes to crops with less consumptive irrigation requirements were allowed.

One of the conditions that must be imposed on the model that can significantly impact the baseline projection is the selected weather pattern. The two basic choices are to use the historical average, or to repeat some historical period in the future. In the first case, the period of record selected can affect the average if it includes abnormal periods of

State of Nebraska
NATURAL RESOURCES COMMISSION
Planning Division

FARE Model Regions

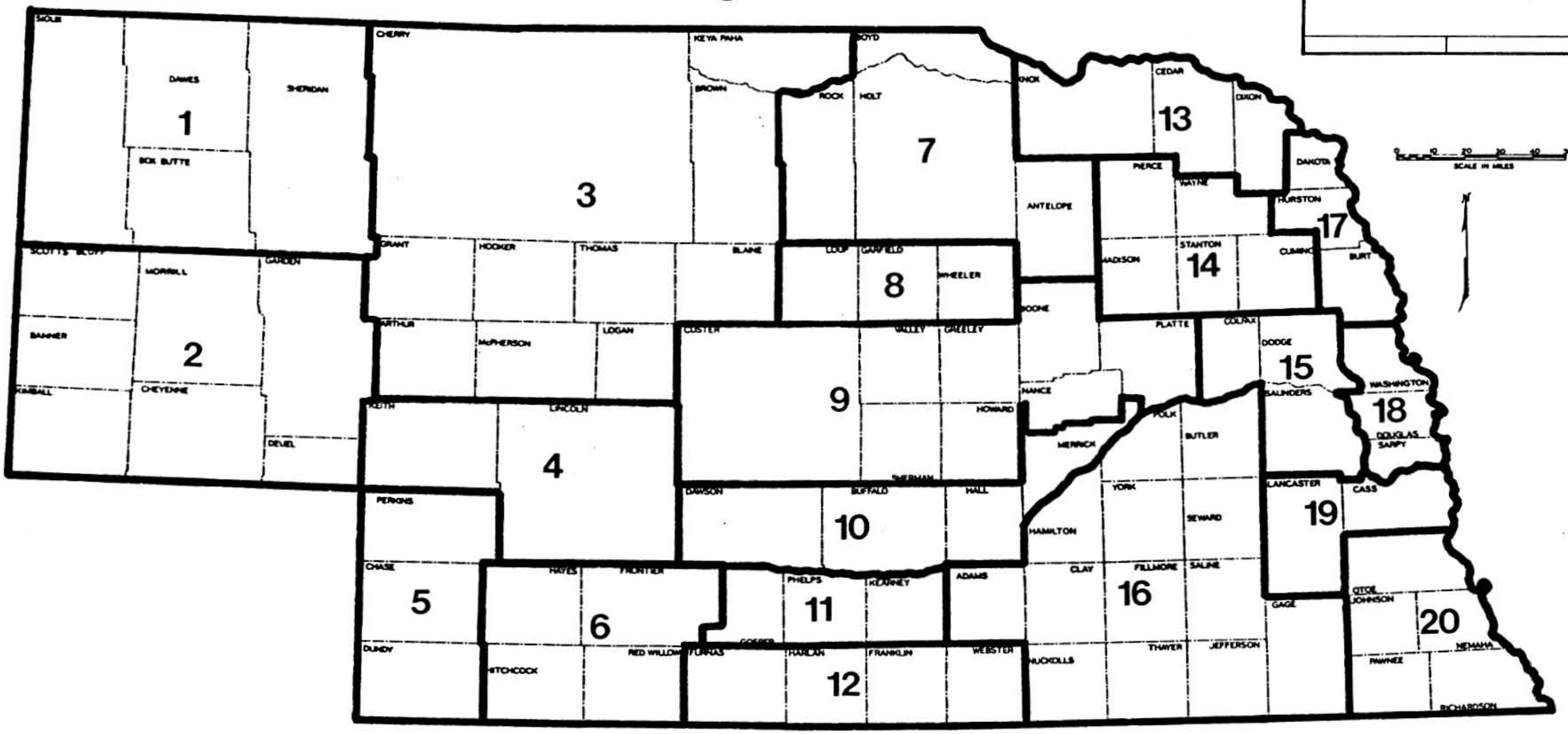


Figure 10

drought or high precipitation. In the second case, starting in an abnormal period such as a drought can affect the early results. For the baseline and all other predictive simulations, the historical record of 1940 to 1980 was repeated. This provided drought periods in the 1950s and 1970s and a wet period in the 1960s, as well as a record of adequate length.

Economic Model Conditions

Three factors in the model largely established the economic conditions used for the baseline. These were crop yields, prices (input and commodity), and resource data (water and land). Projections of crop yields to 2020 were made using trend analysis. The projections from the trend analysis were adjusted using the best judgment of experts considering such factors as genetic improvement, disease control, fertility management, cultural practices, insect control, and harvesting and storing practices. This procedure was developed for the High Plains Study and updated for the most recent version of FARE. The projected yields are listed in Table 11.

Costs of production are sensitive to the prices of inputs such as fertilizer, seed, fuel, and other chemicals. Perhaps the most unstable of these prices are the ones that are related to petroleum products. The uncertainty in the world oil market made forecasting very difficult. Consequently, 1985 prices were assumed to prevail throughout the period.

Crop prices also tend to be somewhat unstable over time, but they are less volatile than oil prices. Crop prices for the initial time period (1985) were an average price for that year. The crop price projections were based on current United States Department of Agriculture (USDA) projections. The projected crop prices used in the FARE model are listed in Table 12.

Another important price is the price of money, or the interest rate for borrowed money. The interest rate not only influences the cost of crop production, it is also important to investment decisions. The long-term average real interest rate charged by the Federal Land Bank was used in the model. A real interest rate is one that has been adjusted for inflation. The rates used in the model are listed in Table 12.

BASELINE RESULTS

The results of the ground water and economic models were dependent on each other. The ground water model first produced general results the FARE model could use to determine water-dependent relationships. The FARE model then produced irrigation development projections the ground water model used to locate and calculate the magnitude of water table impacts.

Projected Ground Water Changes

The primary results of the ground water model simulations were future water table elevations and ground water gains and losses to base flows in streams. For the baseline, future declines and rises from 1981 water levels and changes in saturated thickness of the aquifer were projected.

Figure 11 shows the water table change from 1981 levels by the year 2000 if development occurs under baseline conditions. The most significant features of this map are the area of water table rise in Gosper and Frontier counties and the area of decline in Phelps, Kearney, Harlan, and Franklin counties.

The area of water table rise is located near Elwood Reservoir. The water table around that reservoir, which was built in 1978, had not stabilized by 1985. It is projected to rise 40 feet more by the year 2000.

The area of projected decline covers much of Phelps and Kearney counties and a significant part of Harlan, Franklin, and Adams counties. The CNPPID is located in the northern half of this decline area. Since the CNPPID was developed in the early 1940s, the water table under and around it rose more than 50 feet, but that will be reversed under baseline conditions by 2000. This decline is a result of a decrease in canal seepage produced by

Table 11
Projected Irrigated and Dryland Yields in Regions 11 and 12

Crop	Units [1]	1985	1990	2000	2010	2020
			Region 11			
Dryland:						
Corn	Bu.	70	78	92	107	122
Sorghum	Bu.	76	85	103	120	138
Soybeans	Bu.	28	29	32	34	36
Alfalfa	T.	3.5	3.7	4.2	4.7	5.1
Wheat	Bu.	45	49	57	64	72
Irrigated:						
Corn	Bu.	160	175	205	235	265
Sorghum	Bu.	102	111	129	147	165
Soybeans	Bu.	46	49	55	61	67
Alfalfa	T.	5.0	5.3	5.8	6.3	6.9
Wheat	Bu.	54	59	69	77	86
			Region 12			
Dryland:						
Corn	Bu.	67	74	88	103	117
Sorghum	Bu.	72	80	97	113	130
Soybeans	Bu.	33	34	37	40	42
Alfalfa	T.	3.2	3.5	3.9	4.3	4.8
Wheat	Bu.	45	49	56	64	71
Irrigated:						
Corn	Bu.	143	156	183	210	237
Sorghum	Bu.	104	113	131	149	167
Soybeans	Bu.	47	49	55	61	67
Alfalfa	T.	5.1	5.4	5.9	6.4	7.0
Wheat	Bu.	53	58	68	76	84

[1] Units are bushels (Bu.) or tons (T.)

CNPPID's improvement project and current ground water irrigation, plus a projected increase in new irrigation at the baseline rate of less than two percent per year. This rate is similar to the early 1980's rate of development. It contrasts sharply with the 1970's rate of approximately 10 percent.

Figure 12 shows the percent decrease in 1981 saturated thickness by 2000. It shows two areas where 100 percent of the aquifer would be lost, but this is not particularly important. As shown in Figure 13, the saturated thickness in both places was very small in 1981, so these areas would not support ground water irrigation. Most important are the 25 percent losses shown in the southeast corners of both Phelps and Kearney counties, where the 1981 saturated thickness was about 125 feet and 75 feet respectively. These areas were irrigated extensively, and both experienced declines of more than 15 feet by the fall of 1986. This indicates

Table 12

Crop Prices and Interest Rates Used in the FARE Model

Year	Corn	Grain Sorghum	Wheat	Soybeans	All Hay	Interest Rates
	($/Bushel)	($/Bushel)	($/Bushel)	($/Bushel)	($/Ton)	(Percent)
1985	2.49	2.17	2.97	5.18	46.35	9.51
1990	1.89	1.62	2.12	5.52	35.18	6.93
1995	2.34	2.07	2.87	5.32	43.55	4.35
2000	2.75	2.39	3.66	6.10	51.19	3.37
2005	3.17	2.71	4.45	6.88	59.00	2.40
2010	3.17	2.71	4.45	6.88	59.00	2.40
2015	3.17	2.71	4.45	6.88	59.00	2.40
2020	3.17	2.71	4.45	6.88	59.00	2.40

the current decline can be expected to intensify and expand.

Figure 14 shows the 2020 water table changes. The contour patterns are similar to the 2000 changes. The difference is due to the expansion of both the rise and decline areas. The rise in Gosper County associated with Elwood Reservoir would not be much higher than in 2000 but it would cover a slightly larger area. This indicates that natural drains could stabilize the water table.

The area with declines in 2000 would expand greatly by 2020 to cover most of Phelps and Kearney counties and the northern half of Harlan and Franklin counties. It would have a maximum decline of about 75 feet. Figure 15 shows that in this area, 25 to 50 percent of the 1981 saturated thickness would be lost. In eastern Frontier County, over 50 percent would be lost due to a 20-foot decline.

Four other small areas with declines also appear. An area in south-central Gosper County declined over 20 feet by the fall of 1986 and could decline an additional 20 to 30 feet by 2020. The Frontier County decline was greater than 15 feet. It could also decline 20 to 30 feet more by 2020. Both areas have considerable irrigation development. The other two small areas (in Harlan and Webster counties) support little irrigation.

Projected Economic Impacts

Using the FARE model, a baseline projection was made of the future of the agricultural economy of the seven counties in regions 11 and 12, shown in Figure 10. This included projections of the annual rate of growth of irrigation development in the future.

The amount and rate of projected irrigation development depend on the relationship between irrigated and dryland corn yields, an average real crop price variable, a real interest rate, and a variable which accounts for technological change. The first three factors are related to the profitability of irrigation and the fourth accounts for technological factors such as the advent of the center pivot. In addition to these factors, the rate of development also depends on the amount of irrigable area in a region that is still available for development. It was assumed that the rate would progressively become slower as the maximum level of development was approached. The projected development for regions 11 and 12 is shown in Table 13.

The baseline projection provided information about estimated farm income, changes in land use, cropping pattern changes, the amount of water pumped for irrigation, and the irrigation application level. Estimates of returns to land and management (farm income)

Baseline Water Table Changes from 1981 Levels by 2000

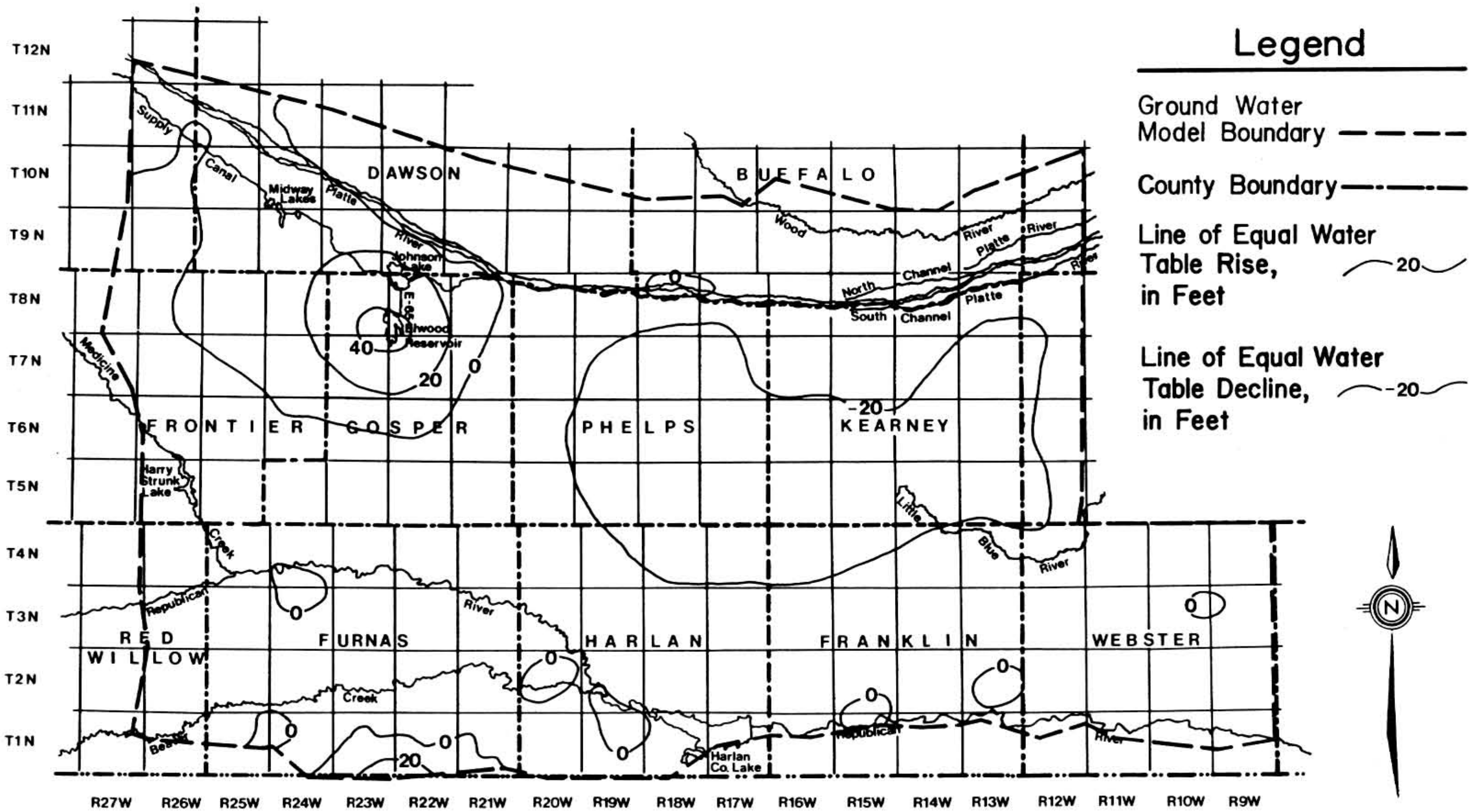
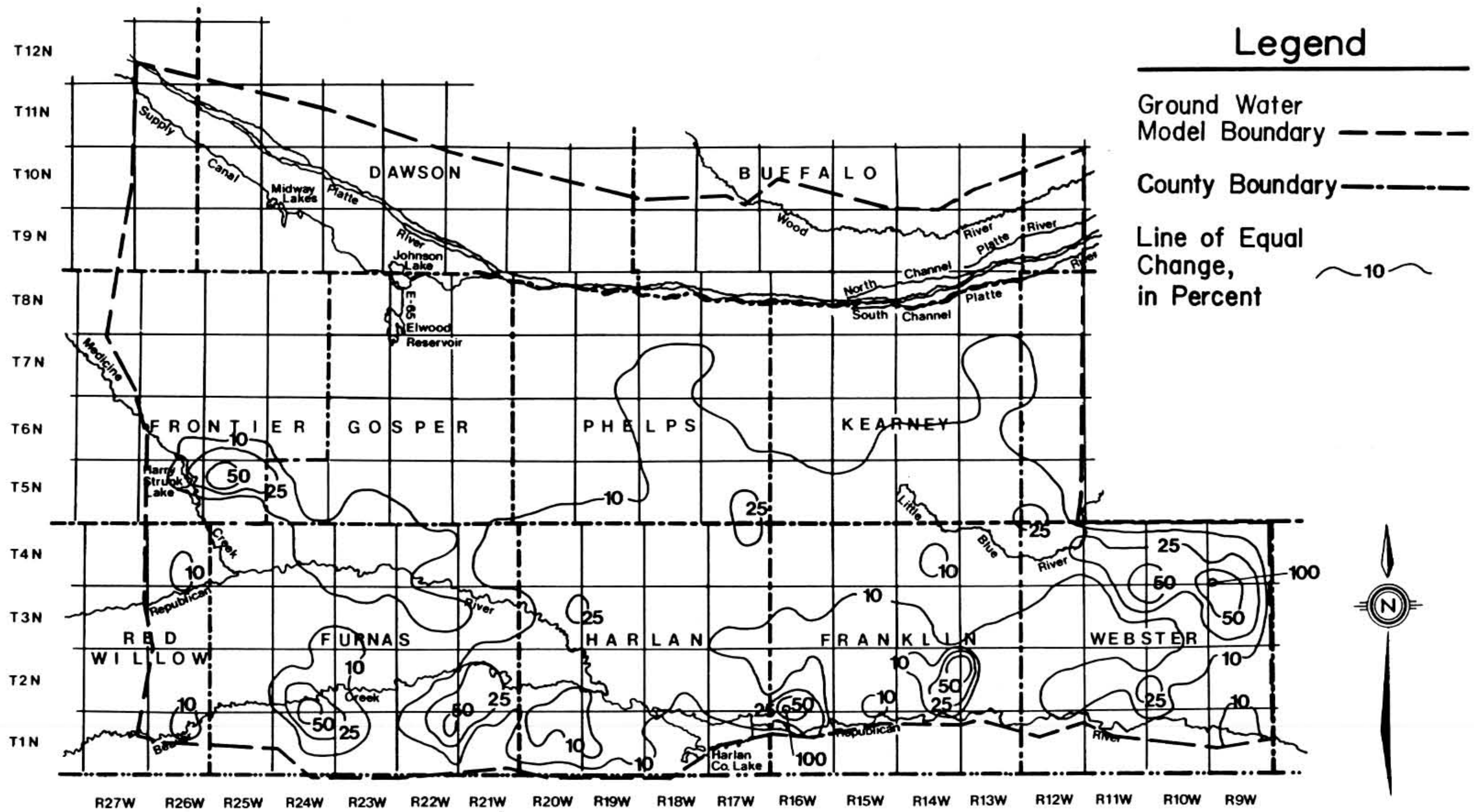


Figure 11

Figure 12

Percent Decrease in 1981 Saturated Thickness by 2000
Under Baseline Conditions



Saturated Thickness of the Principal Aquifer in 1981

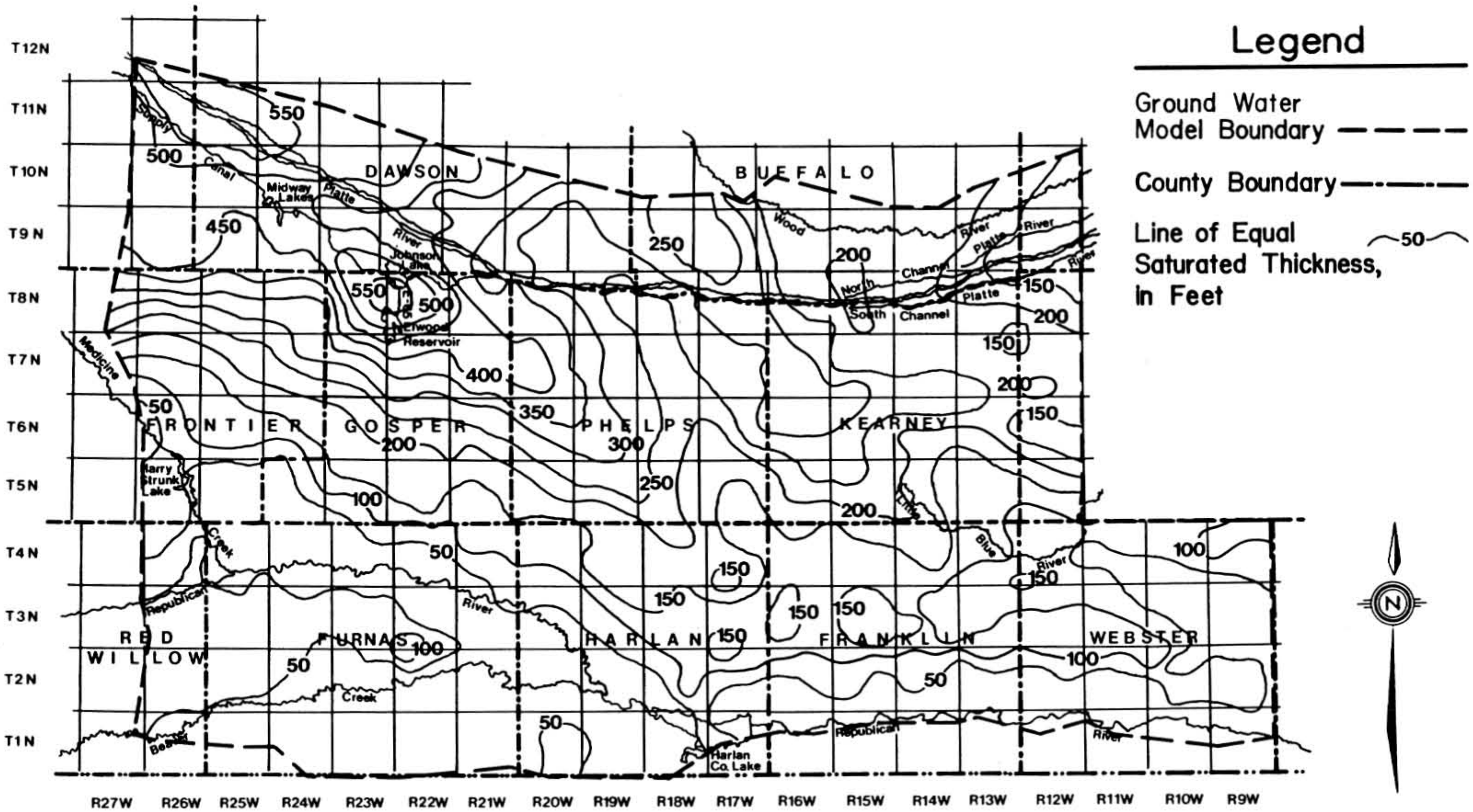
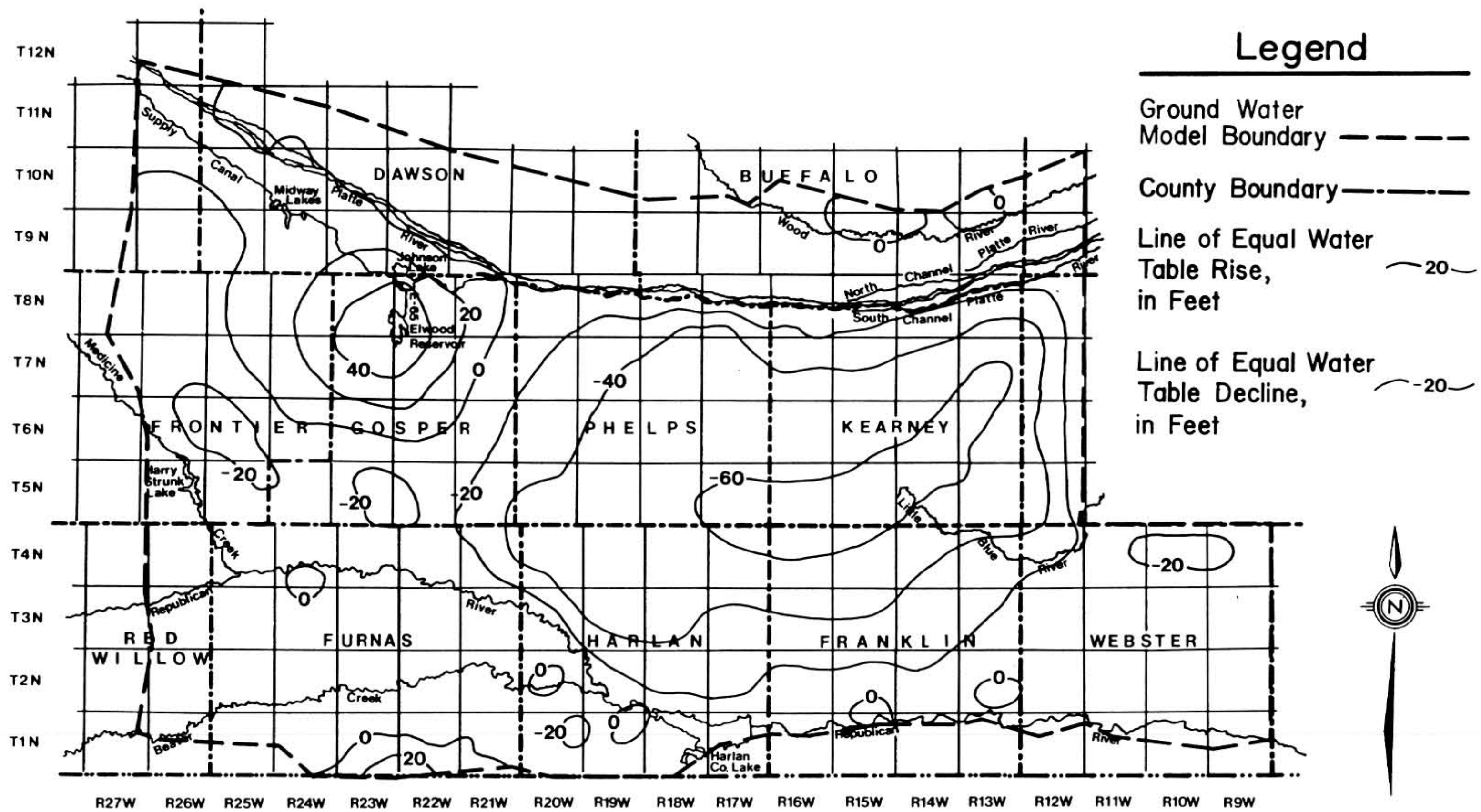


Figure 13

Baseline Water Table Changes from 1981 Levels by 2020



Percent Decrease in 1981 Saturated Thickness by 2020 for Baseline Projection

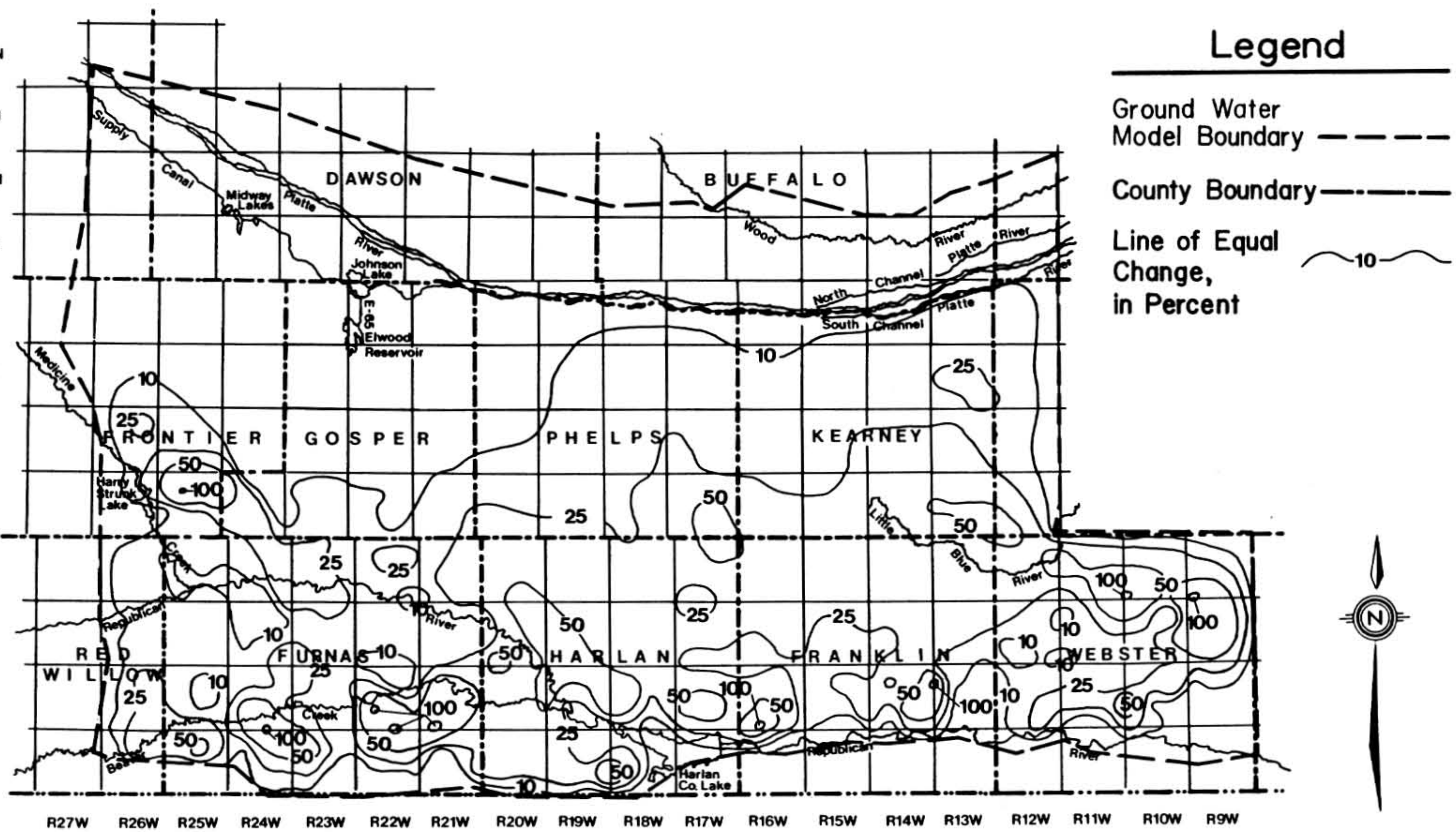


Figure 15

for baseline conditions are shown in Figure 16. The returns are shown for both irrigated and non-irrigated cropland and for pasture. The returns for non-irrigated cropland were approximately $34 million in 1985, but declined to around $21 million in 1990, then grew steadily to about $105 million in 2020. Irrigated returns exhibited a similar pattern. They began at about $92 million in 1985, declined to about $58 million in 1990, and then grew steadily to about $557 million by 2020. Pasture returns remained fairly stable over the simulation period, ranging from about $2 million to about $2.5 million.

The projected returns declined in 1990 due to a decrease in commodity prices that was projected to occur between 1985 and 1990. Prices were projected to increase after 1990. Increasing prices combined with improving yields accounted for the growth in returns for dryland crops. The large increase in returns for irrigated crops was caused by those two factors plus growth in the number of acres. The total returns for dryland crops and pasture grew more slowly than the irrigated returns because some dryland crop and pasture acres were converted to irrigation.

The amount of land in three categories of agricultural land use: dryland crops, irrigated crops, and pasture, is shown in Figure 17. Two factors that influenced these categories were the amount of land developed for irrigation and the amount of irrigated land that reverted to dryland production or pasture because of aquifer exhaustion. In the study area, very little irrigated land reverted to dryland, so the development factor was the only significant influence on land use during the period from 1985 to 2020. The amount of irrigated land grew from about 681,000 acres in 1985 to about 1.1 million acres in 2020. Non-irrigated cropland declined from 594,000 acres in 1985 to

Table 13

Projected Ground Water Irrigated Areas

County	Year				
	1985	1990	2000	2010	2020
	(acres)				
			Region 11		
Gosper	89,727	94,860	106,090	119,663	135,656
Kearney	148,979	163,584	195,965	231,187	258,528
Phelps	111,697	126,503	152,774	165,094	168,278
Total	350,403	384,947	454,829	515,944	562,462
			Region 12		
Franklin	64,752	69,895	81,404	95,962	113,996
Furnas	36,742	38,616	41,573	46,531	52,336
Harlan	67,780	71,069	77,508	87,878	100,704
Webster	36,693	38,957	44,463	53,469	70,165
Total	205,967	218,537	244,948	283,840	337,201

Figure 16

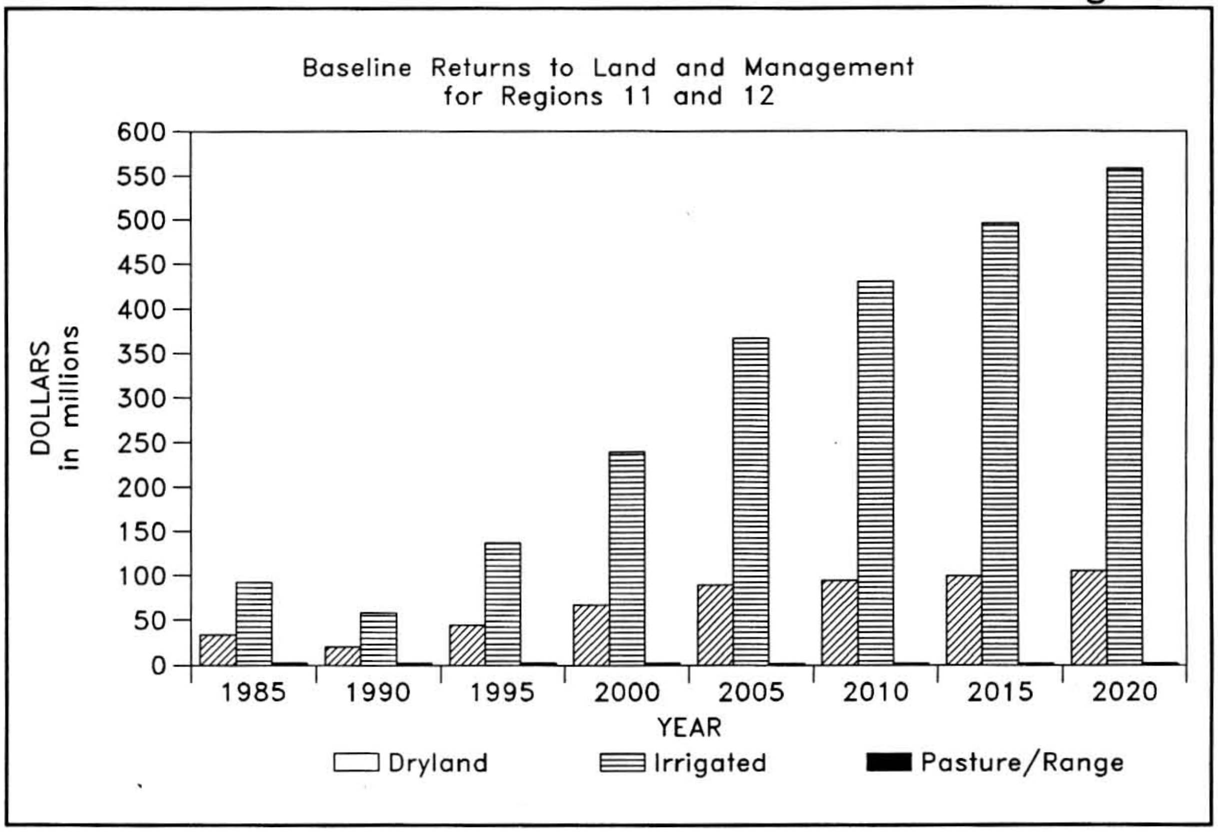
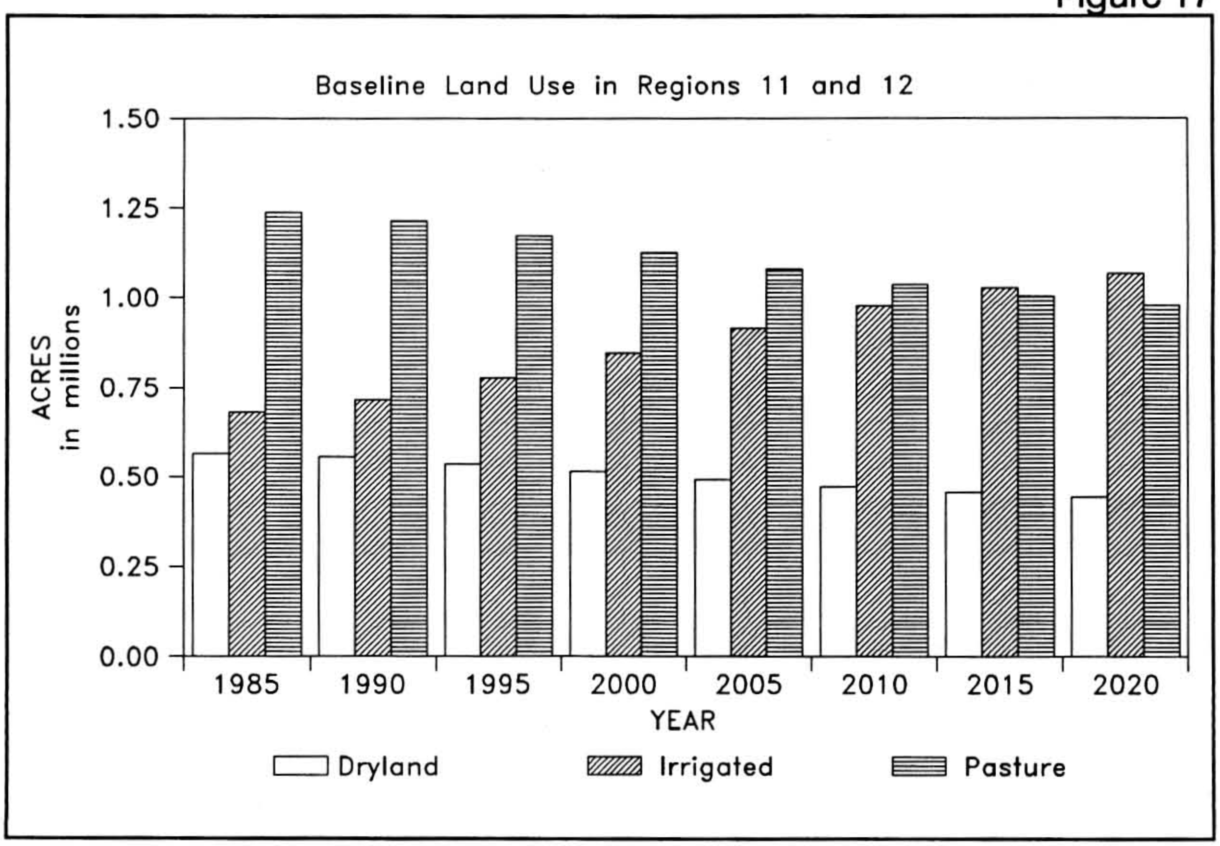


Figure 17



470,000 acres in 2020. Pasture land was reduced from 1.24 million acres in 1985 to about 975,000 acres in 2020.

The cropping pattern for the dryland acres in the study area for selected years is shown in Figure 18. In 1985, approximately four percent of the acres were corn; alfalfa and soybeans each accounted for about 8 percent; and grain sorghum and wheat were 40 and 41 percent, respectively. During the 35 year simulation period, the percentage of corn increased from about 4 percent to 25 percent because of increased profitability due to projected yield increases. Alfalfa remained stable between 6 and 8 percent of the pattern throughout the period. Soybeans increased from about 8 to 16 percent from 1985 to 1995 but declined to just over 2 percent by 2020. Grain sorghum became the most common dryland crop by 2020. By that time it occupied one-half of the total acreage. Wheat dropped from 41 percent of the dryland acres in 1985 to about 17 percent in 2020.

The cropping pattern for irrigated land is shown in Figure 19. The distribution is dominated by corn, which accounts for about 90 percent of irrigated acreage during the simulation period. Wheat makes up only a small portion of irrigated crops during the early part of the simulation period and disappears completely after 1995. The other three crops remain fairly stable, ranging from two percent to about five percent.

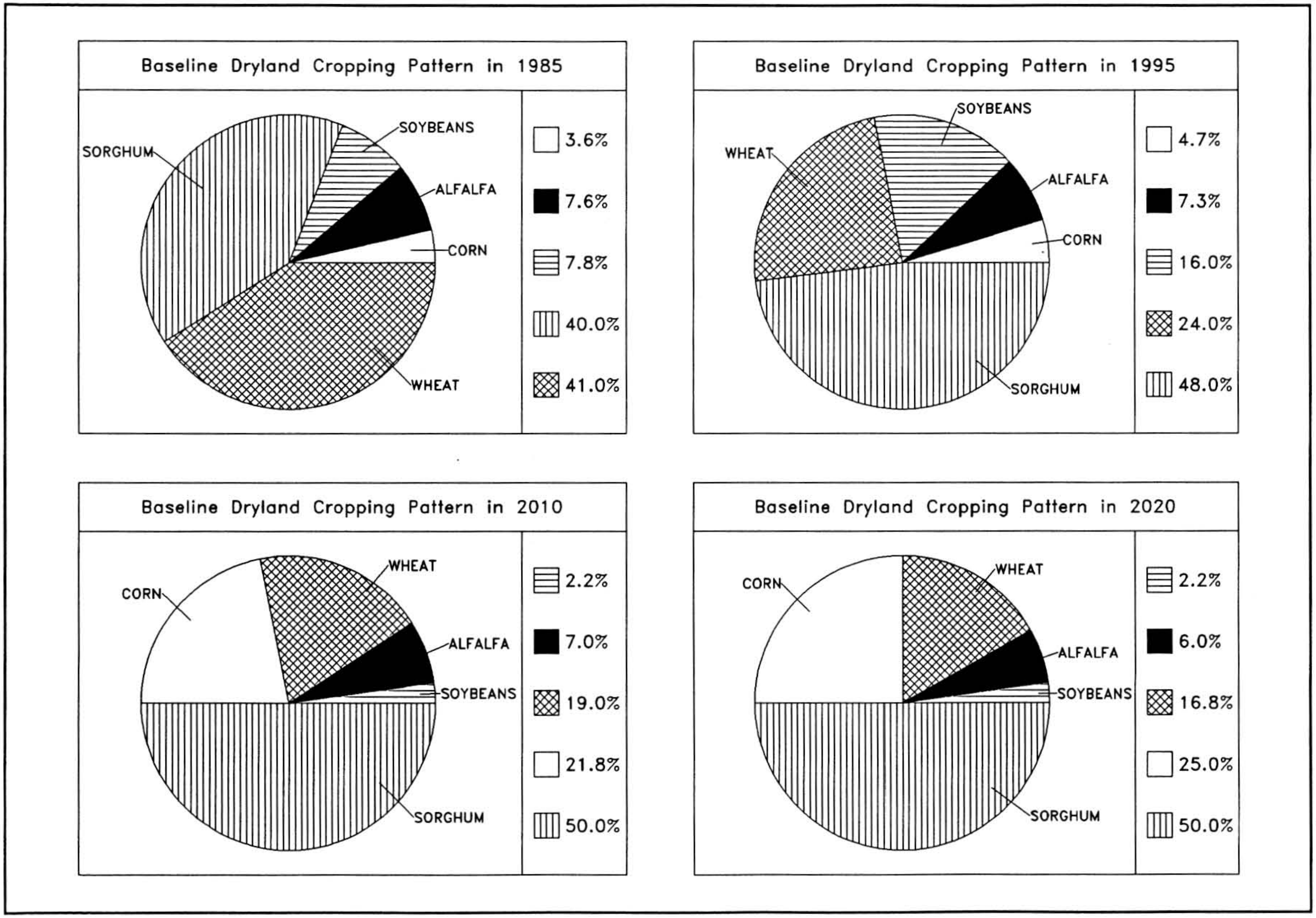
Each irrigated crop received water at one of three levels during the simulation period: full irrigation, 90 percent, and 70 percent of full irrigation. Full irrigation is the average application that would produce the maximum potential yield for a crop. Yields and other production inputs were adjusted accordingly for the 90 and 70 percent levels. The number of acres projected for each level for 1985-2020 is shown in Figure 20.

The most used water application level throughout the simulation period was the 90 percent level. The number of acres of 90 percent irrigation ranged from about 480,000 in 1985 to almost 800,000 in 2020. The full irrigation level had the second highest number of acres during most of the simulation period. This level ranged from about 200,000 acres in 1985 to about 300,000 in 2020. Acres that were irrigated at the 70 percent level occurred only during the early part of the simulation period. In 1985, there were about 5,000 acres using the 70 percent level; in 1990, there were about 160,000 acres. The reduction in acres under the full and 90 percent levels and the increase in the 70 percent level in 1990 were due primarily to low commodity prices. The irrigated acres were still more profitable than the dryland acres. The extra water applied for the full and 90 percent irrigation levels, however, did not generate enough additional revenue to cover the extra expenses.

The amount of water used in the baseline case was influenced only by the economic environment and the availability of water. The amount of water pumped for irrigation in selected years is shown in Figure 21. The amount pumped in 1985 was about 786,000 acre-feet. Although more acres were irrigated in 1990 (Figure 20), the total amount of water pumped decreased to about 742,000 acre-feet. The decline in water pumped from 1985 to 1990 was due to low commodity prices and the resulting decrease in water use per acre. After 1990, total water pumped increased at a fairly steady pace, to an annual rate of just over 1.1 million acre-feet by 2020.

SIMULATIONS OF IRRIGATION ALTERNATIVES

In addition to the baseline, several other alternatives were simulated with the ground water model at the request of the three NRDs involved in the study. Requested simulations were of two types. The first approximated the effects on the water table of selected surface



Baseline Dryland Cropping Pattern in 1985
SORGHUM
SOYBEANS
ALFALFA
CORN
WHEAT
3.6%
7.6%
7.8%
40.0%
41.0%
Baseline Dryland Cropping Pattern in 1995
SOYBEANS
WHEAT
ALFALFA
CORN
SORGHUM
4.7%
7.3%
16.0%
24.0%
48.0%
Baseline Dryland Cropping Pattern in 2010
WHEAT
CORN
ALFALFA
SOYBEANS
SORGHUM
2.2%
7.0%
19.0%
21.8%
50.0%
Baseline Dryland Cropping Pattern in 2020
WHEAT
CORN
ALFALFA
SOYBEANS
SORGHUM
2.2%
6.0%
16.8%
25.0%
50.0%

Figure 18

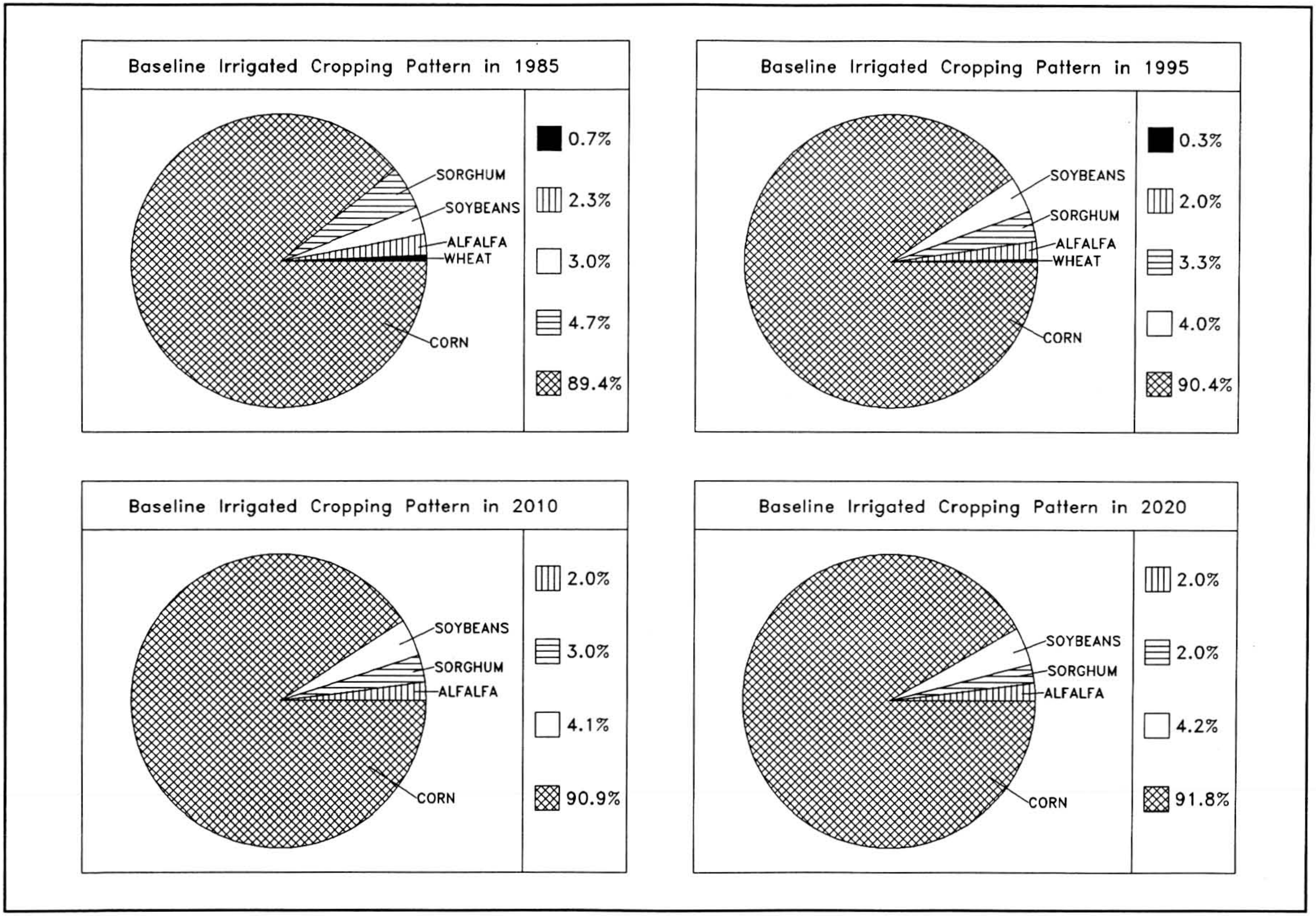

Baseline Irrigated Cropping Pattern in 1985
SORGHUM
SOYBEANS
ALFALFA
WHEAT
CORN
0.7%
2.3%
3.0%
4.7%
89.4%
Baseline Irrigated Cropping Pattern in 1995
SOYBEANS
SORGHUM
ALFALFA
WHEAT
CORN
0.3%
2.0%
3.3%
4.0%
90.4%
Baseline Irrigated Cropping Pattern in 2010
SOYBEANS
SORGHUM
ALFALFA
CORN
2.0%
3.0%
4.1%
90.9%
Baseline Irrigated Cropping Pattern in 2020
SOYBEANS
SORGHUM
ALFALFA
CORN
2.0%
2.0%
4.2%
91.8%

Figure 19

Figure 20

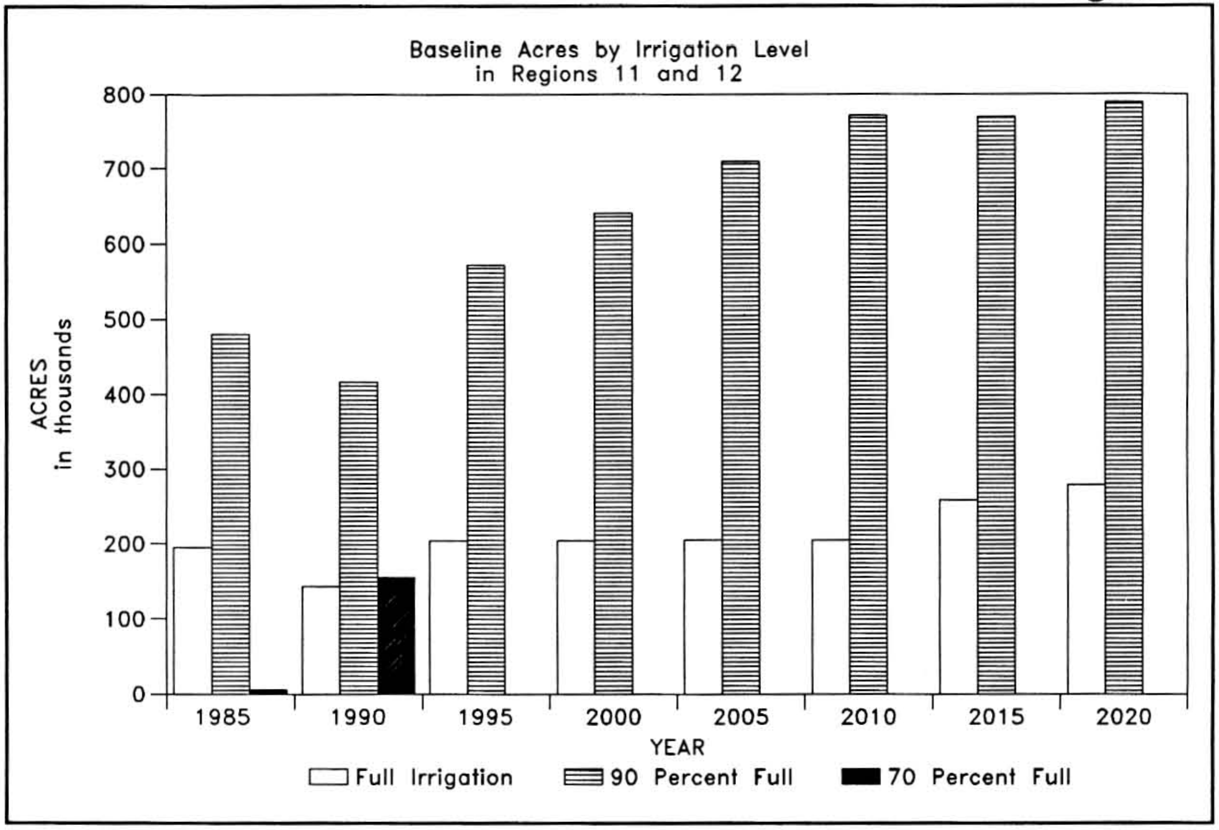
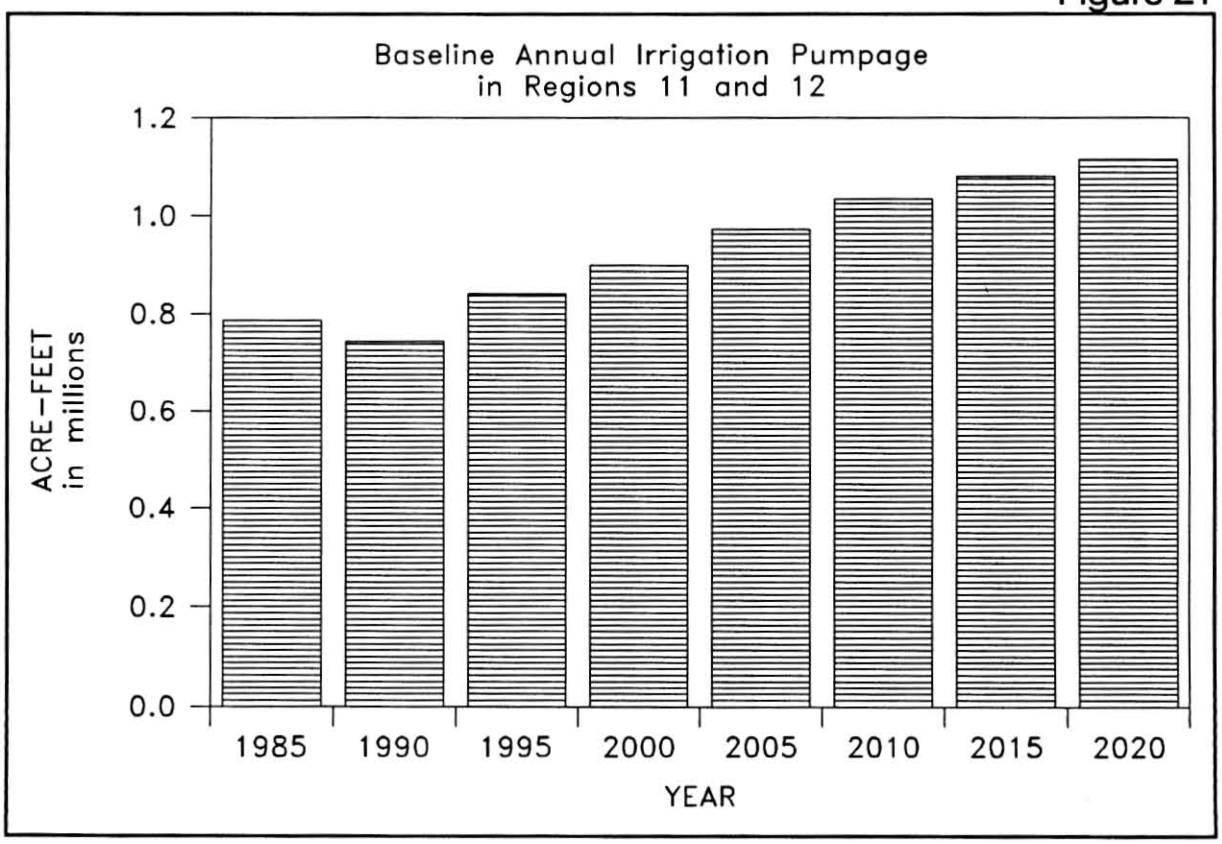


Figure 21



water projects in the area. The second evaluated the effects on the water table of increasing or decreasing ground water irrigation development.

GROUND WATER EFFECTS OF SELECTED SURFACE WATER PROJECTS

Each NRD was interested in simulating the effects on ground water of a surface water project in its district. The NRDs selected the conditions to be used in modeling.

Projections for the Central Platte NRD

Early in the study, the Central Platte NRD expressed an interest in having the model designed so water table rises caused by surface water irrigation and associated canals in southwestern Dawson County could be investigated. Historic conditions could not be duplicated, because data from the early 1900s were not available. It was also impossible to show future conditions without the projects, because ground water is available and some land in the district could be converted to that source. To fulfill the NRD's request, a hypothetical situation was simulated that, in effect, represented the conditions that would prevail if surface water irrigation were removed and other development remained static at the 1981 level for 40 years.

The period 1981-2020 was first simulated as though the four canals in the area (Orchard-Alfalfa, Six-Mile, Thirty-Mile, and the Tri-County Supply Canal) were removed from service. Seepage from the four canals and from Johnson Lake was removed and surface water irrigated acres associated with these canals were converted to dryland crops. Ground water irrigated acres were held constant at the 1981 level of development. The E-65, E-67, and Phelps County canals and the acres they serve were not changed, because they did not affect the main area of interest in these simulations. They were treated as though their water supply could be provided by a canal diverting directly from the Platte River that would not allow any seepage to ground water. The result of this simulation was a water table map that would serve as the basis for comparison of conditions with and without the canals.

In the second simulation, the Orchard-Alfalfa Canal and its associated seepage, surface water irrigated acres, and recharge from irrigation were included as they existed in 1981. Ground water table elevations from the first simulation were subtracted from the second to approximate the rise in water table attributable to the Orchard-Alfalfa Canal.

A third run was made with both the Orchard-Alfalfa and Six-Mile Canals included. Figure 22 shows the difference between the first and third runs. It represents the rise in the water table that can be attributed to these two canals when it stabilizes under hypothetical conditions. A maximum rise of about seven feet was centered near Section 6, Township 9 North, Range 23 West. Most of the rise was caused by the Orchard-Alfalfa Canal. The maximum rise associated with Six-Mile Canal was only about 0.5 feet. It was located at the northwestern corner of the zone of influence.

A fourth simulation evaluated the effects of Thirty-Mile Canal. The map in Figure 23 shows the difference between the fourth and third runs, which represents the effect of that canal. The maximum rise associated with Thirty-Mile canal was approximately 13 feet. It was centered near Section 14, Township 10 North, Range 25 West.

The final Central Platte NRD simulation re-introduced the Tri-County Supply Canal and Johnson Lake. Subtracting the results of the fourth simulation from this one approximated the water table rise attributable to the Tri-County Supply Canal and associated facilities. Figure 24 shows that the stabilized water table rise would be centered under Johnson Lake. The maximum was 170 feet. Rises on the north side of the study area were constrained by the Platte River and a number of drains to the Platte.

The area in southeastern Gosper County and southwestern Kearney County with a 40 foot rise in the water table occurred because of declines that would result from ground water

Simulated Increase in 2020 Water Table Attributed to Orchard-Alfalfa and Six-Mile Canals

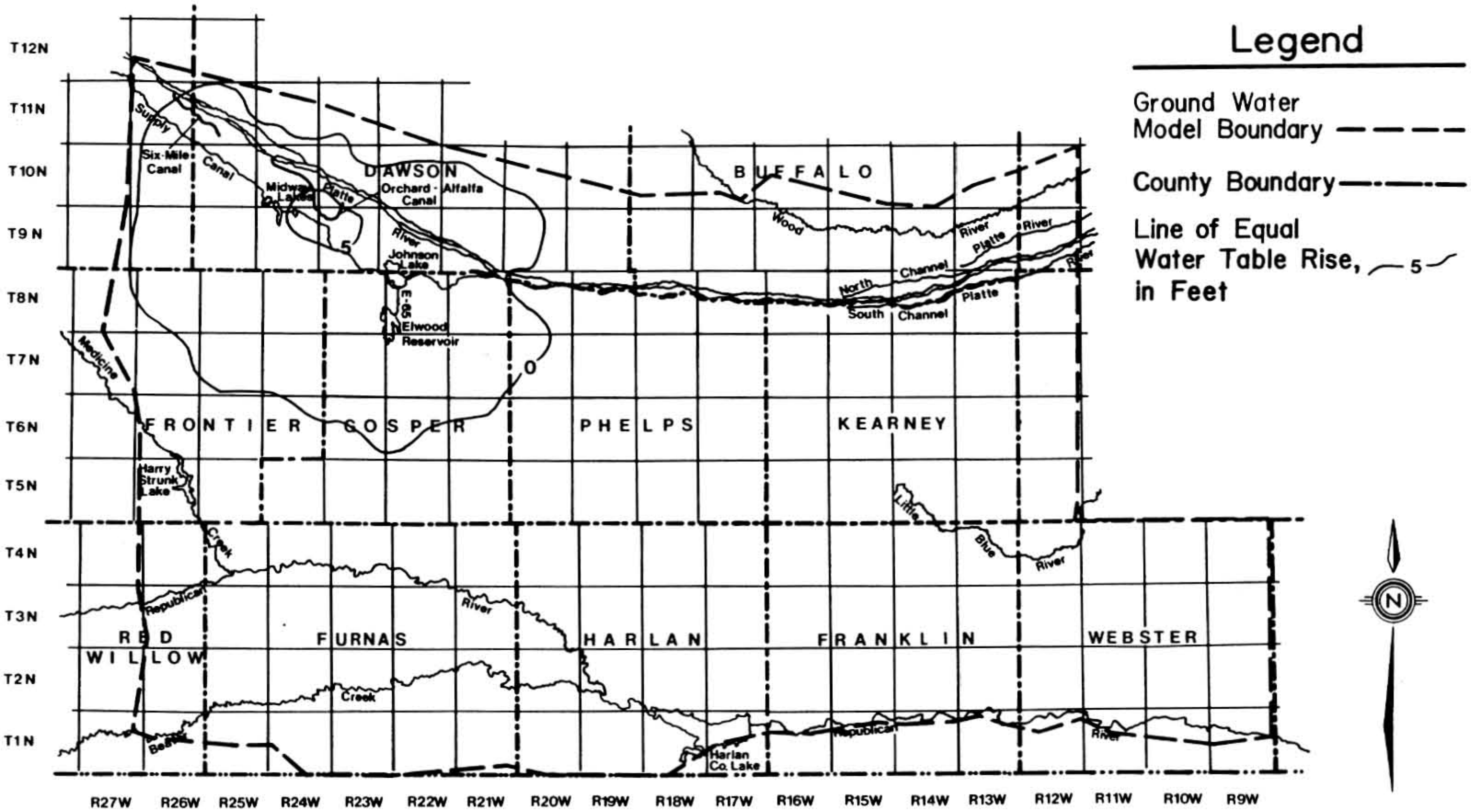
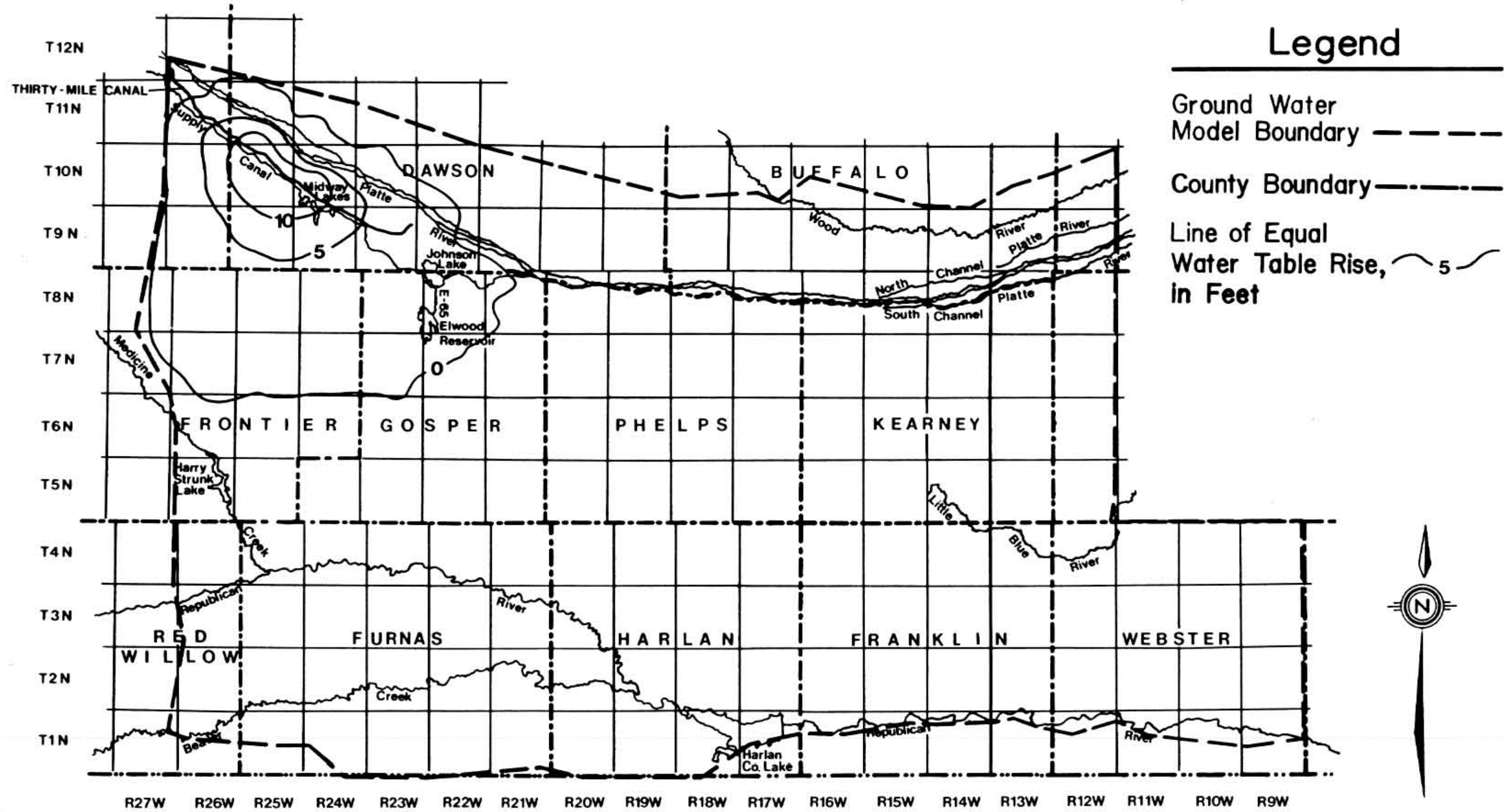


Figure 22

Figure 23

Simulated Increase in 2020 Water Table Attributed to Thirty-Mile Canal



Simulated Increase in 2020 Water Table Attributed to CNPPID Supply Canal and Johnson Lake

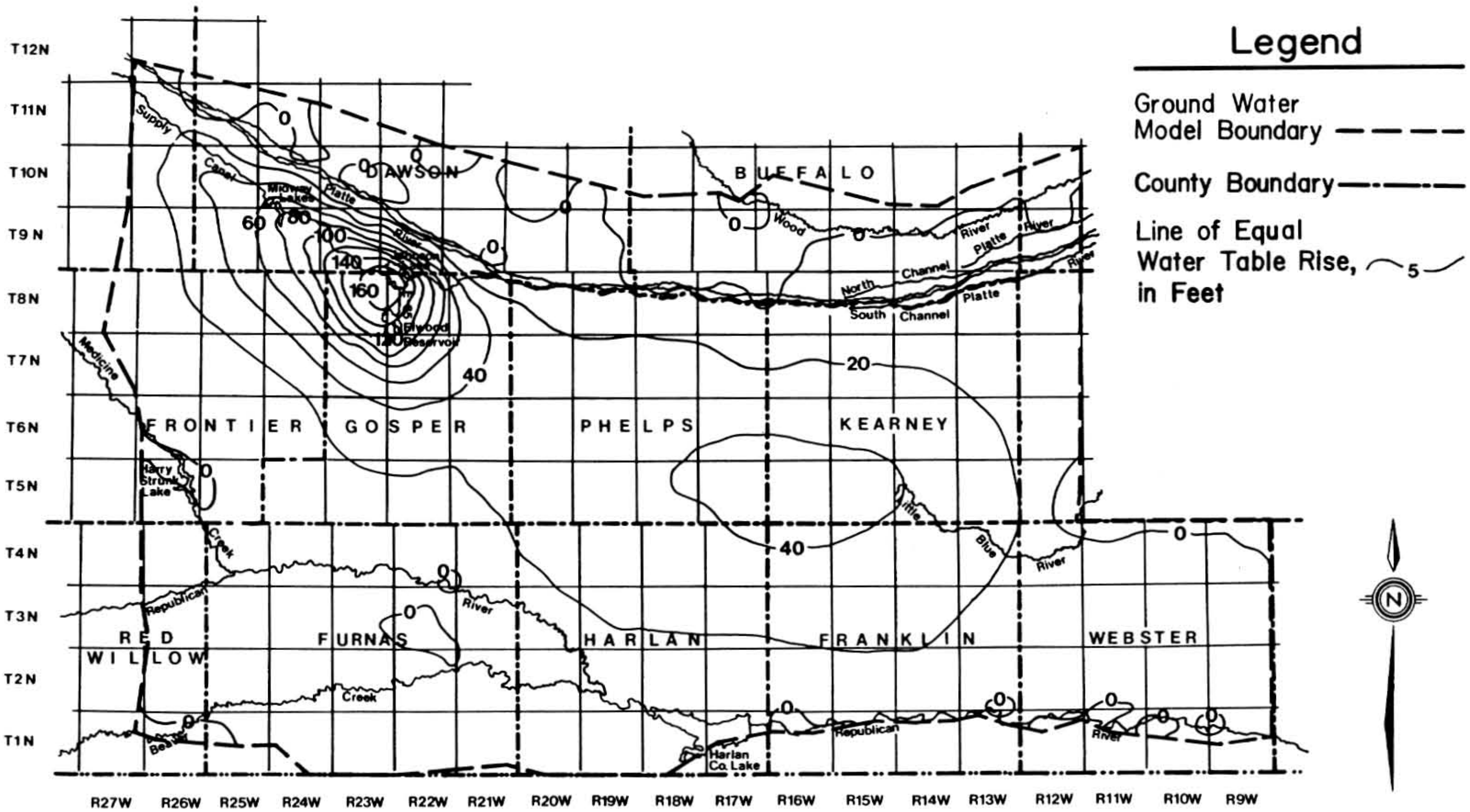


Figure 24

irrigation at the 1981 level without the CNPPID system. Hypothetically, the Tri-County Supply Canal and associated facilities refilled the declines. Limitations of the model may restrict it from accurately simulating the spread of this 40 foot rise into southwestern Adams and northwestern Webster counties. Rises in the southeast portion of the study area are reduced because ground water contributes to the base flow of tributaries to the Republican River.

Projections for the Tri-Basin NRD

The Tri-Basin NRD requested simulations similar to those requested by the Central Platte NRD. Their intent was to evaluate the impact of the Phelps County Canal and the irrigated land it served by using the model to approximate the magnitude and extent of the rise in ground water levels.

As a basis for comparison a simulation of the period from 1981 to 2020 was made with all the facilities in place. The number of ground water irrigated acres was held constant at the 1981 level throughout the period. A second simulation was run with Elwood Reservoir and the E-65, E-67, and Phelps County canals removed. The associated surface water irrigated acres in Gosper, Phelps, and Kearney counties were converted to dryland crops. The power facilities, including Johnson Lake, and the Tri-County Supply Canal and its appurtenant irrigated acres, were retained.

The difference between the results of these two simulations, mapped in Figure 25, shows the rise in ground water levels that could be attributed to this part of the Tri-County system under the 1981 level of irrigation development. The greatest rise, about 70 feet, was northwest of Holdrege in Township 7 North, Range 19 West in an area between the E-65 and Phelps County canals. The axis of the mound marked by the contour lines corresponds with the ground water divide running through Gosper, Phelps, and Kearney counties in the 1981 water table map (Figure 5).

Seepage from Elwood Reservoir was the primary cause of a rise of 35 feet west of the reservoir. Despite appearances, this rise in the ground water table would not cause ground water to flow west. As water seeps from the reservoir, it forms a mound which slows and reduces the flow from west to east. The mound acts like a dam, causing ground water to build up to the west of it and create a higher ridge on the contour maps.

Projections for the Lower Republican NRD

The Lower Republican NRD requested simulations which included conditions with and without the canals, reservoirs, and surface water irrigated acres of the Frenchman-Cambridge and Bostwick Divisions. Figure 26 shows the difference between the two simulations. Three significant areas of rise are evident. The rise at the western edge, with a maximum of 12 feet, was due to seepage from Harry Strunk Lake on Medicine Creek. The 20 foot rise in the center was caused by Harlan County Lake.

The 10 foot rise in the southeast corner of the modeled area was probably due to limitations of models called boundary conditions. The modeled area is usually extended beyond the actual area of interest because boundaries can introduce errors. This model was not extended east of Webster County due to the absence of an adequate aquifer everywhere but in the Republican valley. This prevents the model from simulating flow out of the corner area to the east fast enough to avoid simulated mounding. This should not significantly affect any other results.

EFFECTS OF SELECTED IRRIGATION INCREASES OR REDUCTIONS

The Lower Republican and Tri-Basin NRDs wanted to evaluate the effects of a wide range of increases or decreases in ground water irrigated acres. To accomplish this objective, the NRDs and the NRC chose to simulate future ground water conditions if irrigated acres annually increased or decreased by 2, 5,

Simulated Increase in 2020 Water Table Attributed to Surface Water Irrigation in Gosper, Phelps and Kearney Counties

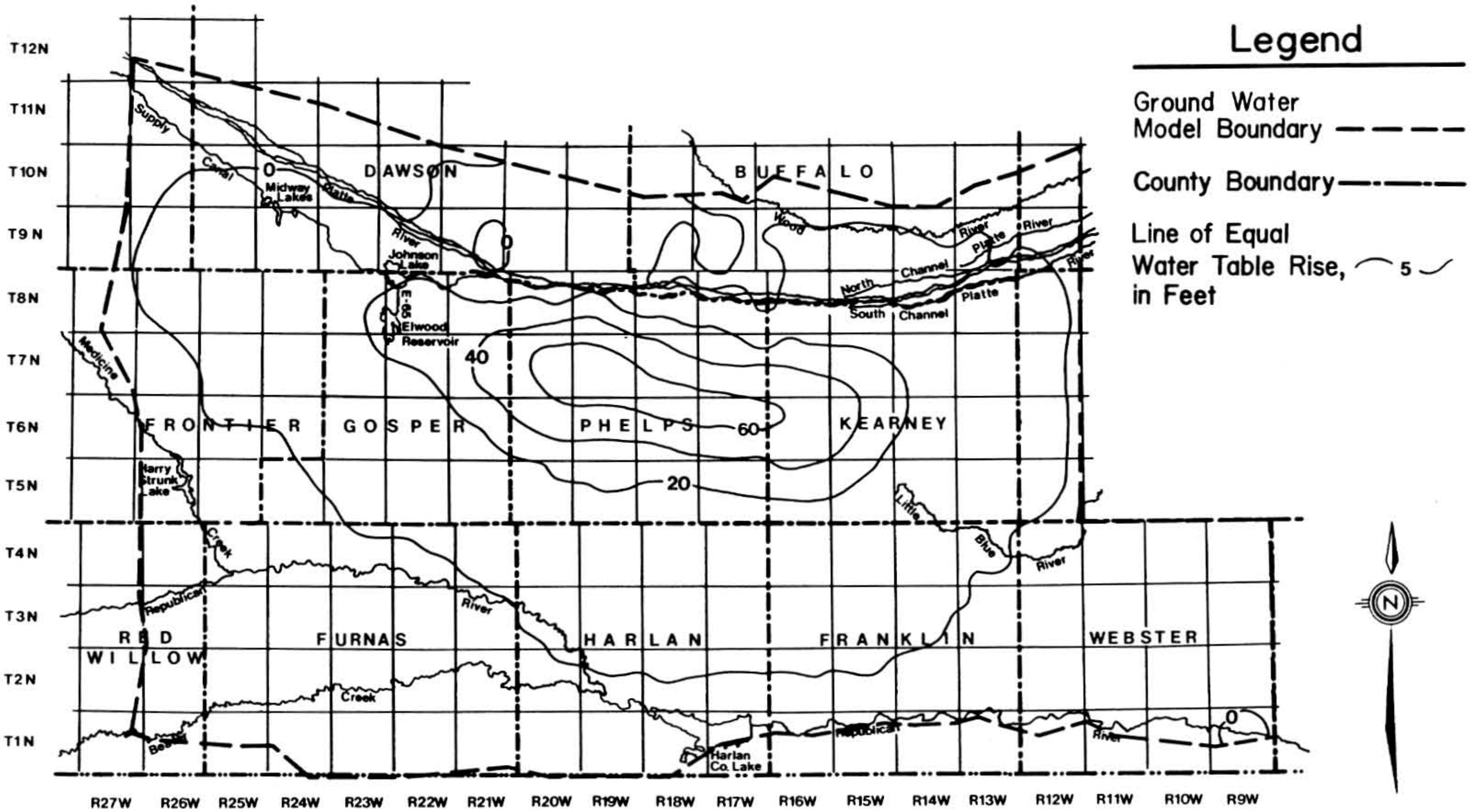
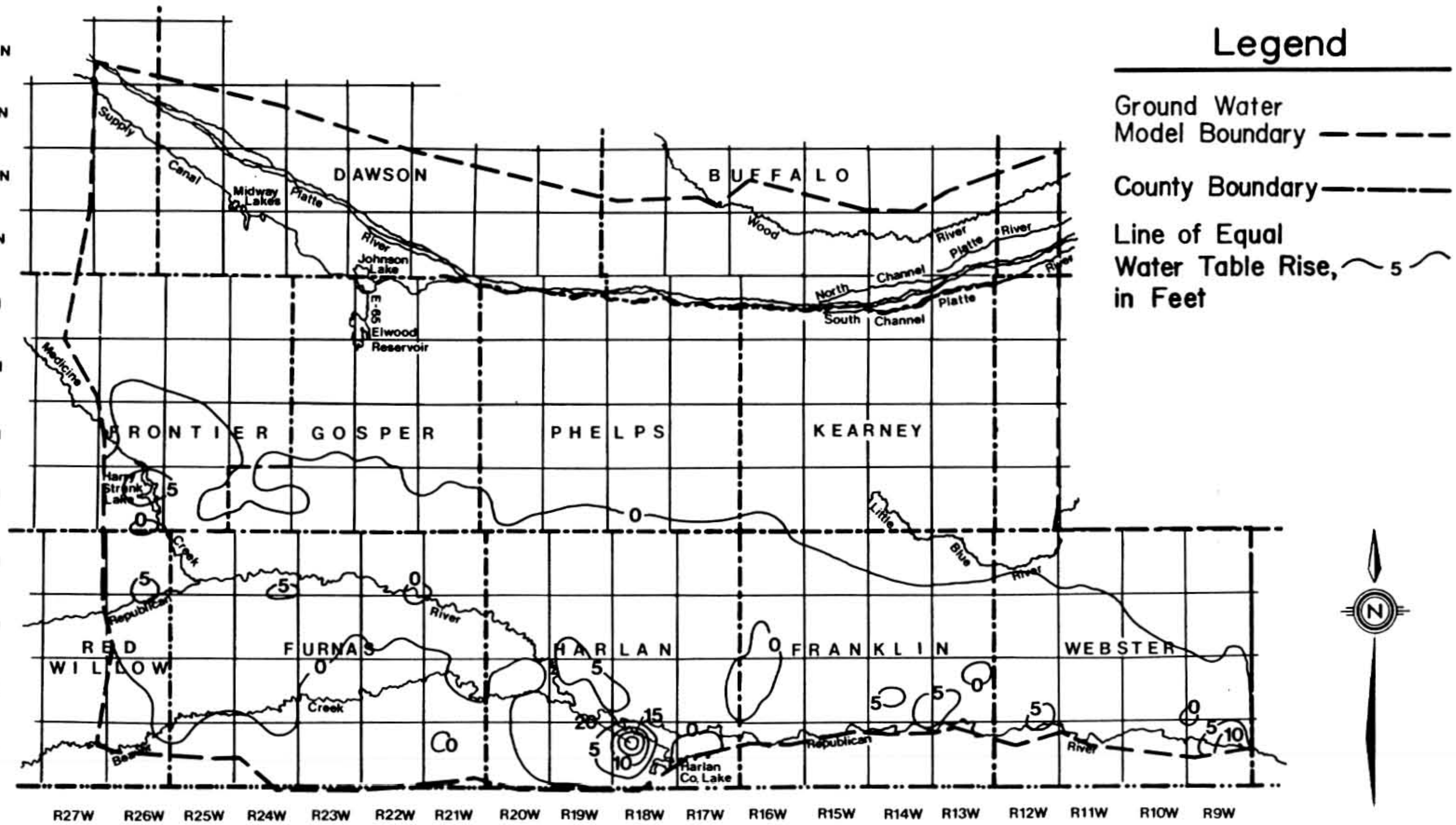


Figure 25

Simulated Increase in 2020 Water Table Attributed to Surface Water Irrigation in the Republican River Valley



and 10 percent of the 1981 irrigated area. As a basis for comparison, they chose a "no change" simulation, sometimes called a moratorium, which maintained constant 1981 acres.

Each increase or decrease was at a constant, not compound, rate. The number of acres of ground water irrigated row crops in 1981 in each cell of the model was multiplied by the appropriate percentage. This constant number of acres was either added to or subtracted from the total ground water irrigated acres each year until a limit was reached. For increasing rates, the constant increase was added to total ground water irrigated acres until either no irrigable acres remained or all dryland row crop, range, and pasture acres had been converted, whichever came first. For decreasing rates, the constant decrease was subtracted from total ground water irrigated acres until no irrigated row crops remained. Dryland row crops, range, and pasture increased as the irrigated row crops decreased.

For example, a five percent increase in total ground water irrigated acres caused ground water irrigated acres to double every 20 years if irrigable and convertible land were available. A five percent decrease left no ground water irrigated acres after 20 years.

The water table declines with no change in irrigated acres (moratorium conditions) are shown in Figure 27. Probably the most significant feature on the map is the area within the 30 foot contour, the area with the greatest decline. Declines had already occurred in this area in 1985, and the map shows that it would continue, even with no further development after 1981.

Figure 28 shows the difference in the water table in 2020 between an annual increase of five percent in irrigated acres and no change in irrigated acres. It shows that, under those conditions, the additional irrigation would cause an additional decline in the water table of about 25 feet in southern Kearney and northern Franklin counties, 35 feet in northcentral Harlan County, and 25 feet in eastern Frontier County. When combined with the moratorium decline, a total reduction of 60 feet would occur in the first two areas, and 40 feet in the third.

The difference in water table level with an annual decrease of five percent in ground water irrigated row crops is shown in Figure 29. With that rate of decrease, there would be no ground water irrigated acres after 2000. By 2020, the water table would be 50 feet higher than moratorium levels in southwestern Kearney County, 45 feet in northcentral Kearney County, and 15 feet in eastern Frontier County. At the three locations above, this decrease would produce net rises from 1981 levels of 20 feet, 30 feet, and 5 feet, respectively.

SIMULATION OF POTENTIAL MANAGEMENT CONDITIONS

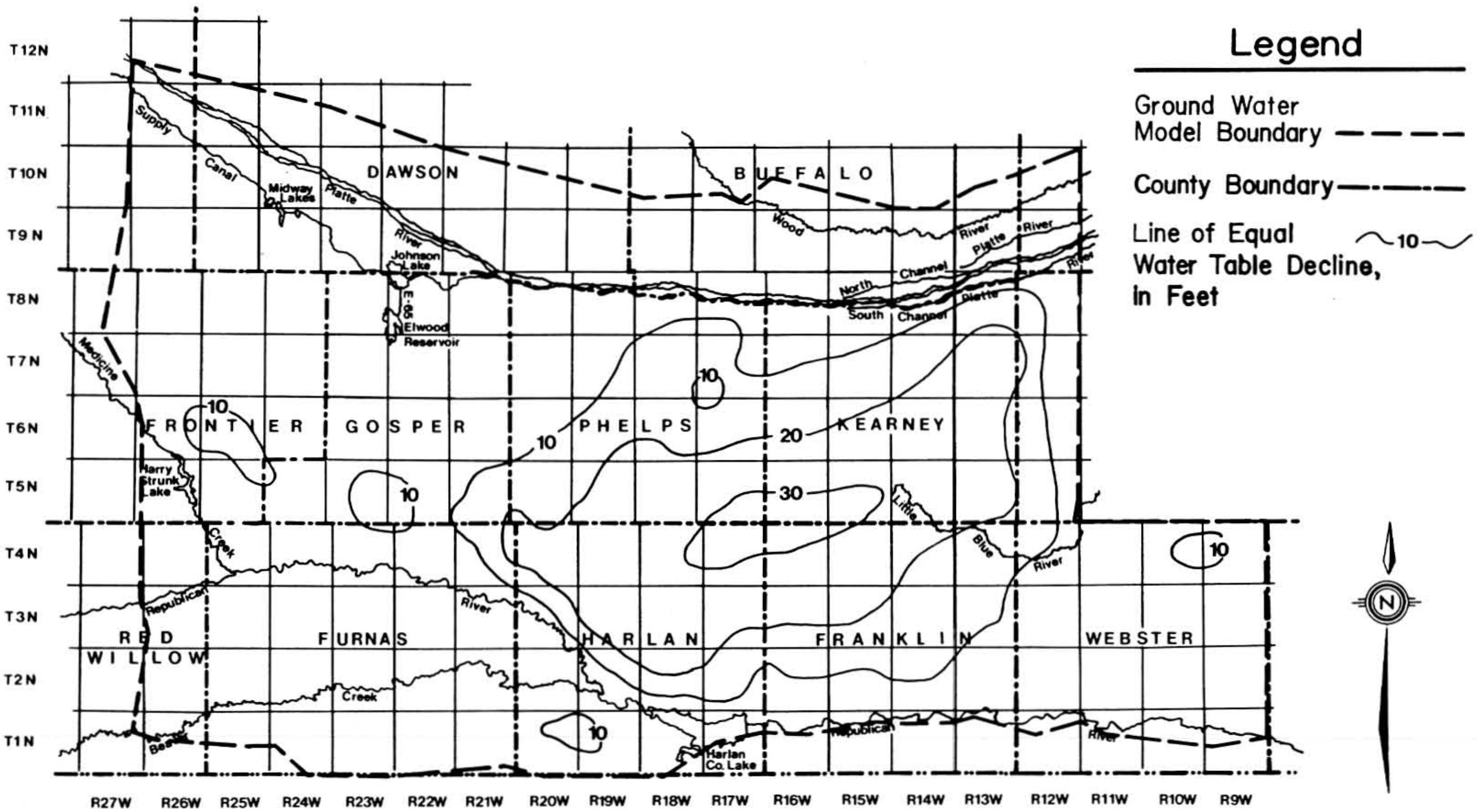
In 1984, the Legislature directed that each NRD develop a ground water management plan. These plans were to include the NRD's aquifer life goal, the measures necessary to insure that the goal is met, and an implementation schedule defining the conditions which would trigger the management actions. Several NRDs adopted a goal of infinite life for the aquifers in their district. This means that at some time in the future they must implement the controls necessary to halt water table declines if irrigation development and other uses cause net withdrawal of ground water.

There are many approaches to controlling water use and extending the life of the ground water supply. These approaches vary in the timing of action and the types of action that can be taken to balance withdrawals from the ground water reservoir with inflow to it. One approach would be to attempt to calculate how much development could be allowed before declines start and never allow pumpage to exceed that level. The opposite approach would be to allow growth to continue and declines to accelerate until the aquifer is not quite exhausted, and then place severe restrictions on

57

Figure 27

Water Table Declines in 2020 with No Change in Irrigation from 1981



Projected Change in Water Table by 2020 with Five Percent Rate of Growth in Ground Water Irrigation

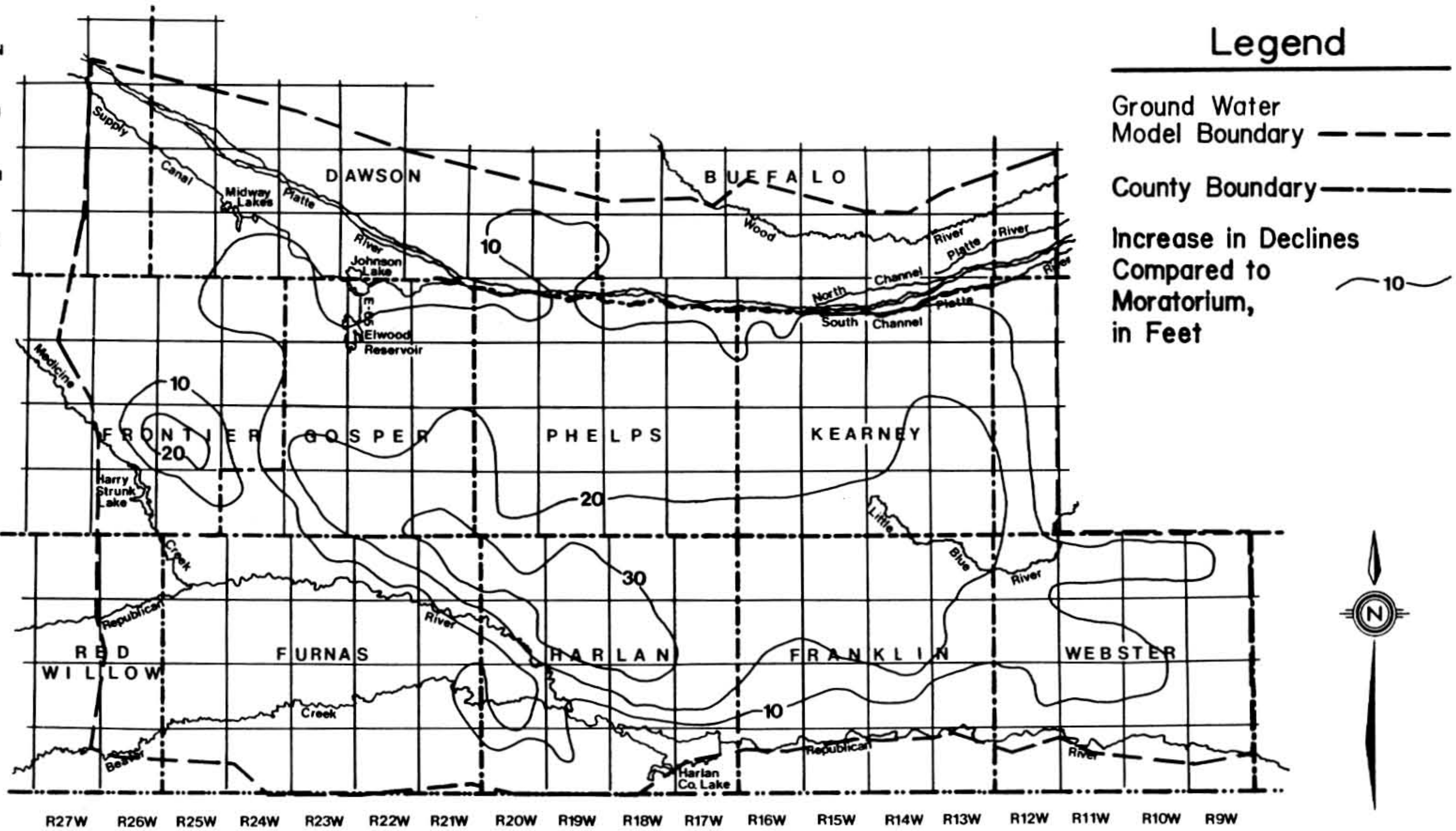
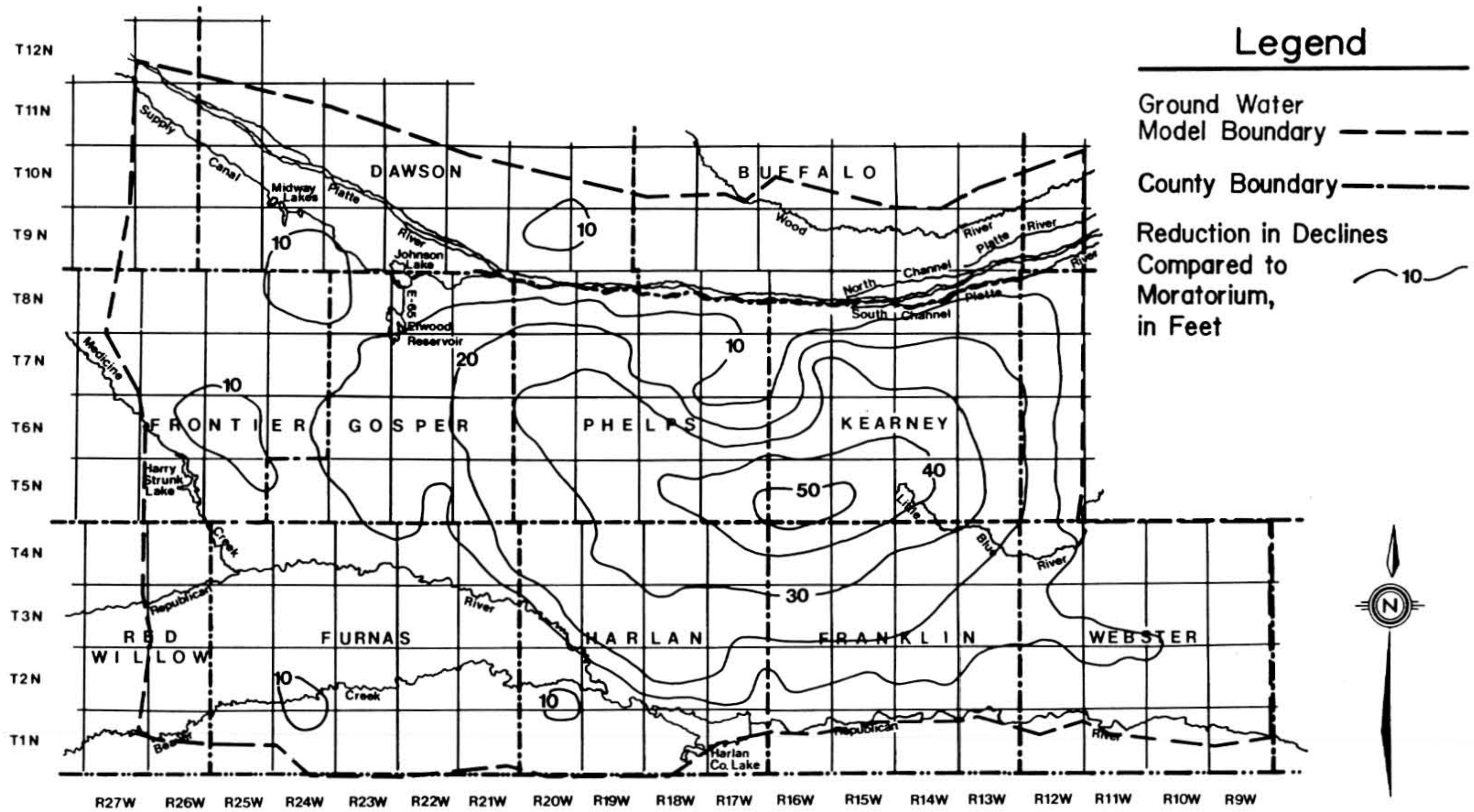


Figure 28

Figure 29

Projected Change in Water Table in 2020 with Five Percent Rate of Reduction in Ground Water Irrigation



use to stabilize levels at that point. The first approach would provide a stable economy, possibly at a level that might be too low, while the other approach would provide a "boom and bust" economic situation.

The objective of this section of the study was to begin to define the magnitude of the restrictions on irrigation pumping that might have to be used to meet the infinite life goal under the conditions specified by some NRDs. The Lower Republican was one district that selected an infinite life goal and specified the approach it would use to reach that goal. The district chose to allow limited declines from the 1981 water table level before putting management controls into effect, to allow for climatic variations, including drought. The primary management technique they selected was allocation, but they also included rotation and well spacing. Their system was applied over the entire model area to see what the magnitude of the controls would have to be.

PROJECTED GROUND WATER MANAGEMENT REQUIREMENTS AND AREAS IMPACTED

An examination of the results of the simulation of moratorium conditions (shown in Figure 27) clearly shows that even with no further development of irrigated acres, pumpage would have to be reduced below 1981 levels in many areas. Declines would exceed 10 feet in most of four counties. Simply restricting pumpage to the amount used in 1981 would not stabilize water levels in those areas. Controls would have to be even more restrictive if development were allowed to continue until declines became even greater.

For this simulation, irrigation development was allowed to continue at the baseline rate (about 2 percent per year) until declines reached 10 feet. Restrictions were then placed on the amount of pumpage until water levels stabilized. In order to show the impact on known water tables, pumpage was restricted by reducing the number of acres that were irrigated with ground water in 1981. The number of ground water irrigated acres in all areas with 10 feet of decline was cut back to 1981 levels and reduced by 10 percent. In many areas, water table levels still did not stabilize, so 1981 irrigated acreage was reduced by 25 percent for the second simulation. Two more simulations were necessary to stabilize the water table in the entire model area. The first reduced 1981 acreage for each declining area by 50 percent; the final simulation reduced it by 65 percent.

For the final simulation, the level of restriction required to stabilize the water table was identified for each area. The time period when this restriction would have to be initiated was also identified. Figure 30 shows the area that would require management and the level of restriction required to stabilize the water table by the year 1990. Part of the area requiring stabilization management is in the service area of the CNPPID, where drainage problems are prevalent, so it might be beneficial to allow greater declines before trying to stabilize the water table.

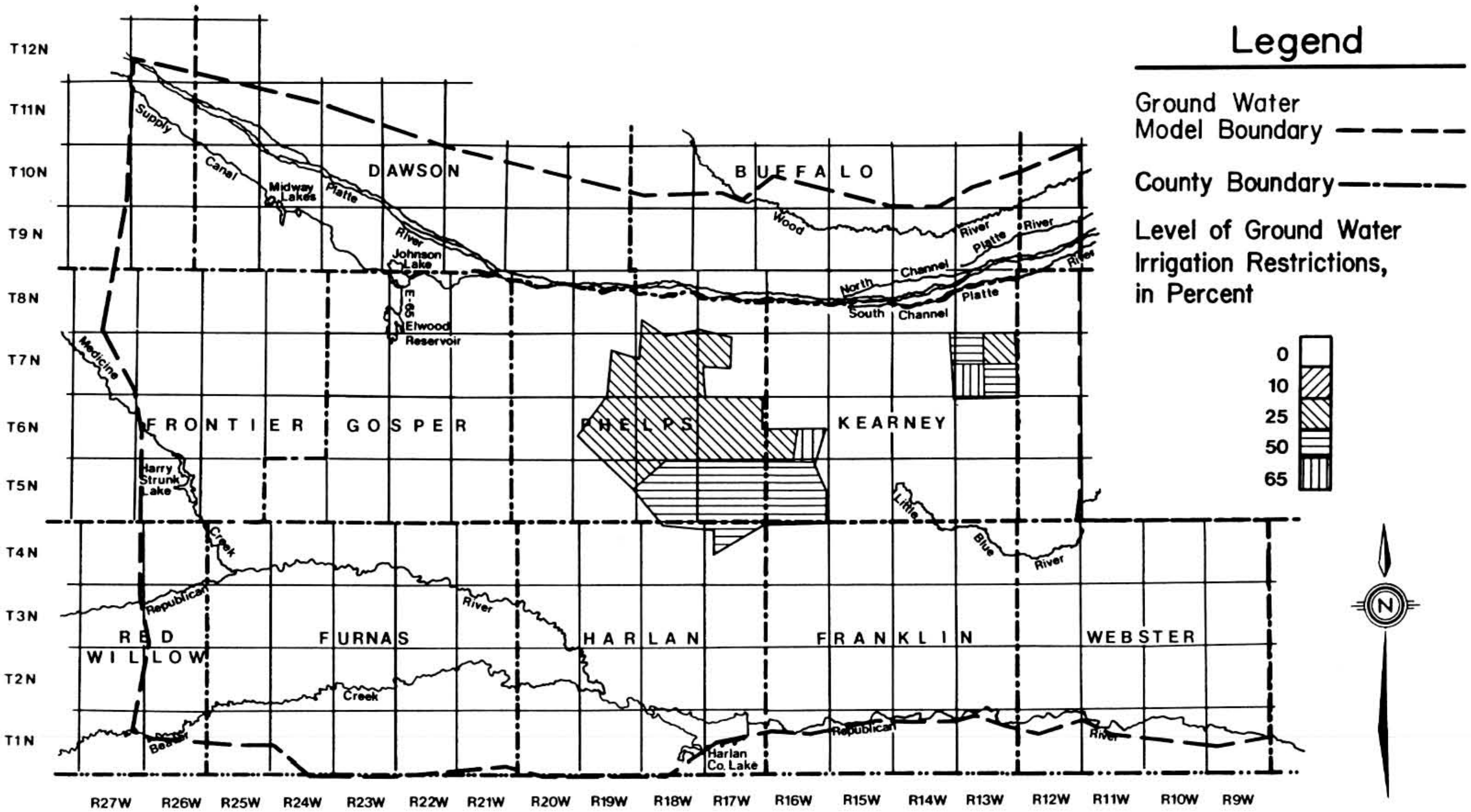
The area that would require management by 2000, shown in Figure 31, includes most of Phelps and Kearney counties, much of northern Harlan and Franklin counties, and an area in Frontier County. As shown in Figure 32, by 2010 the main area extends farther south in Franklin County and into Webster County. By 2020 an area is added in Furnas County, as shown in Figure 33.

The areas added in the later years developed a 10 foot decline over a longer time period. Consequently, restrictions needed to control these declines would not be as severe as those needed where the declines would develop over a shorter period.

EVALUATION OF ECONOMIC IMPACTS OF THE MANAGEMENT ALTERNATIVE

Economic modeling was used to estimate the effect of the water management alternative on agricultural income. Two methods of managing the application of a specified allocation of water were analyzed with the FARE model to determine which would provide greater eco-

Projected Management Areas and Restrictions in 1990



Projected Management Areas and Restrictions in 2000

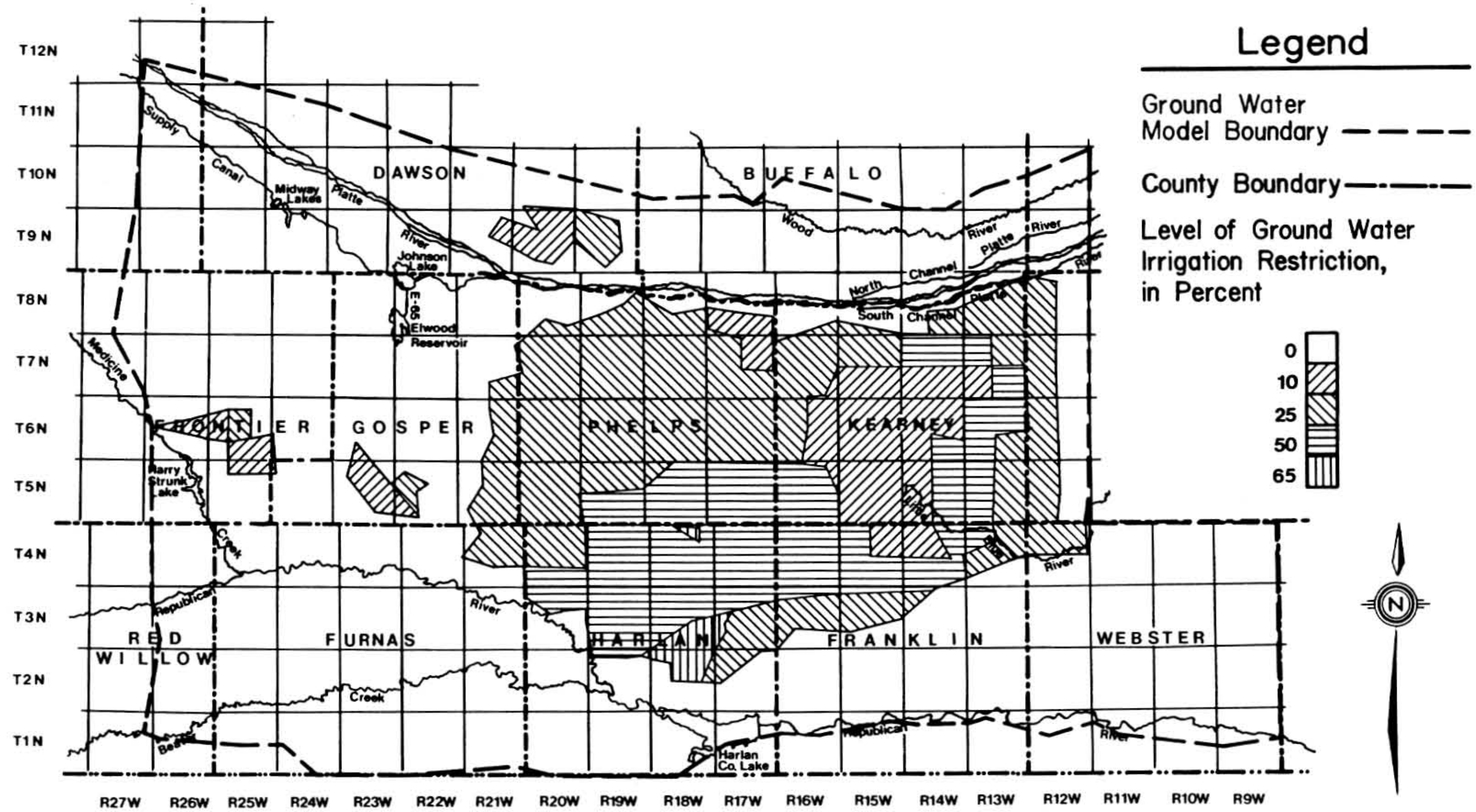
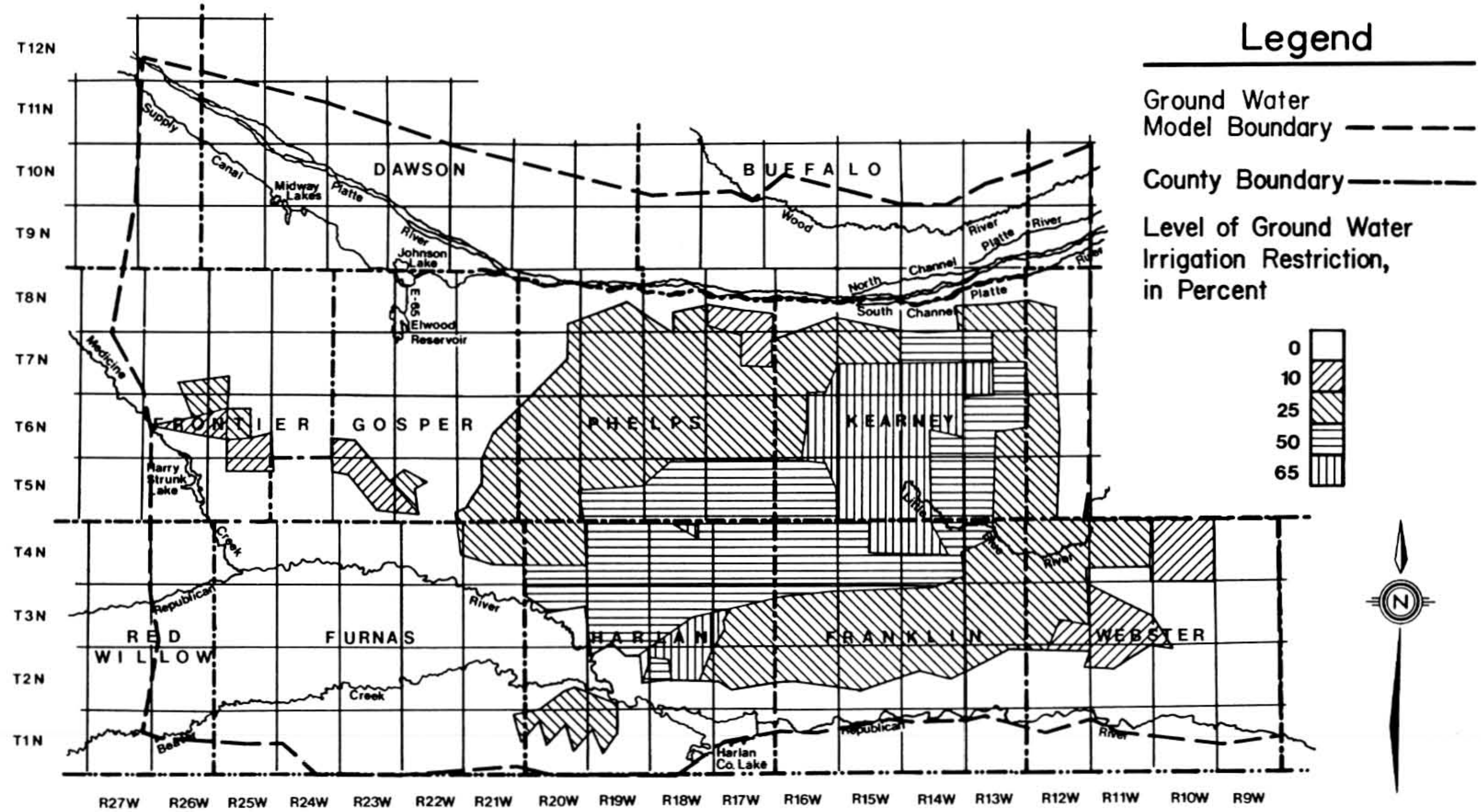


Figure 31

Figure 32

Projected Management Areas and Restrictions in 2010



Projected Management Areas and Restrictions in 2020

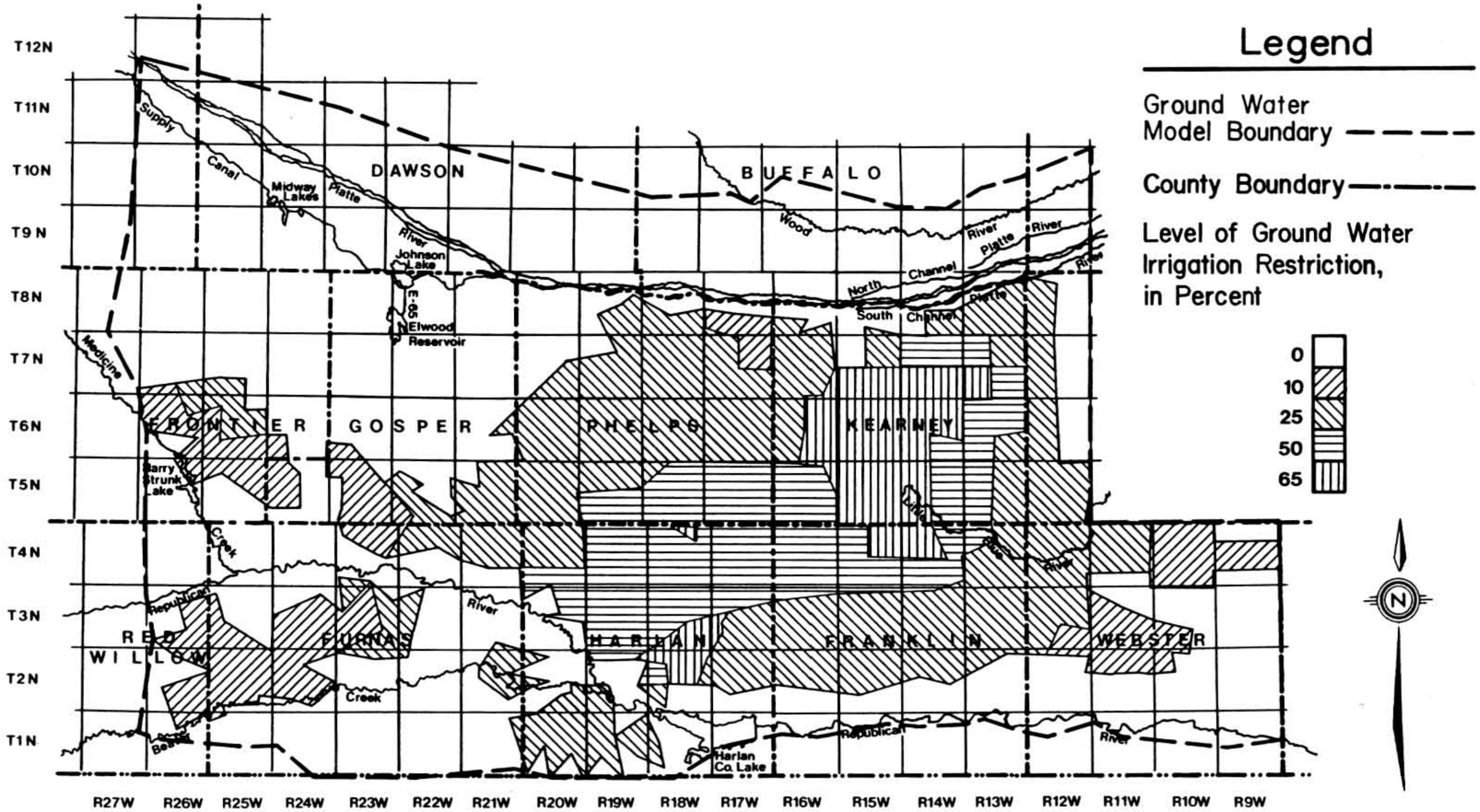


Figure 33

nomic returns. The regional economic impacts were then analyzed to estimate the effects of water use regulations.

Analysis of Irrigation Management Methods

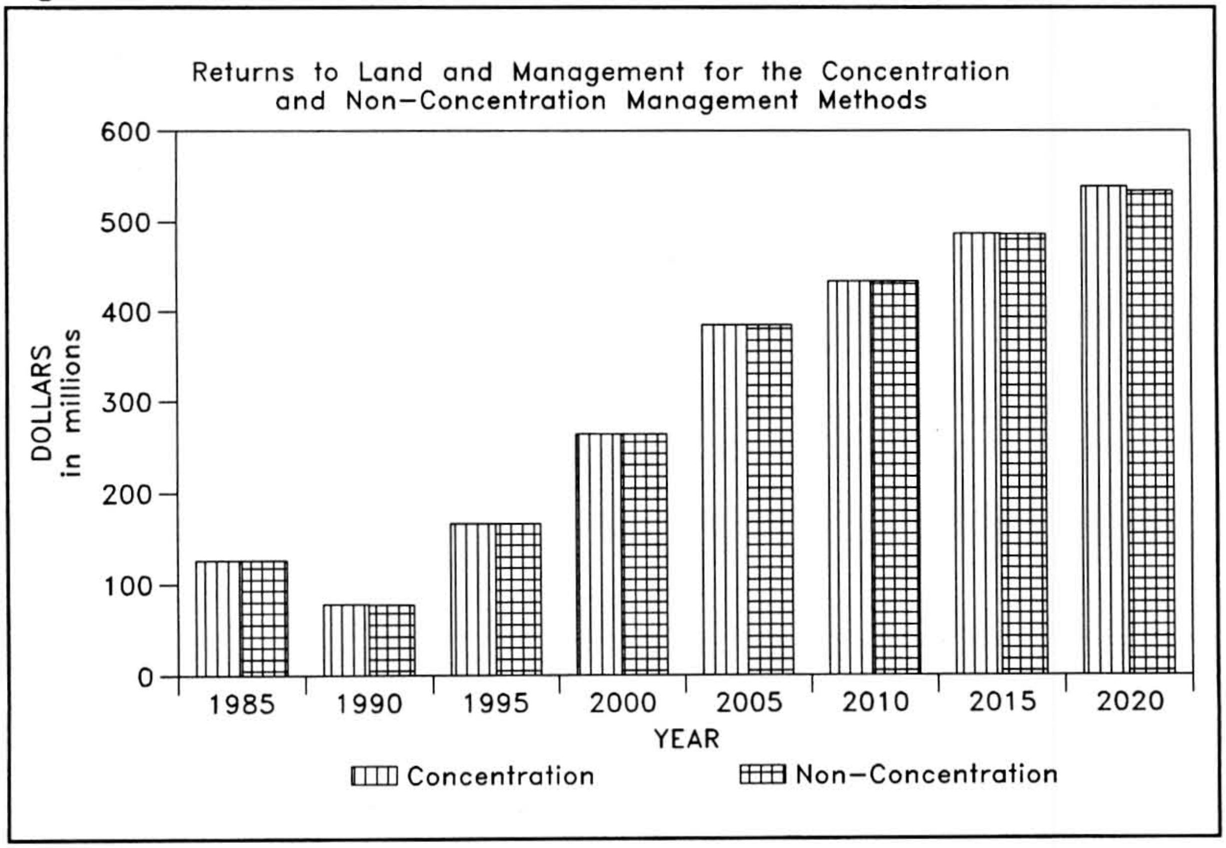
The FARE model was used to determine whether greater economic returns could be obtained from different methods of management. In both methods, the amount of water that could be pumped was restricted to the amount that the ground water model determined would stabilize the ground water level. In the ground water model, the number of acres irrigated was limited in order to control the amount pumped. In the FARE model, the amount of pumpage was limited directly.

In one management method evaluated with the FARE model, water was allowed to be used in any way that would maximize returns to land and management. It could be concentrated on fewer acres rather than spreading a smaller amount of water over the total irrigated acreage. The other method required that every acre developed for irrigation be irrigated. The amount of water that could be pumped in any year was the same in both. This showed the economic effect of allowing concentration or forcing irrigators to irrigate all acres that are developed for that purpose.

The primary factor used as the basis for comparison was the estimated change in income. The total returns to land and management for the two methods are shown in Figure 34. There was little difference in returns to land and management between the concentration and non-concentration methods.

Other results of the model were also examined to determine if there were differences between the two methods. One was the use of the land. Figure 35 shows the amount of land used for non-irrigated crops, irrigated crops, and pasture for the two methods. In most years, land use would be the same for both. In

Figure 34



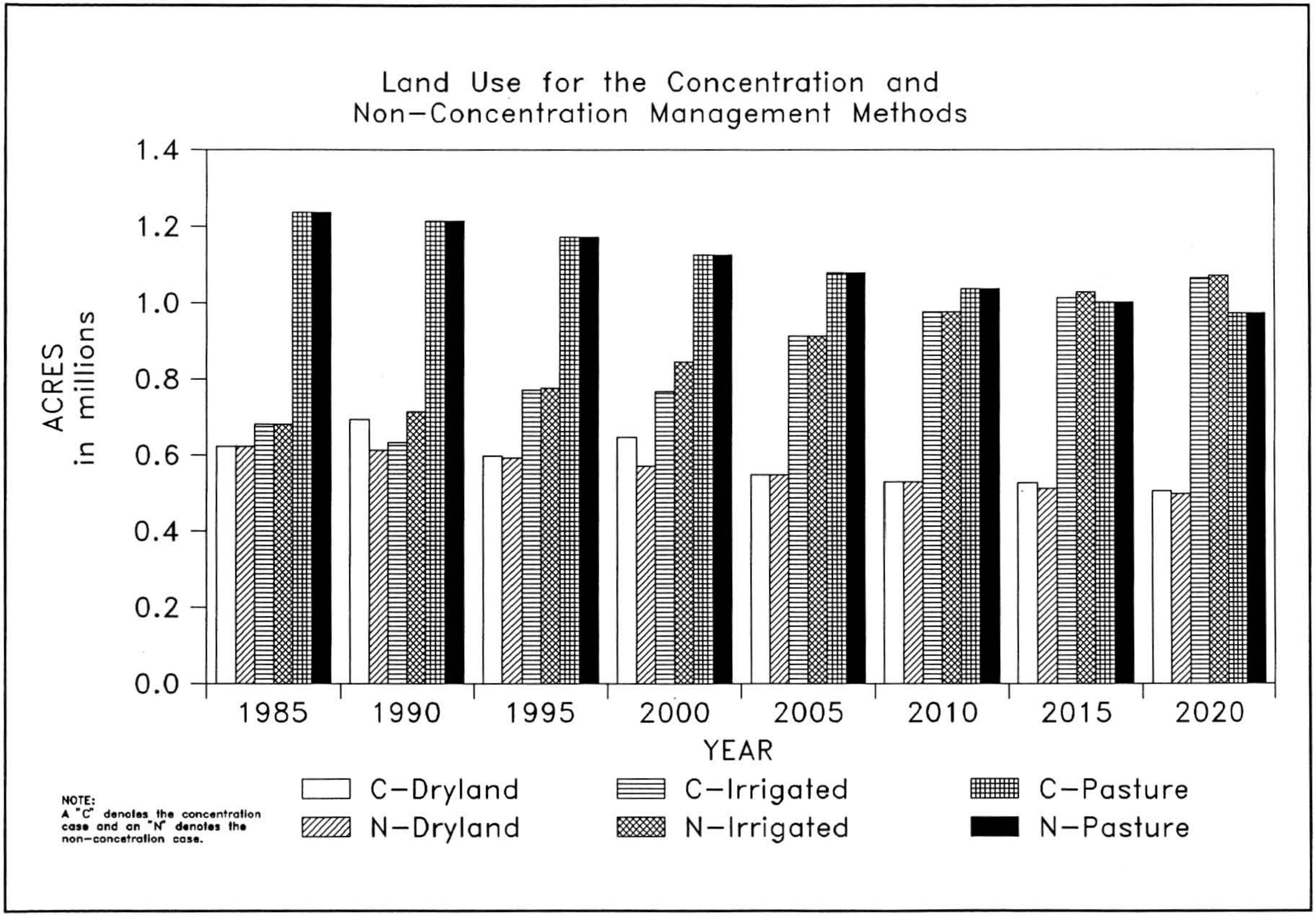

Land Use for the Concentration and
Non-Concentration Management Methods
ACRES
in millions
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1985
1990
1995
2000
2005
2010
2015
2020
YEAR
C-Dryland
N-Dryland
C-Irrigated
N-Irrigated
C-Pasture
N-Pasture
NOTE:
A "C" denotes the concentration case and an "N" denotes the non-concetration case.

Figure 35

1990 and 2000, the concentration method had more dryland and less irrigated land than the non-concentration method. There were dryland cropping alternatives that were at least as profitable as any partially irrigated cropping option, so some lands that were developed for irrigation were farmed dryland. This was allowed only for the concentration method.

Economic Effects of the NRD Management Plan

The NRD's management plan established the goal of infinite life for the aquifer. Stabilizing the water level and preserving the water supply would require controls on pumpage in specific areas where declines would occur.

The plan specified that control areas be established when water levels decline 10 feet below 1981 levels. Measures must then be taken to reduce pumpage to an amount that will stabilize the water level. This process was simulated in the ground water model by reducing the number of irrigated acres in the control areas because it was easier to reduce acres than pumpage. The number of acres was first reduced to 90 percent of the 1981 irrigated acres. If water levels continued to decline the irrigated acreage was progressively reduced until the decline stopped. In some areas, irrigated acres were reduced to 35 percent of the 1981 irrigated acreage. The number of acres in control areas with different levels of reduction in each simulation period is shown in Figure 36.

The economic model does not have the capability of estimating economic effects for areas smaller than an economic model region. To determine the economic effect of these kinds of control for areas smaller than the regions, the four levels of control (10, 25, 50, and 65 percent reductions) were applied to the entire region. The results of the simulations for each of these reductions were used to calculate returns to land and management per acre for the various levels of control. These values were then used with the number of acres determined by the ground water model to project returns to land and management over time for regions 11 and 12.

The estimated returns to land and management for the baseline and ground water management alternative are shown in Figure 37. The reduction in returns began after 1990 when the control areas were first instituted. After 1995, as the amount of water reduction became more restrictive, the economic effect of the controls was more evident. The reduction in returns from the baseline increased from about $34 million in the year 2000 to about $103 million in the year 2020.

The economic consequences of regulating ground water use in the South-Central region appear to be substantial. Stabilizing the ground water level by regulation may cost as much as $100 million annually in reduced agricultural returns.

Figure 36

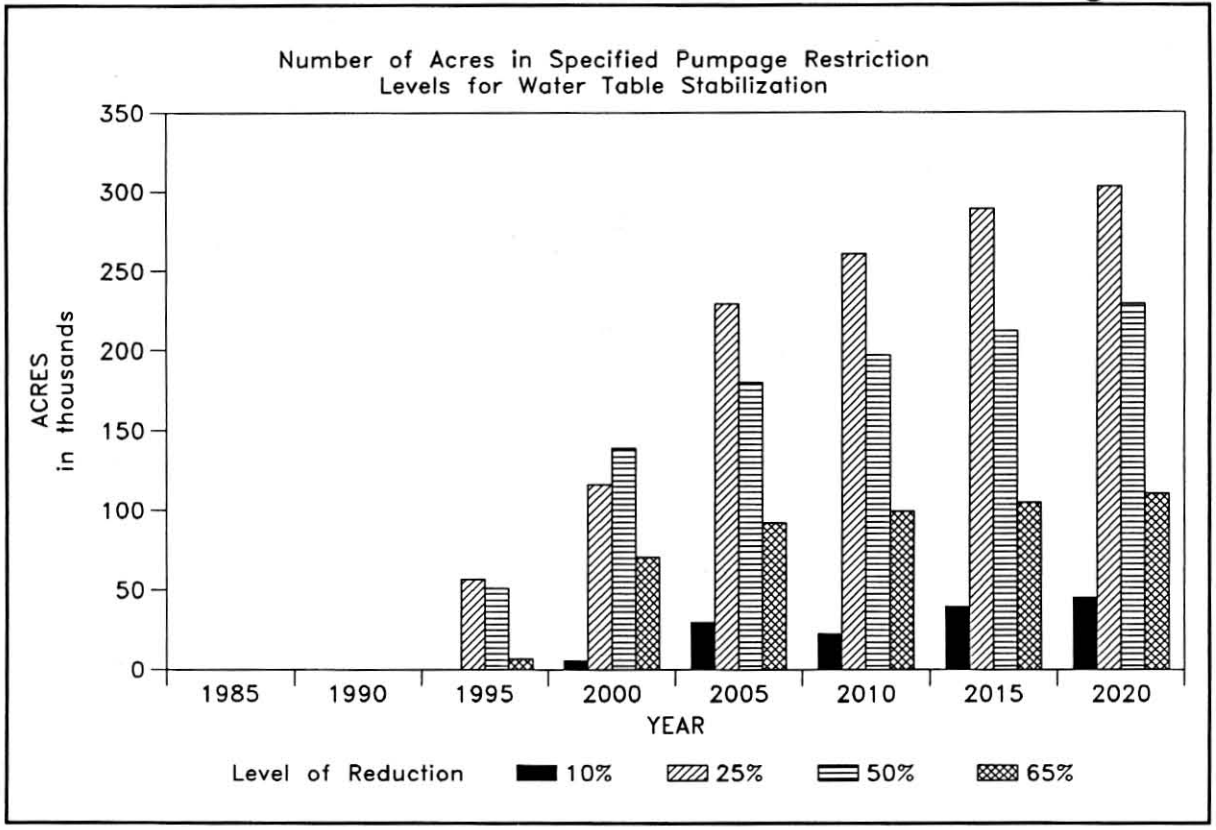
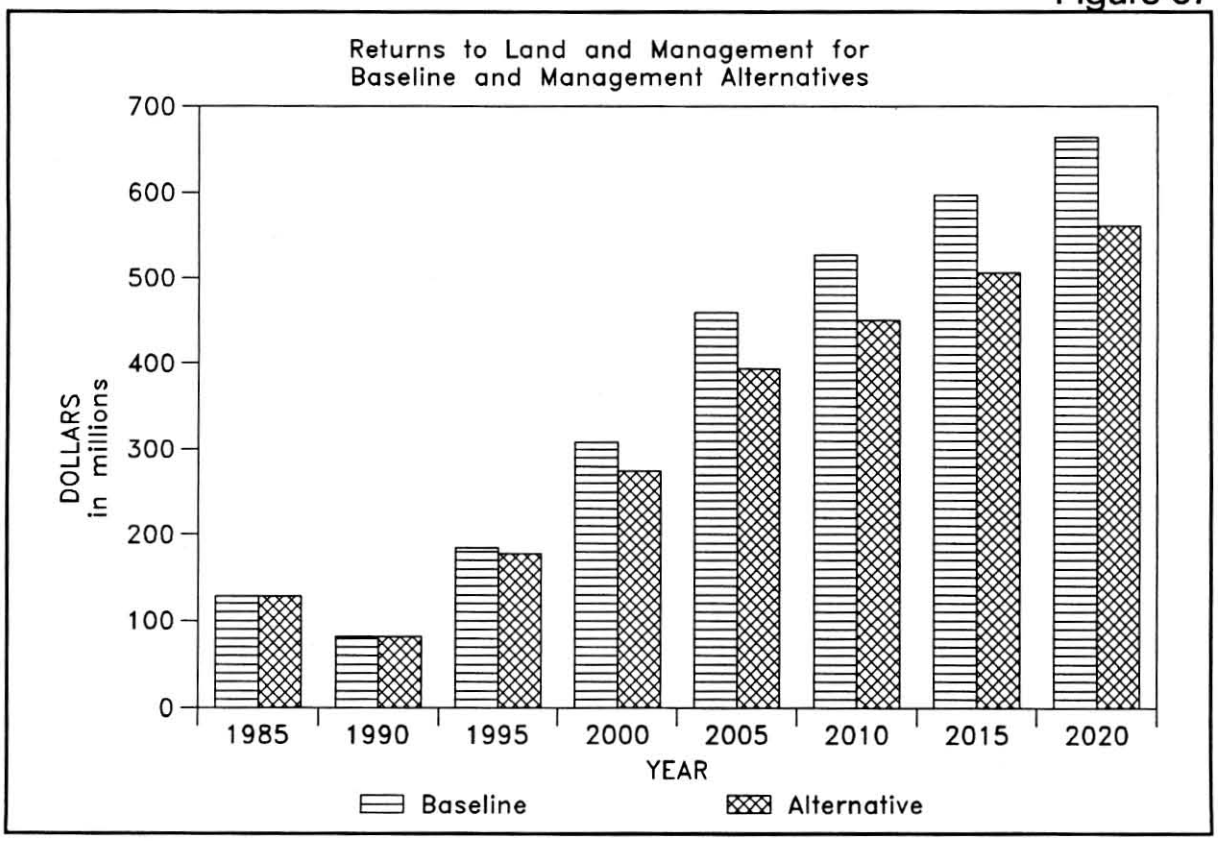


Figure 37



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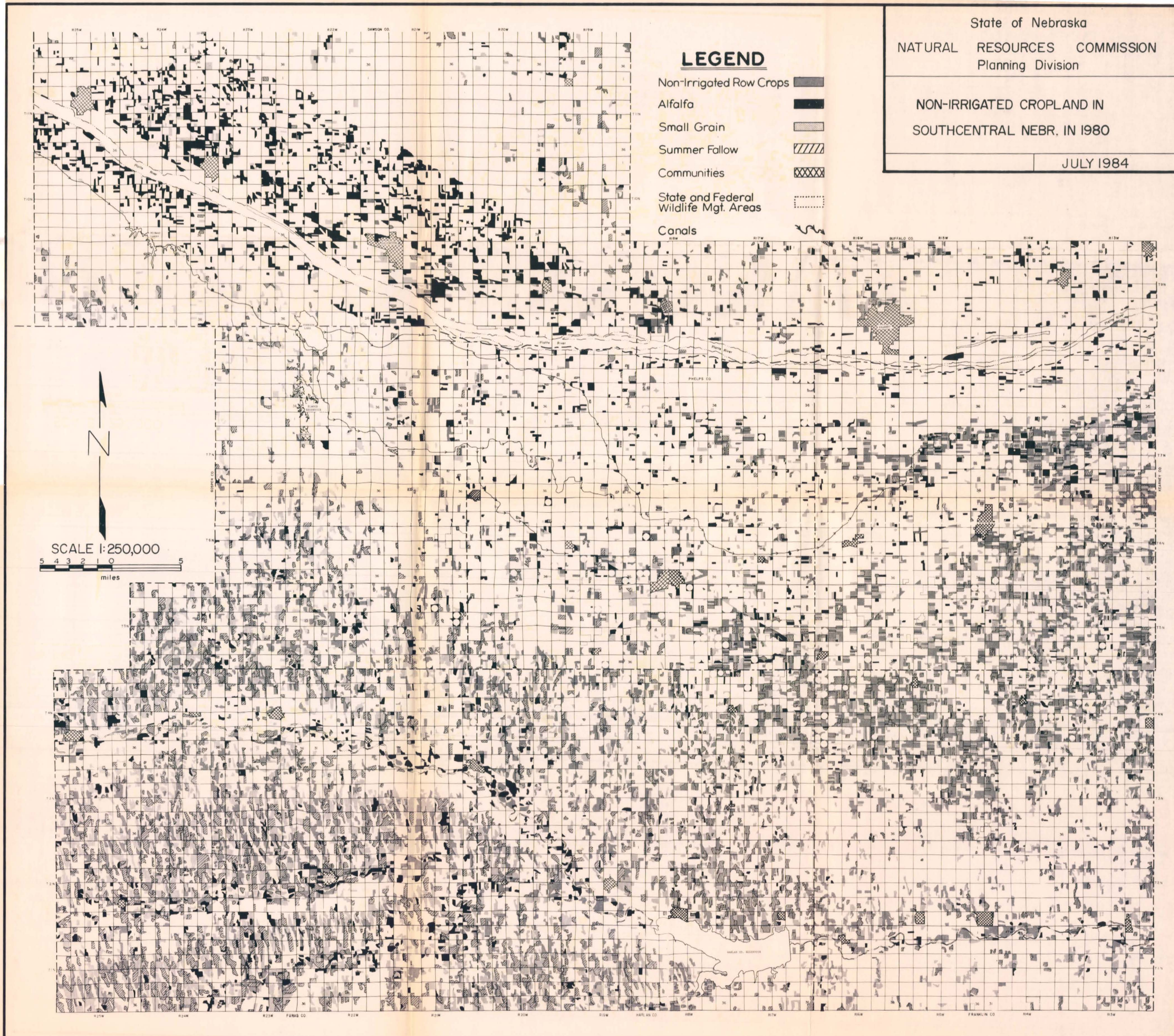
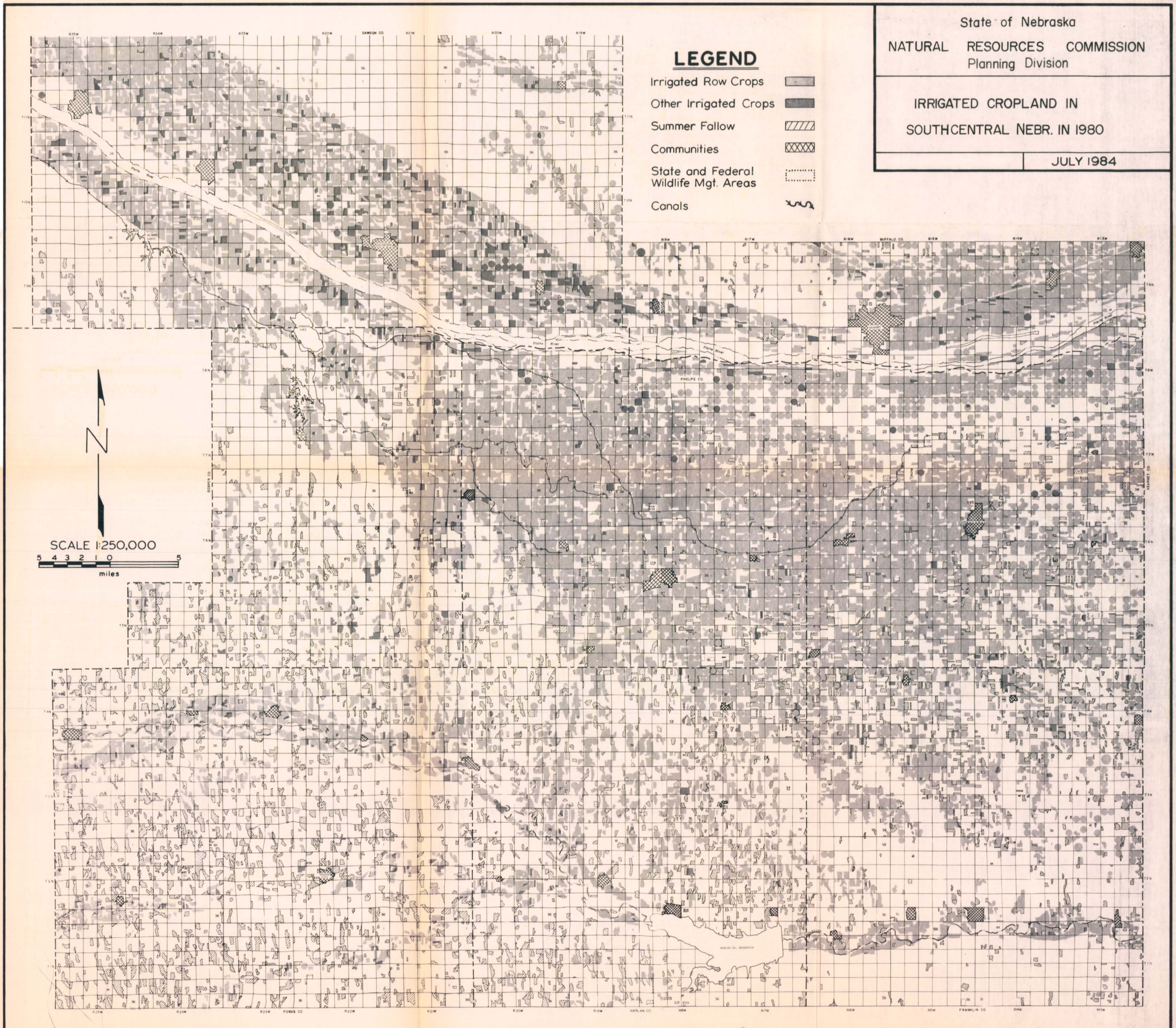

State of Nebraska
NATURAL RESOURCES COMMISSION
Planning Division
NON-IRRIGATED CROPLAND IN
SOUTHCENTRAL NEBR. IN 1980
JULY 1984
LEGEND
Non-Irrigated Row Crops
Alfalfa
Small Grain
Summer Fallow
Communities
State and Federal
Wildlife Mgt. Areas
Canals
SCALE 1:250,000
5 4 3 2 1 0 5
miles
N



State of Nebraska
NATURAL RESOURCES COMMISSION
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IRRIGATED CROPLAND IN
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JULY 1984
LEGEND
Irrigated Row Crops
Other Irrigated Crops
Summer Fallow
Communities
State and Federal Wildlife Mgt. Areas
Canals
N
SCALE 1:250,000
5 4 3 2 1 0 5
miles

State of Nebraska

NATURAL RESOURCES COMMISSION

Planning Division

SOUTH-CENTRAL GEOHYDROLOGY STUDY

AGRICULTURAL LAND USE IN WEBSTER COUNTY, 1980

Aug 1984