# WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER UNDERLYING PARTS OF SOUTH DAKOTA, WYOMING, NEBRASKA, COLORADO, KANSAS, NEW MEXICO, OKLAHOMA, AND TEXAS--PREDEVELOPMENT THROUGH NONIRRIGATION SEASON 1987-88

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CONTENTS

## FIGURES

## TABLES

## CONVERSION FACTORS

The following report uses inch-pound units as the primary system of measurement. Inch-pound units can be converted to metric units by multiplying by the factors given in the following list.

| *Inch-pound unit* | *Multiply by* | *To obtain metric unit* |
| --- | --- | --- |
| acre | 0.4047 | hectare |
| acre-foot | 1,233 | cubic meter |
| foot | 0.3048 | meter |
| inch | 25.40 | millimeter |
| mile | 1.609 | kilometer |
| million gallons per day | 0.003785 | million cubic meters per day |
| square mile | 2.590 | square kilometer |

To convert degree Fahrenheit (°F) to degree Celsius (°C) use the following formula:

$$°C = 5/9(°F-32).$$

# WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER UNDERLYING PARTS OF SOUTH DAKOTA, WYOMING, NEBRASKA, COLORADO, KANSAS, NEW MEXICO, OKLAHOMA, AND TEXAS-- PREDEVELOPMENT THROUGH NONIRRIGATION SEASON 1987-88

by W.M. Kastner, D.E. Schild, and D.S. Spahr

## ABSTRACT

Changes in water levels in the High Plains aquifer underlying parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas are caused by interacting changes in precipitation, land use, and annual pumpage. Water levels declined from the time aquifer development began until 1980 throughout parts of the High Plains of Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas. From 1980 through 1987, water-level changes were mixed, with declines of 10 feet to greater than 25 feet in the highly developed areas of Kansas, New Mexico, Oklahoma and Texas and almost stable to rising water levels throughout the remaining area of the aquifer. The net change was a rise of 0.8 foot. Precipitation generally was greater than normal during 1981-87; therefore, pumping for irrigated agriculture decreased.

Water-level changes also were mixed during 1987. Water-level declines continued in some highly developed areas, but water levels generally rose throughout most of the aquifer. The average area-weighted change was a rise of 0.28 foot. This rise was due to the generally greater than normal precipitation, a decrease in irrigated acreage, and a decrease in pumpage for those areas irrigated.

At the end of the 1988 growing season the drought in the Midwest affected only limited areas of the High Plains. The effects of the drought on water levels in the High Plains aquifer can not be assessed until the water-level measurements for the nonirrigation season of 1988-89 are compiled.

The changes in water levels in the High Plains aquifer from 1980 to 1988 are presented in a map for the entire area, and water-level changes from 1987 to 1988 are shown in individual state maps. The maps were compiled from data obtained from U.S. Geological Survey and State agency data files. Trends in water levels are discussed in relation to precipitation trends and trends of acres irrigated by ground water.

## INTRODUCTION

*Report on Water Levels in the High Plains Aquifer is Requested by Congress.*

The Omnibus Water Resources Development Act of 1986 (Public Law 99-662) amended the Water Resources Research Act of 1984 (Public Law 98-242). The amendment added a Title III to the legislation that states, in Section 306, that the U.S. Geological Survey in cooperation "...with the States of the High Plains region is authorized and directed to monitor the levels of the Ogallala [High Plains] Aquifer, and report annually to Congress." Congress recognized that accurate information on the conditions and changes in the aquifer is necessary to make sound management decisions concerning the use of water, to predict future economic conditions, and to conduct hydrologic research pertaining to the High Plains.

The High Plains aquifer (formerly called the Ogallala aquifer) underlies one of the major agricultural areas in the United States. About 20 percent of the irrigated land in the United States is in the High Plains, and about 30 percent of the ground water used for irrigation in the United States is pumped from the High Plains aquifer (Weeks and others, 1988).

Many studies of parts of the aquifer have been completed by irrigation districts, local agencies, State agencies, and the U.S. Geological Survey and other Federal agencies. A major study that examined the physical features of the entire aquifer recently has been completed by the U.S. Geological Survey. The High Plains Regional Aquifer-Systems Analysis (High Plains RASA) described the geology and hydrology of the aquifer in detail. Computer models for each of the three major areas were developed during the study to simulate the effects of some proposed water-management practices on the aquifer. The analyses of the High Plains RASA were based on data collected before 1981. Water-level data have not been collected uniformly throughout the area or compiled in an aquifer-wide data base since 1980.

From October 1, 1987, through September 30, 1988, the U.S. Geological Survey and cooperating agencies compiled water-level data collected since about 1980 from 12,628 locations. The data were collected by many agencies, for numerous purposes, and do not provide integrated area-wide coverage.

This report was prepared to fulfill requirements of section 306, Title III of Public Law 98-242 as amended. It describes the High Plains aquifer, the factors that affect water levels in the aquifer, the history of development of the aquifer, water-level changes from predevelopment through the nonirrigation season (generally October through March) of 1979-80, water-level changes between the nonirrigation season of 1979-80 and nonirrigation season of 1987-88, precipitation patterns from 1981 through 1987, and water-level changes between the nonirrigation seasons of 1986-87 and 1987-88. This information is followed by maps showing precipitation and water-level changes for 1987 for the parts of the eight states underlain by the aquifer. The changes shown on these maps are supplemented by hydrographs of long-term water levels in selected wells, annual precipitation, and changes in irrigated acreage for selected areas.

U.S. Geological Survey personnel in eight States provided text or information for the State summaries: Alan Burns, Lanna J. Combs, Roy R. Cruz, Michael J. Ellis, Joe B. Gillespie, William F. Horak, Eve L. Kuniansky, Larry F. Land, John R. Little, and Charles L. Qualls.

## EXTENT AND DESCRIPTION OF THE HIGH PLAINS AQUIFER

*High Plains Aquifer Underlies Parts of Eight States-South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas.*

Saturated, predominantly unconsolidated underground deposits provide a source of ground water for the High Plains. This source has been named both the "Ogallala aquifer" and the "High Plains aquifer"; the term "Ogallala aquifer" was used widely in the past, and still is commonly used in areas where the Ogallala Formation comprises most of the aquifer. The High Plains aquifer includes the Ogallala Formation plus the saturated and connected parts of adjacent deposits.

The High Plains aquifer underlies about 174,000 square miles of the High Plains. It underlies parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas (table 1). The thickness of the aquifer ranges from less than 1 foot at the edge to as much as 1,300 feet in north-central Nebraska. The average saturated thickness is about 200 feet. The volume of water that will drain from the aquifer pore spaces differs throughout the area but averages about 15 percent of the total volume of material. Therefore, the total volume of water that could drain from the aquifer would be about 3,250 million acre-feet (Gutentag and others, 1984). All of this water can not be recovered, however, because of economic constraints.

The High Plains are a remnant of an alluvial plain that extended eastward from the Ancestral Rocky Mountains. The formation of the plain was followed by periods of uplift when streams eroded the deposits near the mountain front. This erosion isolated the plain from the mountains in all areas except parts of Wyoming. In places, the original plain was dissected; elsewhere new sediments were deposited on the plain.

The oldest formation included in the High Plains aquifer is the Brule Formation (table 2). The ability of the Brule to transmit water generally is insufficient to provide an economic supply of water to wells. In some areas, however, the rock is fractured and yields adequate quantities of water to wells. In these areas, the formation is considered a part of the High Plains aquifer.

The Arikaree Group was deposited after the Brule Formation and the Ogallala was deposited after the Arikaree. The Ogallala Formation was deposited by streams flowing from the Ancestral Rocky Mountains. The Ogallala is the dominant formation in the High Plains aquifer in the southern part of the High Plains.

Sand was deposited by wind to form areas of sand dunes on the older High Plains deposits. The largest of these areas are in Kansas, south of the Arkansas River, and in the Sand Hills in north-central Nebraska where the deposits exceed 300 feet in thickness. The dunes are now stabilized by vegetation, but major dune formation continued until about 1,500 years before the present (Swinehart, 1989).

Quaternary streams eroded older formations and re-deposited the sediments as valley-fill material. Present streams continue to erode and deposit sediments. Where the sand dunes and stream deposits are saturated and are hydraulically connected to the High Plains aquifer, they are considered to be a part of the High Plains aquifer.

Table 1.--*Characteristics of the High Plains aquifer*

[Source: Gutentag and others, 1984]

| Characteristic | Units of measurement | Total | Area of High Plains aquifer | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | South Dakota | Wyoming | Nebraska | Colorado | Kansas | New Mexico | Okla-homa | Texas |
| Area covered by aquifer. | Square miles | 174,050 | 4,750 | 8,000 | 63,650 | 14,900 | 30,500 | 9,450 | 7,350 | 35,450 |
| Percentage of total aquifer area. | Percent | 100 | 2.7 | 4.6 | 36.6 | 8.6 | 17.5 | 5.4 | 4.2 | 20.4 |
| Percentage of each State covered. | Percent | -- | 7 | 8 | 83 | 14 | 38 | 8 | 11 | 13 |
| Drainable water in storage. | Million acre-feet | 3,250 | 60 | 70 | 2,130 | 120 | 320 | 50 | 110 | 390 |

Table 2.--*Geologic units comprising the High Plains aquifer*

[Source: Emry and others, 1987; Swinehart, 1989; Tedford and others, 1987]

| Geologic unit comprising the aquifer | Age and time before present, in million years | Composition | Location where the unit is a significant part of the High Plains aquifer | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | South Dakota | Wyo-ming | Ne-braska | Colo-rado | Kan-sas | New Mexico | Okla-homa | Texas |
| Valley-fill and aluvial deposits | Quaternary (Holocene and Pleistocene); 1.8 to present. | Clay, silt, sand, and gravel, unconsolidated. | | | X | | X | | | |
| Oune sand | Quaternary (Holocene); 0.008 to 0.0015. | Sand, very fine- to medium-grained, windblown. | | | X | | X | | | |
| Ogallala Formation | Tertiary (Miocene); 19 to 5. | Clay, silt, sand, and gravel gener-ally unconsolidated where cemented by calcium carbonate, forms mortar beds. | X | X | X | X | X | X | X | X |
| Arikaree Group | Tertiary (Miocene and Oligocene); 29 to 19. | Sandstone, very fine- to fine-grained, with beds of volcanic ash, silty sand, and sandy clay. | X | X | X | | | | | |
| Brule Formation | Tertiary (Oligocene); 31 to 29. | Siltstone, massive, with beds of sand-stone, volcanic ash, and clay. | | X | X | X | | | | |

## FACTORS AFFECTING WATER-LEVEL CHANGE--RECHARGE BY SURFACE WATER AND PRECIPITATION

*Recharge to the High Plains Aquifer Is Affected by Climatic Conditions, Land Use, Vegetative Cover and Soil Characteristics.*

Water-level changes in an aquifer reflect the difference between recharge to and discharge from the aquifer. Almost all recharge to the High Plains aquifer originates from infiltration and downward percolation of surface water or precipitation. Water-table rises of about 90 feet have occurred in Nebraska due to downward leakage from surface-water irrigation systems. Most recharge, however, is from local precipitation. Recharge from precipitation is affected by climatic conditions, land use, vegetative cover, and soil characteristics.

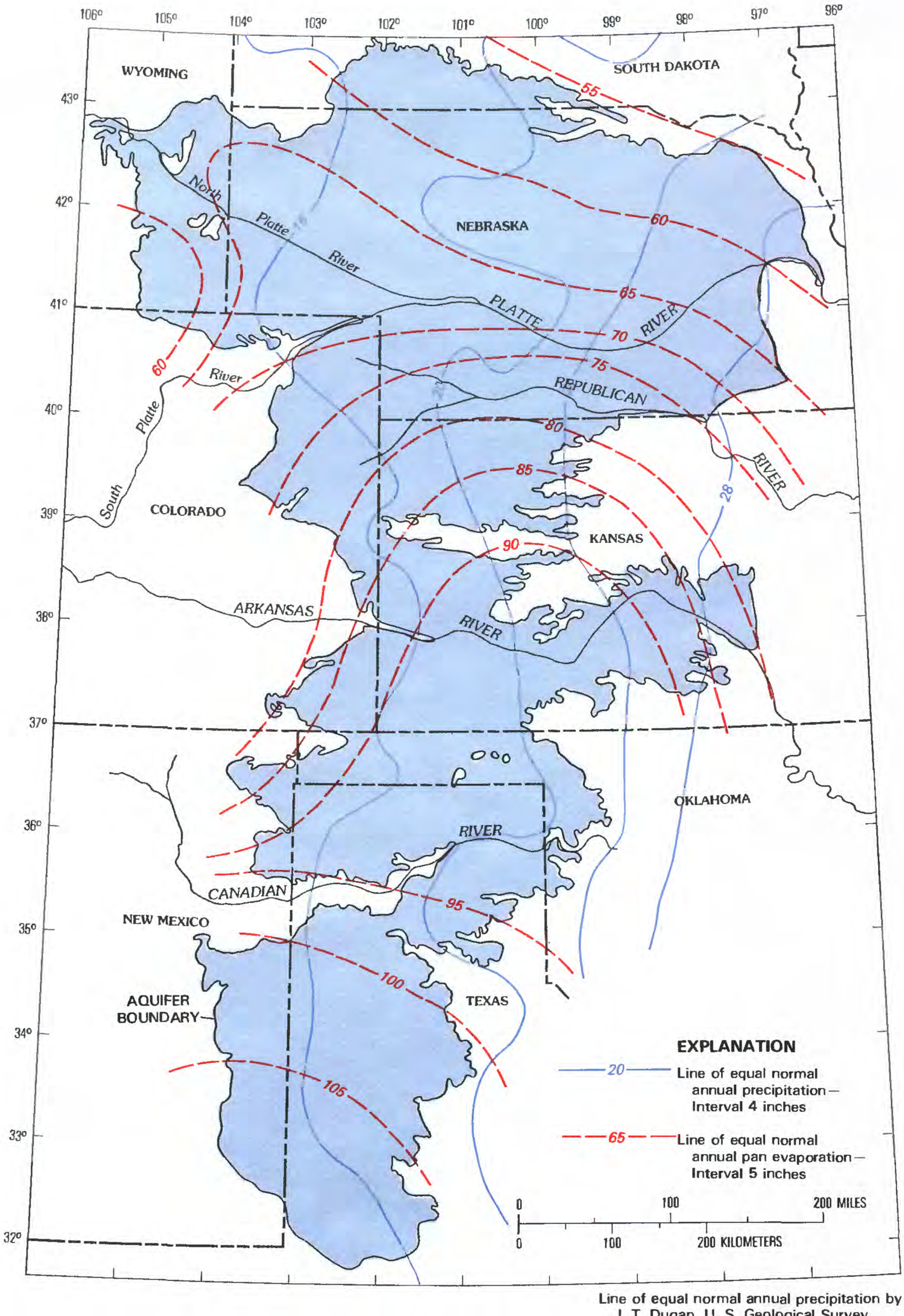
Annual precipitation ranges from about 16 inches along the western part of the High Plains to about 28 inches in eastern Nebraska and central Kansas (fig. 1). About 75 percent of the precipitation usually falls during thunderstorms from April to September. The amount of precipitation from these thunderstorms can be substantial and can differ greatly over short distances. A large percentage of the annual precipitation at a given weather station can be from a single thunderstorm, whereas a nearby weather station may not receive any precipitation from the same storm.

The humidity in the High Plains generally is low, winds are persistent, and high temperatures are common during the summer. These conditions result in a substantial rate of evapotranspiration as indicated by measurements of Class A Pan evaporation that range from an annual average of 55 inches in the northeastern part of the High Plains to about 105 inches in the southern part (fig. 1). The potential annual evapotranspiration rate, or the theoretical maximum evapotranspiration that could occur if there was an adequate supply of moisture to meet vegetation demands at all times, exceeds annual precipitation throughout the High Plains, and most of the precipitation returns to the atmosphere. Recharge to the aquifer occurs only when the amount of precipitation and infiltration into the soil exceeds the evapotranspiration demand and the moisture-holding capacity of the soil.

The estimated average annual recharge rate ranges from about 0.025 inch to about 6 inches (Weeks and others, 1988). The annual recharge at a given location may vary considerably from one year to the next. As an example, greater than normal precipitation when plants are dormant and evapotranspiration is minimal may result in more than average recharge. In a continuing, long-term "wet cycle", moisture that collects in the soil zone increases the chances for precipitation to meet the evapotranspiration demands, exceeds the water-holding capacity of the soil, and becomes recharge. Conversely, when precipitation of only moderate intensity falls during the the growing season, it is unlikely to meet the evapotranspiration demand, leaving little or none to become recharge.

In some areas in south-central South Dakota, eastern Nebraska, and central Kansas where the water table is shallow, precipitation from a single storm may cause water-table rises. However, in parts of western Nebraska, western Kansas, and much of the southern High Plains where the water table is deep, periods of intensive precipitation may produce recharge but the recharge may affect the water table only after weeks or months.

The volume of recharge also is affected by land use and vegetation. The conversion of native grassland to cultivated cropland may increase the recharge potential (Luckey and others 1981), whereas the conversion of cultivated cropland to grassland may have the opposite effect. Substantial acreage in the High Plains has been placed in the Conservation Reserve Program (CRP), which was implemented in March of 1986 as part of the Food Security Act of 1985. The CRP is designed to take highly erodable land out of production for 10 years. The conversion of the cropland to grassland may indirectly affect the long-term changes in water levels by decreasing the recharge in those areas that were formerly under dryland farming, and by decreasing ground-water withdrawals on CRP land that formerly was irrigated.




Line of equal normal annual precipitation by J. T. Dugan, U. S. Geological Survey, written commun., 1989.

Figure 1.--Normal annual precipitation (1951-80) and Class A pan evaporation in the High Plains (modified from Thelin and Heimes, 1987).

## FACTORS AFFECTING WATER-LEVEL CHANGE--NATURAL DISCHARGE AND GROUND-WATER WITHDRAWALS

*Discharge from the High Plains Aquifer Is by Evapotranspiration, Seepage to Streams, and Ground-Water Pumpage. Ground-Water Pumpage Decreased in the 1980's.*

Water discharges from an aquifer naturally by evaporation from the soil and transpiration by vegetation where the water table is shallow (evapotranspiration), and by seepage to springs and streams. Water pumped from wells is the principal means of artificial discharge from an aquifer. About 96 percent of the ground water pumped from the High Plains aquifer is for irrigation and other agricultural uses (Wayne Solley, U.S. Geological Survey, written commun., 1988). Other uses of the ground water that are vital to the High Plains are: domestic consumption, livestock watering, mining, and industrial use.

The U.S. Geological Survey in cooperation with State and local agencies throughout the country has collected, stored, and published national water-use information at 5-year intervals since 1950. The High Plains data from 1985 were used to compile a map of ground-water withdrawals by county (fig. 2). The average water use was determined by dividing the total ground water used in the county by the number of acres in the county.

The estimated total water use from the High Plains aquifer for 1985 was 17,070,000 acre-feet (Wayne Solley, U.S. Geological Survey, written commun., 1988). This estimate is based on extrapolation of metered pumpage, which generally represents a small percentage of the total pumpage; the extrapolation of estimated use per person or per head of livestock; and estimates of the water, supplemental to precipitation, required to raise crops.

Use of ground water from the High Plains aquifer in 1985 was about 19 percent less than in 1980 (Wayne Solley, U.S. Geological Survey, written commun., 1988). The decrease in ground-water use was due to several factors:

1. The volume and timing of precipitation during 1985 required less irrigation pumpage than in 1980. As an example, the supplemental water needed for raising crops in Nebraska was estimated to be 22 percent less in 1985 than in 1980 (Steele, 1988).

2. A reduction in farm profits by 1985 resulted in less pumping of irrigation water.

3. Farmers used less water because of improved agricultural practices (minimum tillage, and better knowledge of soil-moisture conditions and plant requirements, etc.).

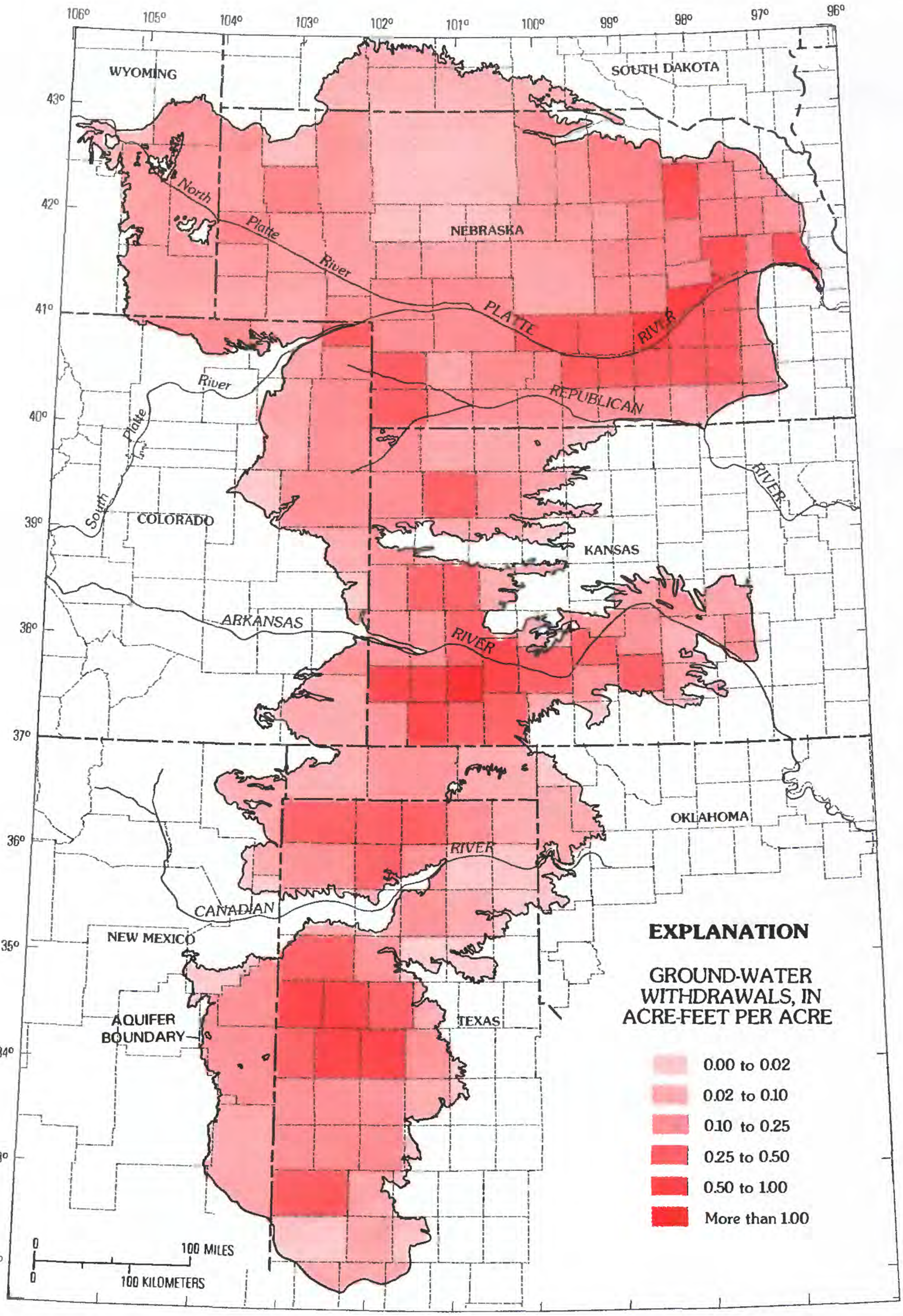



Figure 2.--Ground-water withdrawals during 1985, by county. Withdrawals for hydroelectric-power generation and sewage treatment not included.

## HISTORY OF GROUND-WATER DEVELOPMENT AND HIGH PLAINS WATER-LEVEL CHANGES, PREDEVELOPMENT TO 1980

*High Plains Depends on Water for Irrigation.*

An Army expedition headed by Major Stephen Long crossed part of the High Plains region in 1819-20. In the journals of the expedition the area was described as an "...extensive section of the country...almost wholly unfit for cultivation, and of course uninhabitable by a people depending upon agriculture for their subsistence." (Dick, 1975). Contrary to this assessment, the High Plains has become one of the major agricultural regions of the United States.

Settlement of the High Plains was encouraged through incentives like the Homestead Act of 1862. The development of railroads allowed settlers easier access to the region and made it easier for them to market their agricultural products. The major impetus to the agricultural development of the area, however, was the availability of water for irrigation. Surface water was available in a few areas, but availability of ground water was the major factor in the development of agriculture.

Several factors have encouraged the increase of ground-water irrigation. Climatic fluctuations were especially important. During times of drought, many farmers switched from dryland farming to irrigation in order to continue their farming. During and after the drought of the 1930's, irrigation development increased mainly in the southern High Plains. During the drought of the mid-1950's, there was another expansion in ground-water irrigation, this time, mainly in the northern High Plains.

Fluctuations in the farm economy also have affected ground-water development. Increased crop prices and decreased well-drilling costs have encouraged ground-water irrigation. Development of natural gas fields in the High Plains during the 1950's provided inexpensive energy for pumping and spurred irrigation development. An increase in energy costs that accompanied the "oil embargo" in the mid-1970's and an increase in pumping costs, caused partly by the lowering of water tables, have deterred additional development.

Another important factor in the increase of ground-water irrigation has been the changes in irrigation technology. Before 1900, ground-water withdrawal was by windmills from shallow, hand-dug wells. Improved drilling methods and the availability of gasoline-powered engines by the early 1900's allowed pumping from somewhat greater depths and opened new areas to ground-water irrigation. The development of efficient turbine pumps permitted still deeper wells and more cost-efficient pumping. In the 1960's, center-pivot irrigation systems were developed. These systems made it possible to irrigate areas with sandier soils and steeper topography than could be irrigated with gravity systems. With this advance in technology, ground-water development increased rapidly, especially in the northern High Plains.

The development of the aquifer has affected ground-water levels in most of the High Plains. Water-level changes from predevelopment to 1980 are shown in figure 3 (Weeks and others, 1988, fig. 7). Predevelopment water levels are those estimated to have existed before any effects imposed by human activity. In general, irrigation development had affected water levels south of the Canadian River (southern High Plains) by 1940, between the Canadian River and latitude 39° N (central High Plains) by 1950, and north of latitude 39° N (northern High Plains) by 1960. In parts of the Sand Hills of Nebraska and in parts of South Dakota and Wyoming, ground-water levels still represent predevelopment conditions.

By 1980, the greatest reduction in water levels had occurred in the southern High Plains of New Mexico and Texas. Water levels had declined more than 50 feet in a large part of this area with a maximum decline of nearly 200 feet in Texas. Water levels had declined more than 50 feet also in smaller areas of the central High Plains in northern Texas and southwestern Kansas. In a few areas, predominantly in Nebraska, water levels rose as the result of recharge from surface-water irrigation and leakage from canals and reservoirs (Weeks and others, 1988).

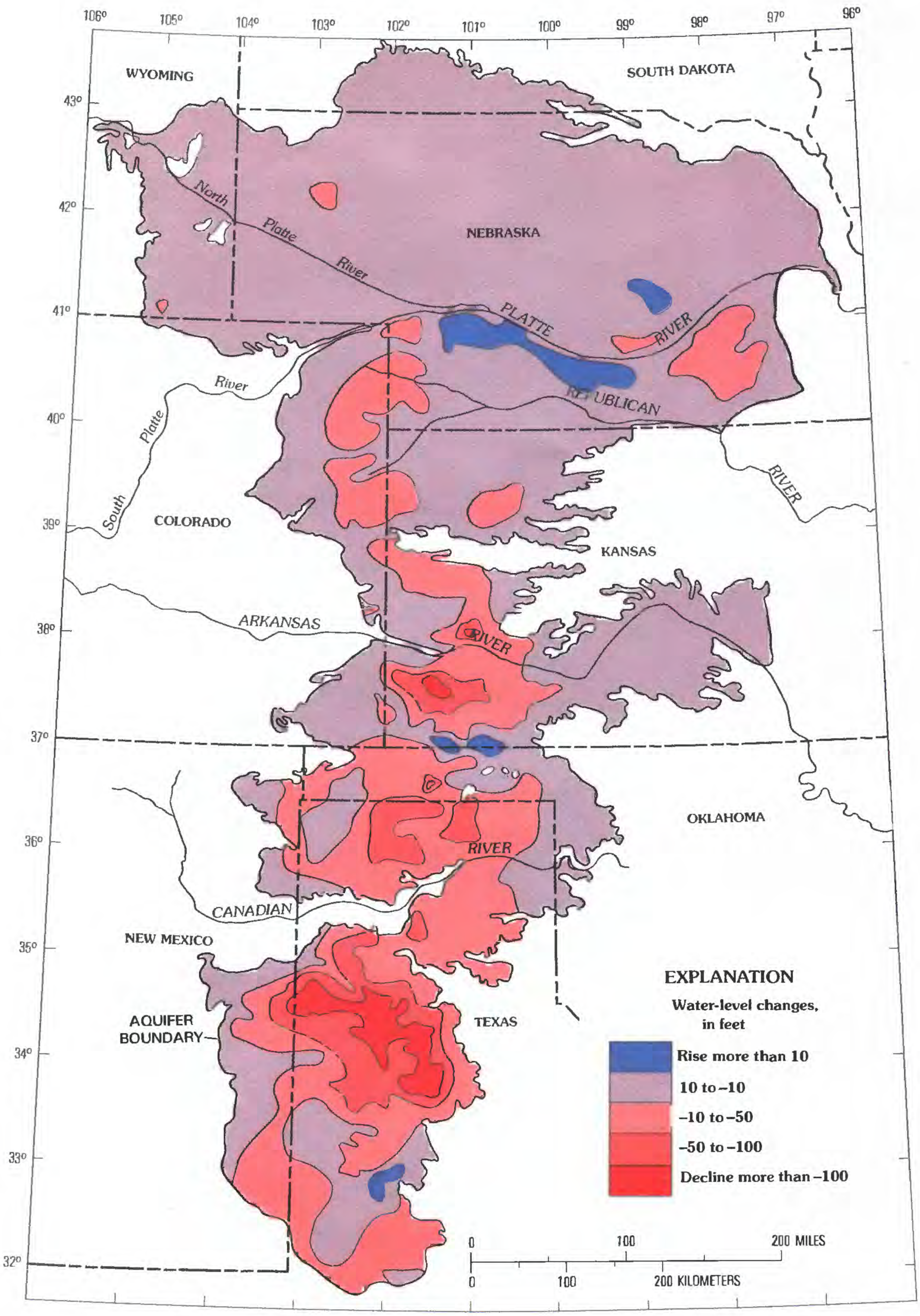



Figure 3.--Water-level changes in the High Plains aquifer, predevelopment to 1980 (modified from Weeks and others, 1988).

## WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER, 1980-88

*Water-Level Declines Have Slowed in the High Plains Aquifer Since 1980.*

The large water-level declines that occurred from predevelopment to 1980 did not continue during 1980-88 (fig. 4). Areas in which water levels rose during 1980-88 are shown in shades of blue on figure 4; these are mostly in eastern Nebraska, the eastern High Plains area of Kansas, the eastern High Plains area of Oklahoma, and the southern High Plains in Texas. Areas of continuing water-level decline, shown in shades of red, occurred in every State; the greatest declines were principally in southwestern Kansas, parts of the Panhandles of Oklahoma and Texas, and the northern part of the southern High Plains in Texas. In most of these areas of continuing water-level decline, however, the rate of decline was less than before 1980. The possible causes for the water-level rises and changes in rates of decline are discussed in the paragraphs that follow.

The major withdrawals from the High Plains aquifer are for crop irrigation and thus are generally from April through September. The local water table around a well, or group of wells, is lowered during the pumping period, but begins to recover after the irrigation season and reaches maximum recovery by late winter before irrigation or pre-irrigation begins for the new growing season. For this reason, water-level changes from one nonirrigation season to the next are considered to represent the annual water-level changes; therefore, most annual water-level measurements are made between October 1 and March 31. If multiple measurements are made at the same location during this period, the last measurement is used in water-level-change computations. In any one area, the annual water levels are generally measured at about the same time each year. However, the time of these once-a-year measurements may vary from area to area within the nonirrigation season.

The water-level changes shown in figure 4 are based on data from 4,719 monitoring wells completed in the High Plains aquifer where water levels were measured during the nonirrigation seasons of 1979-80 and 1987-88. Despite the use of data collected during a time of general water-table recovery, there still is disparity in the water-level-measurement values between adjacent wells. Factors that can cause these inconsistencies from one year to the next are pumping of nearby wells shortly before or during the time of measurement, return flow from irrigation, or variation in the starting or ending time of the irrigation season. A meaningful contour map is difficult to prepare when the data are disparate and conditions affecting the water level at each well at the time of each measurement are not known. Therefore, a mapping method was selected that uses the unadjusted water-level-change value at each well and assigns this value to the area closest to the well. This mapping technique is called the Theissen-polygon method (Theissen, 1911). Where wells are closely spaced, the polygons are small, and each water-level-change value represents only a small area. Where wells are widely spaced, however, each represents a large area. In areas such as parts of Wyoming and New Mexico where monitoring wells are widely spaced and the water-level changes in isolated wells do not necessarily represent the regional water-level change, any map of water-level changes may present a distorted picture of those changes.

The average water-level change for all monitoring wells from the nonirrigation season of 1979-80 to the nonirrigation season of 1987-88 was a rise of 0.05 foot. The density of monitoring wells generally is greater in areas of intense development and these areas are more likely to be areas with greater water-level declines. The density is generally less in less developed areas and these areas are less likely to show declines. Therefore the water-level change weighted by areal coverage was a rise of 0.8 foot. Bias caused by uneven distribution of wells is removed in area weighting. By using 15 percent as an average amount of water recoverable from pore spaces (Weeks and others, 1988), the area-weighted rise from 1980 to 1988 would represent an increase in available water of about 13,400,000 acre-feet.

The water-level rises in the High Plains aquifer from 1980 to 1988 (fig. 4) need to be interpreted in light of the following factors:

1. The years 1980-88 represent a period of greater than normal precipitation and one of stable or decreasing agricultural activity. The rate of ground-water withdrawal decreased during this period, but might increase again during periods of drought or agricultural expansion.
2. The water-table rise is not distributed uniformly. Much of the rise is in areas with only minimal development and little irrigation demand. Declines have continued in many of the areas of major irrigation development as in southwestern Kansas and the northern part of the southern High Plains in Texas.
3. Some of the rises may be due to increased recharge with an actual increase in stored water. However, others may be local recoveries in local cones of depression as a result of decreased pumpage, where regionally there may be no increase of ground water in storage.

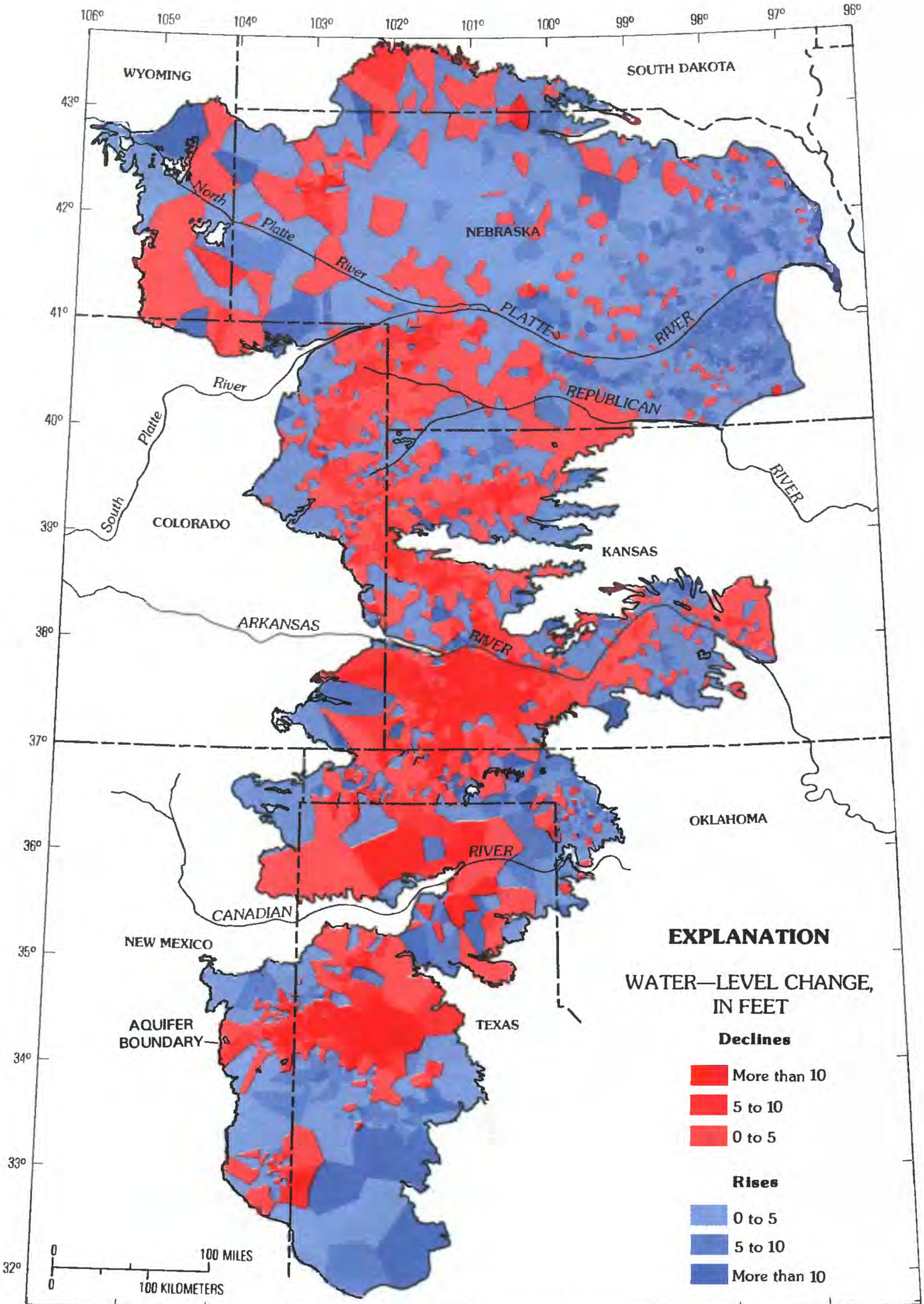



Figure 4.--Water-level changes in the High Plains aquifer, 1980-88.

## PRECIPITATION IN THE HIGH PLAINS, 1981-87

*Greater Than Normal Precipitation Fell in the High Plains from 1981 through 1987.*

The U.S. Department of Commerce, National Climatic Data Center, calculates the normal precipitation and temperature for selected weather stations. The calculated normal values are a 30-year average that are revised every 10 years. The current (1988) normal is the average for the years 1951 through 1980. The mean annual departure from normal precipitation for the period 1981-87 is shown in figure 5. The Theissen-polygon method was used to assign the areal coverage for the departure.

In general, the High Plains received greater than normal precipitation during 1981-87 with an average annual station departure of 3.16 inches greater than normal. The area-weighted departure from normal was 2.94 inches greater than normal. The largest positive departures from normal precipitation were in the eastern High Plains of Nebraska, Kansas, and Oklahoma, and the southern High Plains of New Mexico and Texas south of the Canadian River. Stations with negative departures from normal precipitation were scattered, although several were located in north-central Kansas and in northwestern Nebraska.

Many areas with greater than normal precipitation also had either a rise in the water table (fig. 4) or a decrease in the rate of decline in the water table. This correlation may be due either to increased recharge from the greater precipitation or to a decrease in ground-water withdrawals for irrigation.

Variations in temperature also can affect the volumes of recharge and discharge. Lower than normal temperature during the growing season decreases the evapotranspiration demand and therefore decreases the volume of irrigation water required. During 1981-87 the temperature was slightly higher than normal in the northern High Plains and slightly lower than normal in the southern High Plains. However, the average area-weighted annual departure from normal temperature was only 0.06 degree Farenheit less than normal for the entire area and probably had little overall effect on irrigation requirements and pumpage from the total High Plains aquifer.

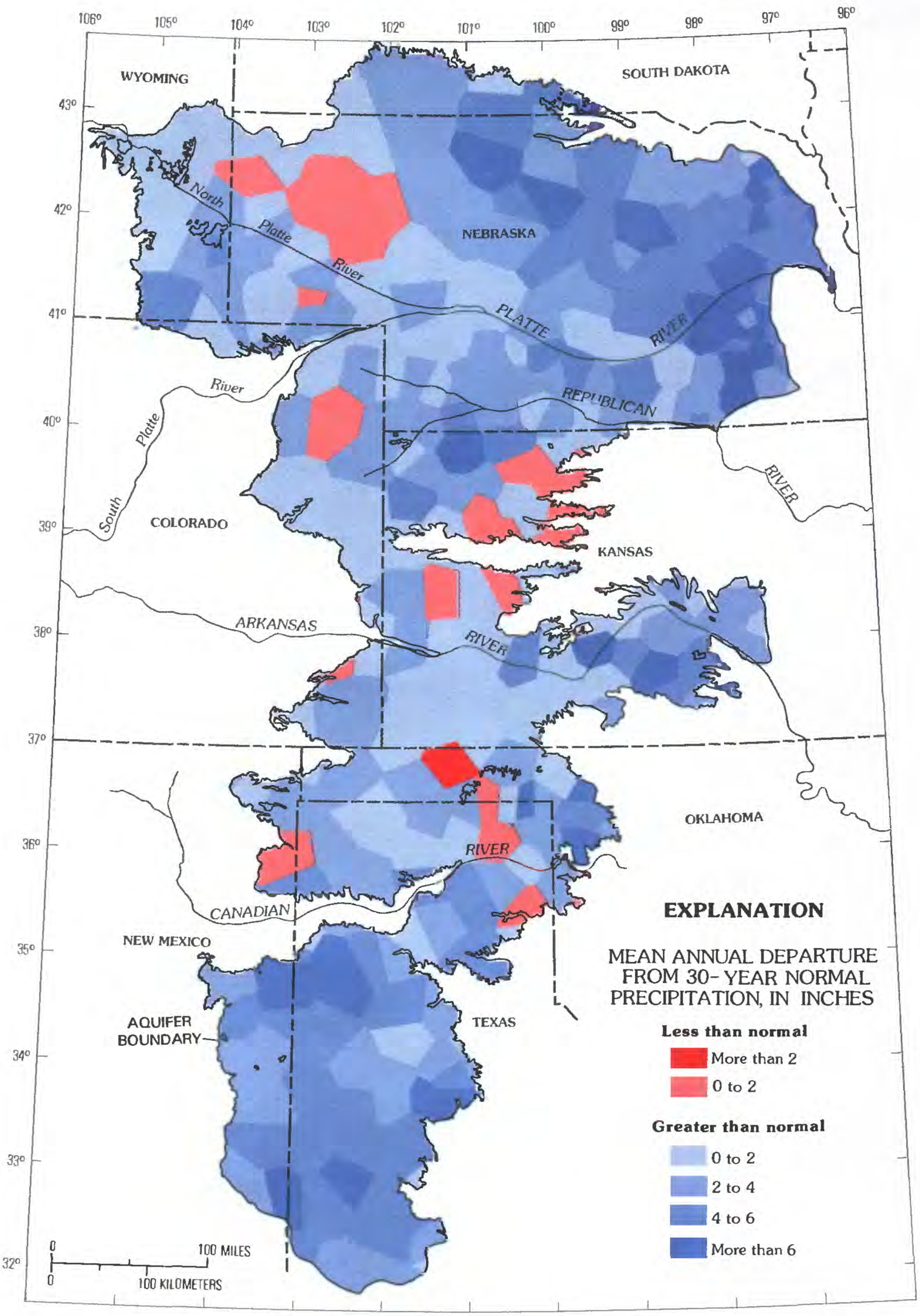



Figure 5.--Mean annual departure from 30-year normal precipitation, 1981-87. Source: U.S. Department of Commerce, National Climatic Data Center.

## WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER, 1987-88

*Water Levels Generally Rose during 1987-88. Aquifer-Wide Effects of the Drought of 1988 on Water Levels through the End of the 1988 Irrigation Season Are Estimated to be Minimal.*

Changes in water levels from the nonirrigation season of 1986-87 to the nonirrigation season of 1987-88 are shown in figure 6. Water-level data for both periods were available for 6,203 observation wells completed in the High Plains aquifer.

In general, the patterns of water-level change are similar to those mapped for 1980-88. Water levels generally rose in much of the High Plains of southeastern Nebraska, south-central Kansas, and the eastern High Plains of Oklahoma and the southwestern High Plains of Texas. Maximum declines occurred principally in northeastern Nebraska, southwestern Kansas, and northwestern Texas. The average water-level change for the 6,203 monitoring wells in the total High Plains was a rise of 0.17 foot. The area-weighted change was a rise of 0.28 foot.

Hydrologic conditions that are temporary or only occur for a 1-year period can give a misleading 1-year change. As an example, in some areas of the Sand Hills in Nebraska, the water levels rose to elevations higher than those for the predevelopment condition. These high water levels were the result of greater than average precipitation before and during the nonirrigation season of 1986-87. The water levels had declined to near average levels by the nonirrigation season of 1987-88 as a result of natural discharge to streams and evapotranspiration. The 1-year change map (fig. 6) shows a decline for these areas, but they are not areas with a trend of declines or water-level problems. A shift in the local season of pumping to earlier or later from one year to the next also may cause a distorted water-level change. In general, caution needs to be exercised in interpretation of 1-year water-level changes. Although long-term trends are the sum of yearly changes, it cannot be assumed that a 1-year change indicates a developing trend. Water-level changes over a minimum of 5 years are more meaningful in identifying trends.

The inconsistencies between water-level measurements in adjacent wells can be as significant for the total water-level changes for 1 year as for a total water-level change for a longer period. The inconsistencies in measurements between adjacent wells may be greater for a 1-year period than for an average annual water-level change for a longer time period because the variability that may affect the water levels during one measurement is averaged with less affected measurements from a longer time period.

Parts of the United States were affected by a severe drought in 1988. However, the area principally affected by the drought through the end of the 1988 growing season was north and east of the area underlain by the High Plains aquifer. The drought severity index (Palmer Index) for October 1, 1988, published by the National Oceanic and Atmospheric Administration and the U.S. Department of Agriculture Joint Agricultural Weather Facility, showed that the area underlain by the High Plains aquifer in Colorado and Wyoming was affected by a mild to moderate drought, the area underlain by the aquifer in eastern Nebraska was affected by a moderate drought, and the area underlain by the aquifer in east-central Kansas was affected by a mild to moderate drought. The remainder of the area underlain by the High Plains aquifer had either normal or greater than normal available moisture. Available moisture was greatest in north-central Nebraska, eastern New Mexico, and the Oklahoma and Texas Panhandles, which were in an "extreme moist spell" as classified by the drought severity index.

The effects of the 1988 precipitation, or lack of it, on irrigation requirements and therefore on the volume of ground-water pumpage and water levels may be significant in limited areas but probably is minimal on an aquifer-wide basis. Because of the variability of summer water-level measurements, the effects of the precipitation during 1988 on water levels can not be fully assessed until the nonirrigation season measurements of 1988-89 are compiled and analyzed.

Some precipitation deficits developed in areas of the High Plains in 1988 after the drought severity index of October 1, 1988, was published and the growing season for most crops had ended. The soil-moisture deficiencies resulting from these deficits may require greater than normal pumpage of ground water in the 1989 irrigation season. The effects of this pumpage on water levels will not be assessable until the nonirrigation season measurements of 1989-90 are compiled and analyzed.

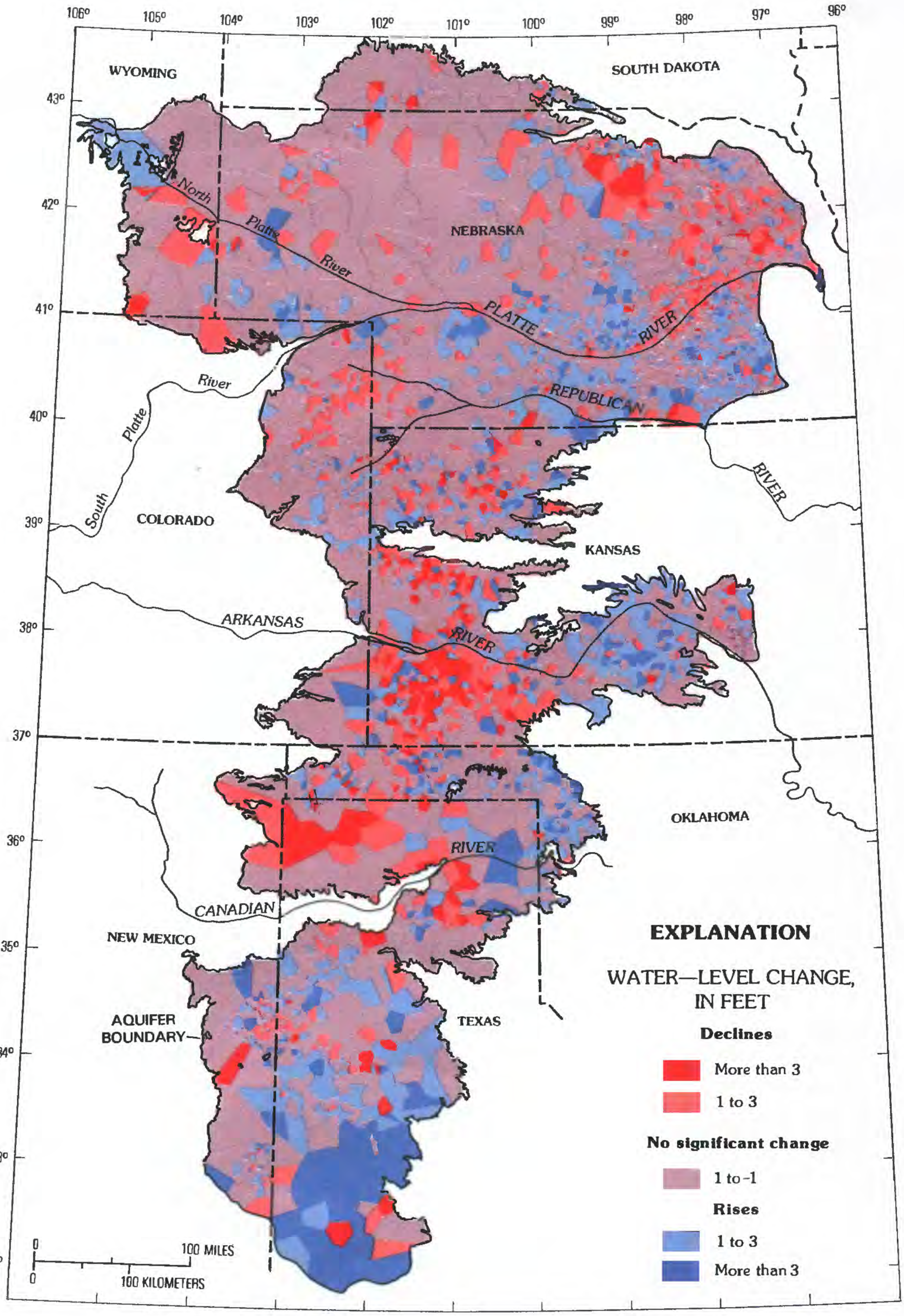



Figure 6.--Water-level changes in the High Plains aquifer, nonirrigation season 1986-87 through nonirrigation season 1987-88.

## STATE SUMMARIES

### SOUTH DAKOTA--WATER-LEVEL CHANGES AND PRECIPITATION, 1987

*High Plains Aquifer Was Not Extensively Used in South Dakota during 1987.*

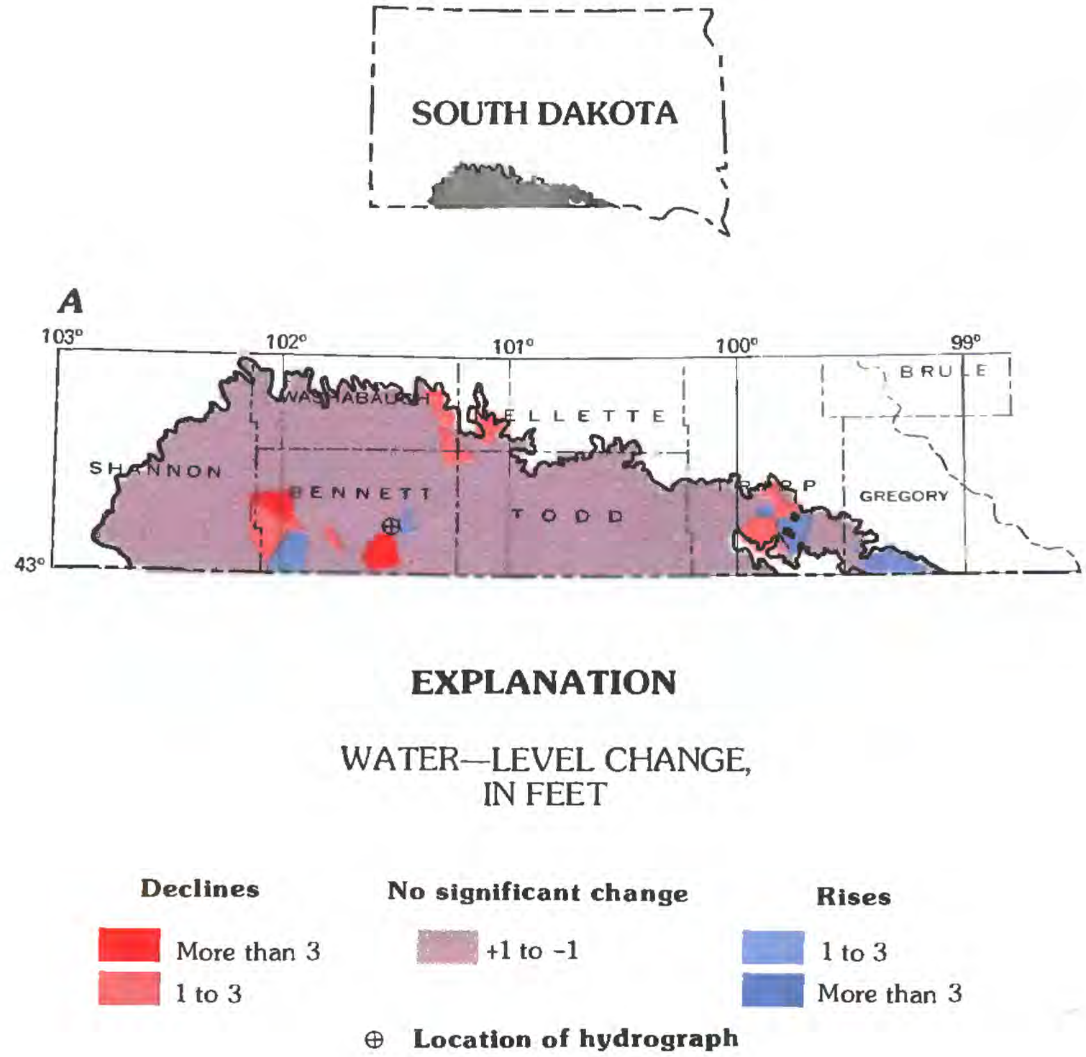
In south-central South Dakota, the High Plains aquifer underlies about 4,750 square miles. The aquifer is not intensely developed compared to development in other States. An estimated 21.84 million gallons per day (24,480 acre-feet) was pumped from the aquifer during 1985 (Wayne Solley, U.S. Geological Survey, written commun., 1988). Agricultural use accounted for about 88 percent of this pumpage; the remainder was used for public-supply, domestic, and commercial purposes. In general, increases in withdrawals of water from the aquifer for irrigation have been minimal since the end of the drought of the mid-1970's. Ground-water pumpage is not areally uniform.

The South Dakota Department of Water and Natural Resources, Division of Water Rights, operates a statewide network of more than 1,500 observation wells. About 100 of these wells are in the High Plains area and are measured monthly in cooperation with the U.S. Geological Survey. Data from these wells are available from either agency.

Water levels did not change substantially in the High Plains aquifer between the nonirrigation season of 1979-80 and the nonirrigation season of 1987-88. The area-weighted water-level change for the 54 wells that were measured in both nonirrigation seasons was a decline of 1.41 feet. Two wells in a small area in Bennett County had measured water-level declines of more than 5 feet, which markedly affected the average decline. However, both of these wells probably are affected by nearby pumpage, and the declines in the water level probably reflect local rather than regional conditions. The area-weighted annual departure from normal precipitation for 1981 through 1987 was 2.96 inches greater than normal.

During 1987, only small water-level changes occurred throughout much of the High Plains aquifer in South Dakota (fig. 7A). The few local declines, which can be attributed to the effect of nearby pumpage shortly before or at the time of the observation-well measurements, overshadowed other water-level changes. Therefore, the area-weighted water-level change for the 83 wells, which were measured during the nonirrigation seasons of 1986-87 and 1987-88, was a decline of 0.08 foot.

Precipitation during 1987 ranged from about 2 inches less than normal in the western part of the High Plains area to about 10 inches greater than normal in the east, with the area-weighted departure from normal precipitation being 1.97 inches greater than normal (fig. 7B). Most of the excess precipitation fell during the nonirrigation season. During the growing season from April 5 to September 5, the weather stations in southwestern and south-central South Dakota reported precipitation of about 3 inches less than normal for that period of the year (South Dakota Agricultural Statistics Service, 1988). Most of the ground-water withdrawals were in June and July. The seasonal variation in precipitation was reflected in the flow of the White River that bounds the High Plains area on the west and north. Streamflow was greater than normal from January through April and was less than normal the rest of the year.



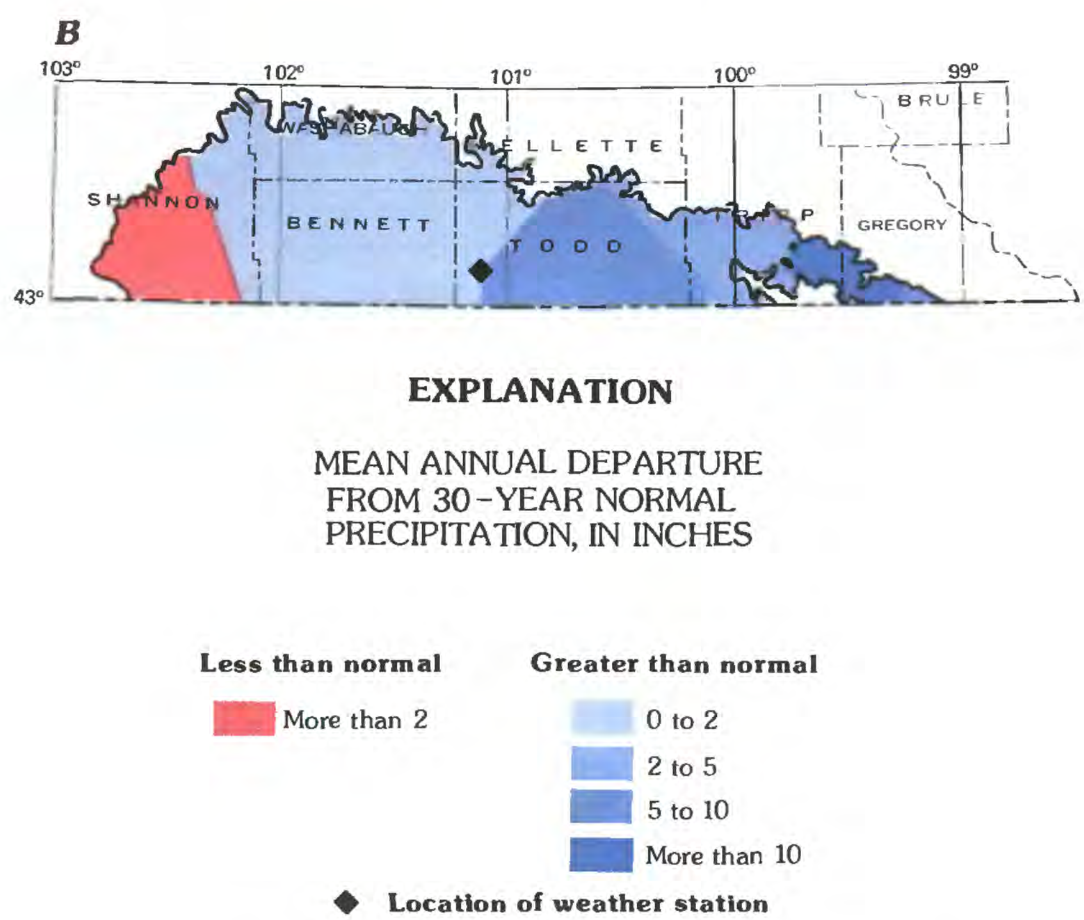




Figure 7.--A, Water-level changes in the High Plains aquifer in South Dakota, nonirrigation season 1986-87 through nonirrigation season 1987-88; and B, Annual departure from 30-year normal precipitation in South Dakota, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## SOUTH DAKOTA--REPRESENTATIVE CONDITIONS IN SOUTH-CENTRAL SOUTH DAKOTA

*Water-Table Fluctuations Primarily Affected by Precipitation in Bennett County.*

Irrigation in Bennett County increased considerably between 1977 and 1985 (fig. 8C). Nevertheless, the density of irrigation wells is relatively sparse compared with other areas of the High Plains aquifer in other States. The hydrograph showing the water-level changes in an observation well in Bennett County (fig. 8A) indicates that the water level was not obviously affected either by the increase in irrigated acreage through 1985 or by the stable to decreasing irrigated acreage of the last few years. The hydrograph fluctuations appear to be more affected by the periods of greater than and less than normal precipitation shown in figure 8B. The water table is shallow, and even brief variations in the precipitation appear to be reflected in water-level changes.

Water-level data are from the files of the U.S. Geological Survey. The annual-precipitation data are from the U.S. Department of Commerce, National Climatic Data Center. The curve of cumulative departure from average precipitation shows the periods of greater than and less than normal precipitation. A declining part of the curve, as in the 1930's and mid-1940's to mid-1950's, represents a period of less than normal precipitation and a rising part of the curve, as in the 1960's and 1980's, represents a period of greater than normal precipitation. The estimates of acres irrigated by ground water were derived from data obtained from the U.S. Department of Commerce, Census of Agriculture, for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the South Dakota Department of Agriculture, South Dakota Agricultural Statistics Service, for 1980-88. The data included all ground-water pumpage.

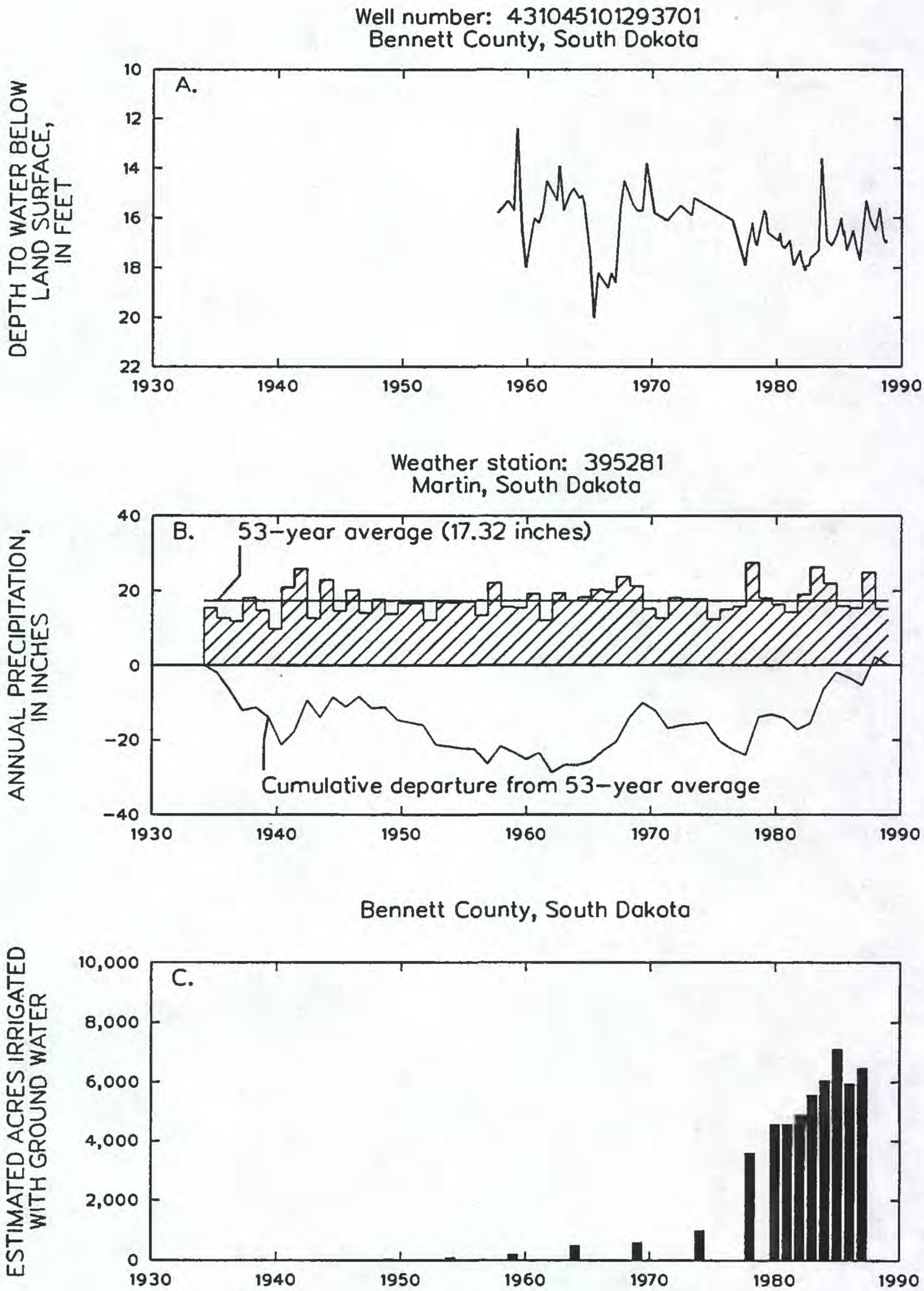



Figure 8.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Bennett County, south-central South Dakota.

## WYOMING--WATER-LEVEL CHANGES AND PRECIPITATION, 1987

*Water-Level Changes and Precipitation Were Variable in the High Plains of Wyoming during 1987.*

The High Plains aquifer underlies about 8,000 square miles in southeastern Wyoming. During 1985, an estimated 268 million gallons per day (300,400 acre-feet) was pumped from the aquifer. Agricultural use accounted for about 89 percent of the total use (Wayne Solley, U.S. Geological Survey, written commun., 1988). Most of the water used for agriculture in Wyoming is used for irrigation of crops, such as alfalfa and other hay, and corn for silage to support the local cattle industry.

The ground-water monitoring program of the High Plains aquifer in Wyoming is conducted by the U.S. Geological Survey in cooperation with the Wyoming State Engineer and the Wyoming Economic Development and Stabilization Board. During 1988, a continuous record of water levels was obtained from 53 wells equipped with digital recorders. Twenty-seven of these wells are located in Laramie County (Kennedy and Green, 1988). Water-level measurements from 37 observation wells, which were measured during October through March of 1986-87 and 1987-88, were used to calculate the annual water-level change using the Theissen-polygon method (fig. 9A).

Traditionally, observation wells in Wyoming have been installed in specific areas to monitor special hydrologic situations. The location of these observation wells near irrigation wells or surface-water irrigation systems may skew statistics derived from water-level data collected at the wells when applied to the High Plains aquifer as a whole. Therefore, the water levels as shown by the Theissen polygons do not adequately define the regional water-table conditions. The pattern superimposed on the water-level change data (fig. 9A) indicates where the regional water-level conditions in the aquifer cannot be defined because of a lack of representative data. Areas where regional water-level conditions can be defined are numbered 1 through 4. A network of observation wells is needed throughout the High Plains of Wyoming to obtain water-level measurements that reflect conditions throughout the aquifer.

Water-level changes in southeastern Laramie County (fig. 9A, area 1) can generally be attributed to irrigation pumpage. During 1987, only minor water-level changes were measured except in the southwestern corner of the county where there were substantial declines in water levels, caused not by irrigation, but by pumpage in the Cheyenne metropolitan area primarily for municipal and self-supplied domestic uses.

Some water levels in southeastern Goshen County have risen (fig. 9A, area 2) whereas others have declined. In the area of water-level rise, the aquifer probably receives substantial recharge from surface-water irrigation systems, whereas in the areas with water-level declines, there is little surface-water irrigation. Greater than normal precipitation in this area during 1987 (fig. 9B) also may have affected the rise of water levels as a result of increased recharge and decreased pumpage. Similar water-level conditions existed in the central part of Platte County (fig. 9A, area 3). Although precipitation was less than normal in this area during 1987 (fig. 9B), water stored in a large reservoir in the northwestern part of the area may have provided substantial, continuous recharge to the aquifer.

In southeastern Niobrara County and northwestern Goshen County (fig. 9A, area 4), large volumes of ground-water are pumped for irrigation from wells completed in the Arikaree Group of the High Plains aquifer. Despite the large volume of ground-water pumpage and less than normal precipitation during 1987 (fig. 9B), water levels did not change significantly and declined only slightly.

The development of ground-water resources for irrigation accelerated in southeastern Wyoming in the late 1960's. At that time, the available center-pivot irrigation systems were high-pressure, high-overhead nozzle systems. In southeastern Wyoming, because of the semiarid climate and prevalent winds, much of the water pumped for delivery by these systems was lost to evaporation and wind drift before reaching the crop. Hence, more water had to be pumped to meet the crop requirements. This problem has been recognized by area irrigators in southeastern Wyoming, as in other areas of the High Plains, and older systems are slowly being replaced by more water-efficient, low-pressure systems with nozzle configurations that allow the use of less water. This change in irrigating systems is affecting water-level changes by decreasing withdrawals.

The placement of cropland in the Conservation Reserve Program may affect recharge to and discharge from the aquifer. Most of the land placed in the program in southeastern Wyoming has been nonirrigated acreage (Gus Meier, U.S. Department of Agriculture, National Agricultural Statistics Service, oral commun., 1988). Due to the planting restrictions of other government programs, some farmers may grow more than one crop on one center-pivot irrigation circle. To satisfy the water requirements of one of the crops in the circle, the other crop, or crops, may be irrigated to excess, resulting in inefficient usage of irrigation water.

The cost of pumping ground water has had an effect on water-level changes. The major source of power for operating center-pivot irrigation systems in southeastern Wyoming is electricity (Richard Stockdale, Office of the Wyoming State Engineer, oral commun., 1988), and electricity is expensive in Wyoming. Therefore, the cost of pumping water from a well increases as the water table declines during the irrigation season or from year to year where ground water is continually being removed from storage. The cost of pumping can become prohibitive and result in a decrease in irrigation and a cessation in local water-level declines.

Recharge to the High Plains aquifer in Wyoming is from infiltration of water from rivers and streams and precipitation. Water from rivers and streams that flow across the outcrop of the High Plains aquifer infiltrate through the streambed and recharge the aquifer, especially during snowmelt in the spring. Most of the streams loose their total flow to infiltration and are, therefore, ephemeral streams. Rivers with perennial flow that cross the outcrop of the High Plains aquifer may still contribute seepage water to the aquifer, but have flow in excess of the volume of water that can infiltrate through the streambed.

Most precipitation in Wyoming is from the accumulation of snow during the nonirrigation season. During the growing season, precipitation normally is localized, intense thunderstorms. From 1981 through 1987, precipitation was substantially greater than the 30-year normal with the mean area-weighted departure being 2.26 inches greater than normal precipitation. During 1987, the area-weighted departure from the 30-year normal precipitation was 0.16 inch greater than normal.

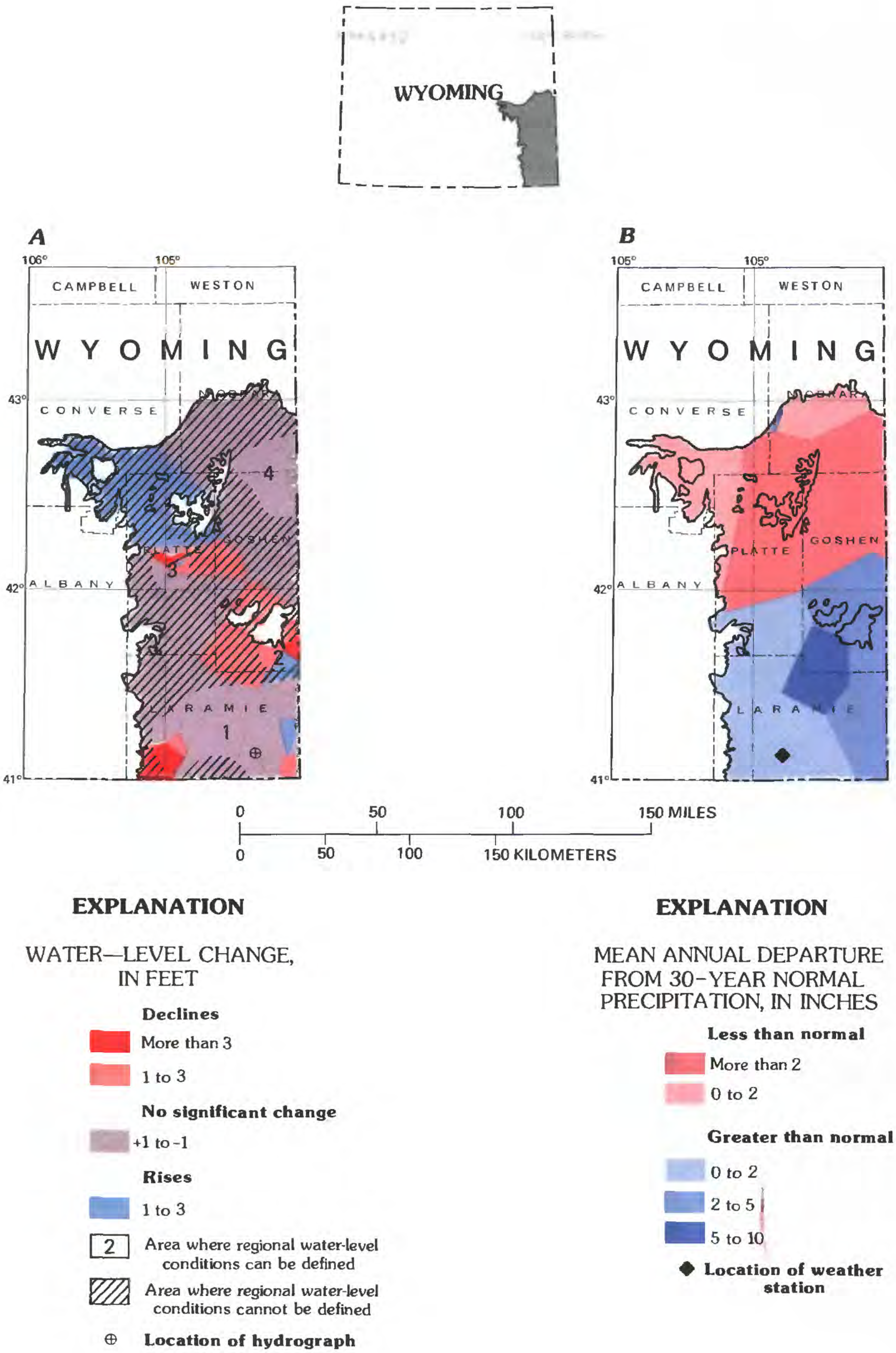



Figure 9.--A, Water-level changes in the High Plains aquifer in Wyoming, nonirrigation season 1986-87 through nonirrigation season 1987-88; and B, Annual departure from 30-year normal precipitation in Wyoming, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## WYOMING--REPRESENTATIVE CONDITIONS IN SOUTHEASTERN WYOMING

*Water-Level Changes Coincide with Changes in Precipitation in Laramie County.*

The hydrograph for a well in Laramie County (fig. 10A) represents observation wells in southeastern Wyoming. This hydrograph shows a declining water table until about 1980. At that time there was a reversal in the downward trend. The rise that followed appears to coincide with the increase in annual precipitation throughout the area (fig. 10B). Since 1986, water levels in the representative well and other local observation wells indicate a return to the general downward trend (Kennedy and Green, 1988). This recent decline may be partly caused by the increase in irrigated acreage in Laramie County that began in 1985 (fig. 10C).

The record of cumulative departure from the average precipitation for the past 52 years compiled from precipitation records collected at two weather stations near Cheyenne shows only minor wet periods for the early part of the record--one in the late 1930's and the other in the early 1940's (fig. 10B). Beginning in about 1964, the negative cumulative departure continually increased, reflecting a long period of less than average precipitation. Since 1980, there has been a reversal in this trend with annual precipitation equaling or exceeding the 52-year average. This increased precipitation may have resulted in increased recharge and a decreased need for ground-water withdrawals for irrigation.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Wyoming Crop and Livestock Reporting Service's Wyoming Agricultural Statistics for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

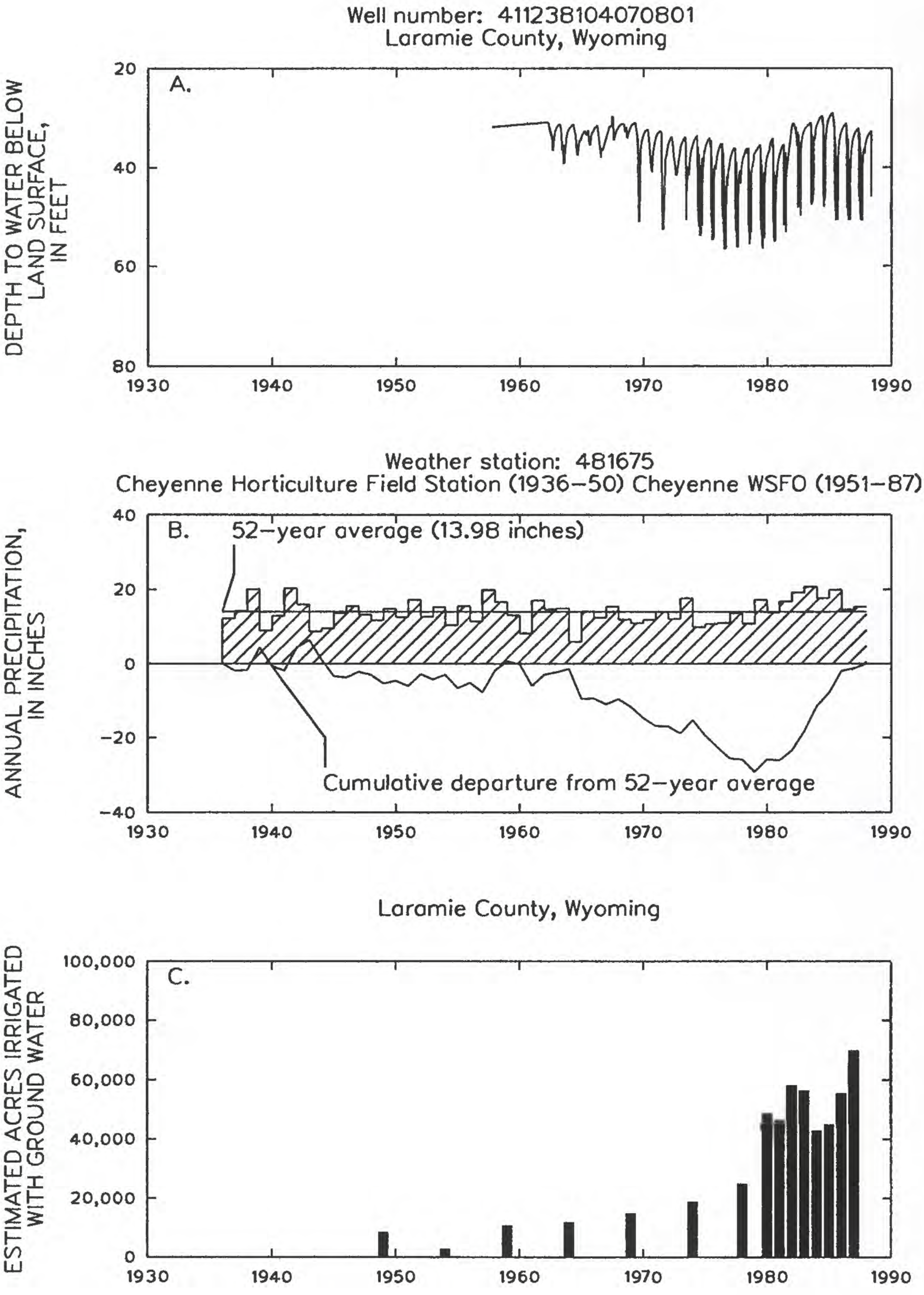



Figure 10.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Laramie County, southeastern Wyoming.

## NEBRASKA--WATER-LEVEL CHANGES, 1987

*Water-Level Rises that Began in 1981 Continued in 1987.*

The High Plains aquifer underlies most of Nebraska, about 63,650 square miles, except for a narrow strip along the eastern and northeastern borders, and an area in the northwestern corner. Estimated ground-water pumpage from the High Plains aquifer during 1985 was 5,170 million gallons per day (5,795,000 acre-feet). Pumpage for agriculture accounted for about 97 percent of this ground-water use (Wayne Solley, U.S. Geological Survey, written commun., 1988).

A statewide observation-well network was established in 1934 as part of a cooperative program between the U.S. Geological Survey and the Conservation and Survey Division of the University of Nebraska, Lincoln. Initially, this network was designed to provide data for a general appraisal of the State's ground-water resources. The need for detailed water-level data for specific areas, however, led to the establishment of a number of local observation-well networks with a greater density of wells. Data from observation-well networks operated by the U.S. Geological Survey, the Conservation and Survey Division, and a number of local agencies and municipalities are made available through the cooperative program.

Water-level data are collected for a variety of needs; therefore, the distribution of observation wells is not uniform. In some counties there are only five or six observation wells, whereas in other counties there are more than 100. The greatest density of observation wells generally is in areas where significant long-term changes in water levels have been recognized. However, there probably are some areas where water-level changes may not be detected or accurately delineated because of insufficient data.

Most of the water levels at the beginning of 1988 ranged between 1.0 foot higher and 1.0 foot lower than levels at the beginning of 1987 (fig. 11). However, the area-weighted annual water-level change for the 3,010 observation wells that were measured both in the nonirrigation season of 1986-87 and 1987-88 was a rise of 0.12 foot. The higher water levels in the southern part of the Panhandle and in southwestern, south-central, and central Nebraska probably are the result of greater than normal recharge from precipitation during February and March 1987 and from near-normal to slightly greater than normal precipitation during the growing season, which decreased the volume of ground water pumped for irrigation.

The primary cause for increased water-level declines in northeastern and north-central Nebraska is that precipitation during the growing season generally was less than normal, resulting in greater than normal use of ground water. A probable secondary cause is that water levels at the beginning of 1987 were at almost record highs; natural discharge through evapotranspiration and seepage to streams tended to lower water levels to near average levels by the beginning of 1988.

Comparison of estimated predevelopment water levels with annual water levels allows for the delineation of most areas where significant long-term declines or rises in water levels have resulted because of the development of water resources. At the beginning of 1988, declines of more than 5.0 feet had occurred under about 3.08 million acres and rises of more than 10.0 feet under about 1.18 million acres (Ellis and Wigley, 1988). Since 1980, the size of most areas with significant declines of more than 5 feet have become smaller each year (Johnson and Pederson, 1981), (Ellis and Wigley, 1988). This decrease in areas of significant decline reflects a general trend of rising water levels that started in 1981 and continued through 1987. This trend probably is most directly a result of normal or greater than normal amounts of precipitation occurring each year during 1981-87.

Areas with water-level declines of more than 5 feet from predevelopment through 1987 have decreased in size by the following percentages since 1980: Big Blue and Little Blue River basin in southeastern Nebraska, 48 percent; Dawson, Buffalo, and Hall Counties north of the Platte River in central Nebraska, 68 percent; south-central Cheyenne County in the Panhandle, 72 percent; Holt County in northeastern Nebraska, 78 percent; and Valley County in central Nebraska, 89 percent.

In southwestern Nebraska and in Box Butte County in the Panhandle, however, water levels generally have continued to decline almost every year since 1980. The change in size of areas with significant declines of 5 feet or more from 1980 through 1987 was an increase of 9 percent in southwestern Nebraska and an increase of 14 percent in Box Butte County.

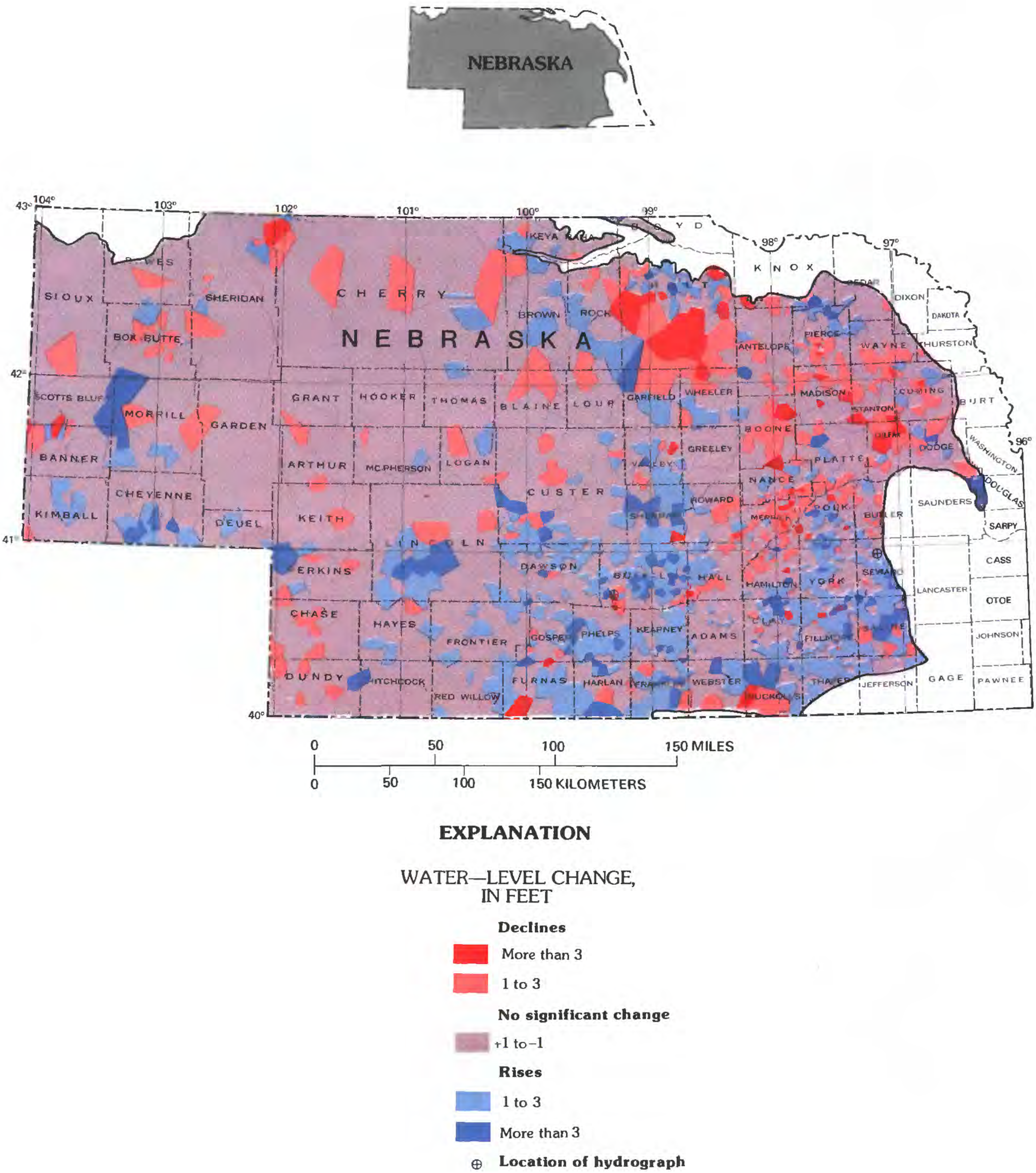



Figure 11.--Water-level changes in the High Plains aquifer in Nebraska, nonirrigation season 1986-87 through nonirrigation season 1987-88.

## NEBRASKA--PRECIPITATION, 1987

*Timing of Precipitation Affected Water-Level Changes in the High Plains Aquifer during 1987.*

Annual precipitation during 1987 (fig. 12) was greater than normal throughout all of the High Plains of Nebraska, except in the northern part of the Panhandle and in the northeastern part of the State. The area-weighted precipitation was 3.61 inches greater than normal. The precipitation that fell during the nongrowing season (October 1986 through March 1987) ranged from 161 to 228 percent of normal. More than 50 percent of this nongrowing-season precipitation fell during February and March of 1987. Because of recharge resulting from this precipitation, water levels in the spring of 1987 generally were substantially higher than water levels in the spring of 1986 throughout most of Nebraska.

During the 1987 growing season (April through September) precipitation ranged from slightly less than normal in northeastern Nebraska to slightly greater than normal in southwestern Nebraska. Although the precipitation that fell during the growing season varied only slightly from normal, the widespread distribution and timeliness of the precipitation was such that, in many parts of the State with the exception of the northeast, less than normal volumes of ground water were pumped for irrigation. In the northeastern part of the State, where precipitation was less than normal, most water levels at the beginning of 1988 were lower than levels at the beginning of 1987.

In most of the High Plains of Nebraska, recharge to aquifers consists of precipitation that infiltrates into the ground near where it falls. A general positive correlation between water-level fluctuations and precipitation quantity can be noted from most of the records. Precipitation quantity also can affect water levels indirectly because the volume of ground water pumped for irrigation and municipal use generally is less during wet periods than during dry periods.

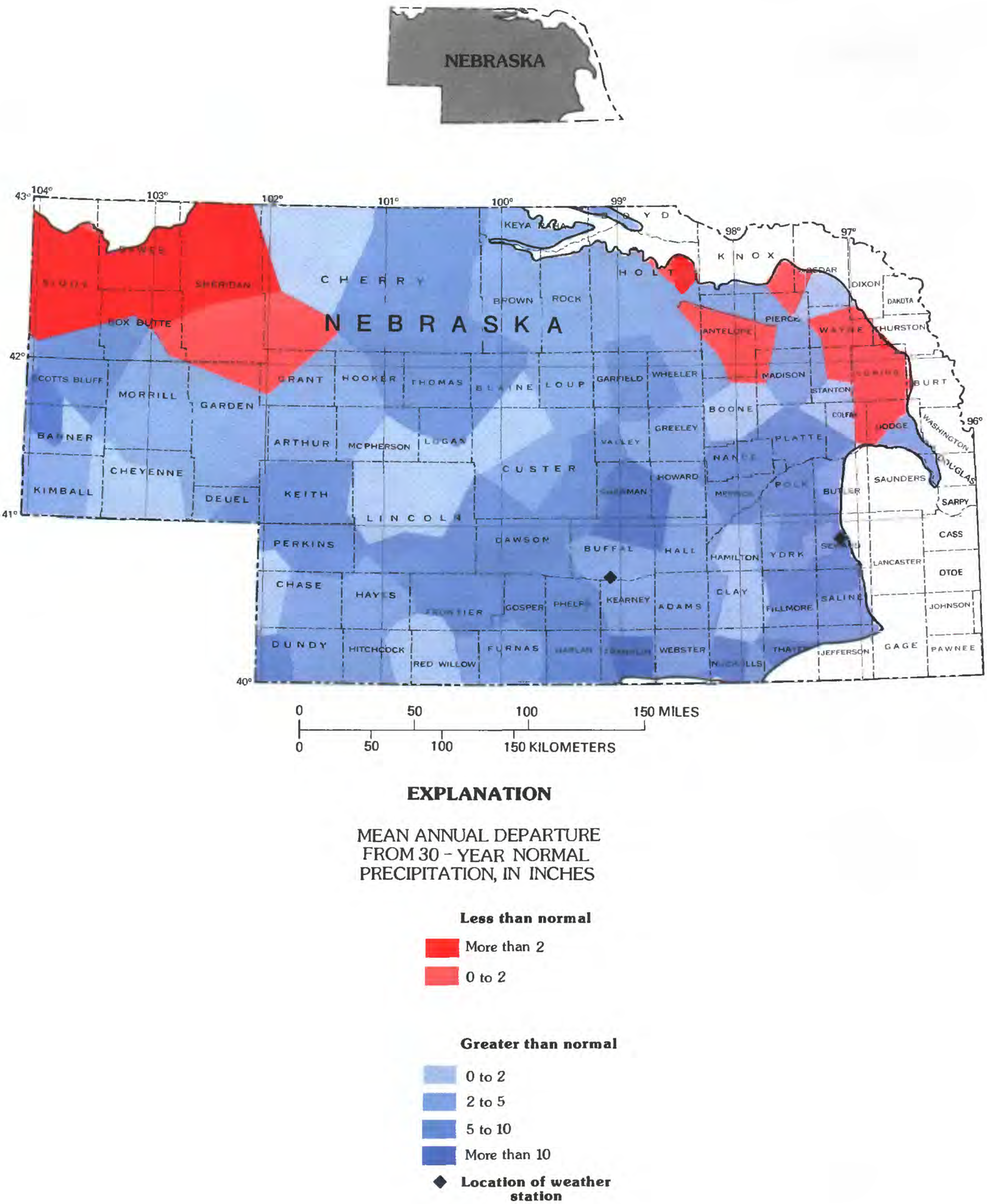



Figure 12.--Annual departure from 30-year normal precipitation in Nebraska, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## NEBRASKA--REPRESENTATIVE CONDITIONS IN SOUTHEASTERN NEBRASKA

*Water Levels in the High Plains Aquifer Change Rapidly in Response to Precipitation and Ground-Water Pumpage in Seward County.*

Water levels in an observation well in Seward County (fig. 13A) generally represent those in the southeastern part of Nebraska where the High Plains aquifer is composed of permeable sand and gravel. In most parts of this area, water levels in the aquifer rise rapidly in response to precipitation. Development of ground water for irrigation has been intensive since the mid-1950's. Within a 1.0 mile radius of this observation well, there are 10 irrigation wells. Water levels in the aquifer decline rapidly when these wells are pumped.

The long-term trend in water levels (fig. 13A) generally follows the same trend as the cumulative departure from the 58-year average precipitation (fig. 13B). The rise in the water table during the 1980's is the cumulative effect of the greater than normal precipitation and the trend to stabilization and possible decrease in the number of acres irrigated with ground water (fig. 13C).

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Nebraska Agricultural Statistics Service for 1980-87. The value of 200 in 1949 is too small to show in figure 13C. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

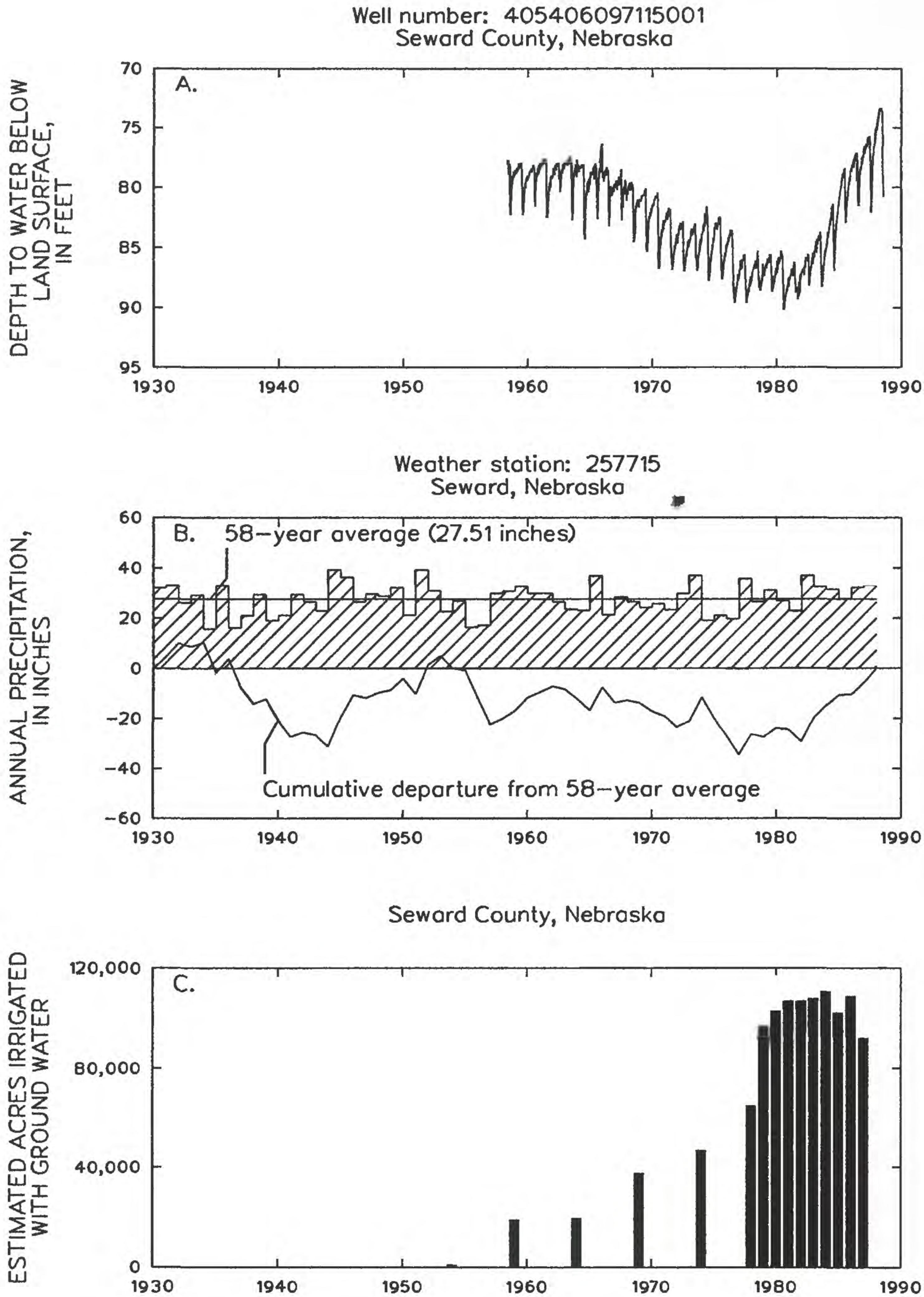



Figure 13.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Seward County, eastern Nebraska.

## NEBRASKA--REPRESENTATIVE CONDITIONS IN THE PLATTE RIVER VALLEY

*Changes in Precipitation Have Resulted in Cyclic Changes in Water Levels in the High Plains Aquifer in Buffalo County.*

Water levels in an observation well in the southeastern part of Buffalo County (fig. 14A) represent those that occur in the High Plains aquifer along the Platte River valley in the central part of Nebraska. There were 11 irrigation wells within a 1.0-mile radius of the observation well by 1950; since 1950, 19 more irrigation wells and 1 municipal well have been installed within a 1.0-mile radius of the observation well. Because the water table is shallow in this area, water-level fluctuations are markedly affected by the quantity and time of precipitation. The large volumes of ground water pumped for irrigation during droughts, such as the mid-1950's, accentuate water-level declines. The long-term trend in water levels (fig. 14A) generally is similar to the trend of the cumulative departure from the 58-year average precipitation (fig. 14B). Since the large decline in water levels in the mid-1950's, water-level changes in the High Plains aquifer have been somewhat cyclic. The stabilization of irrigated acreage in the early 1980's and a decrease in irrigated acreage in recent years (fig. 14C), along with greater than normal precipitation, has resulted in the latest rise in water levels.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Nebraska Agricultural Statistic Service for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

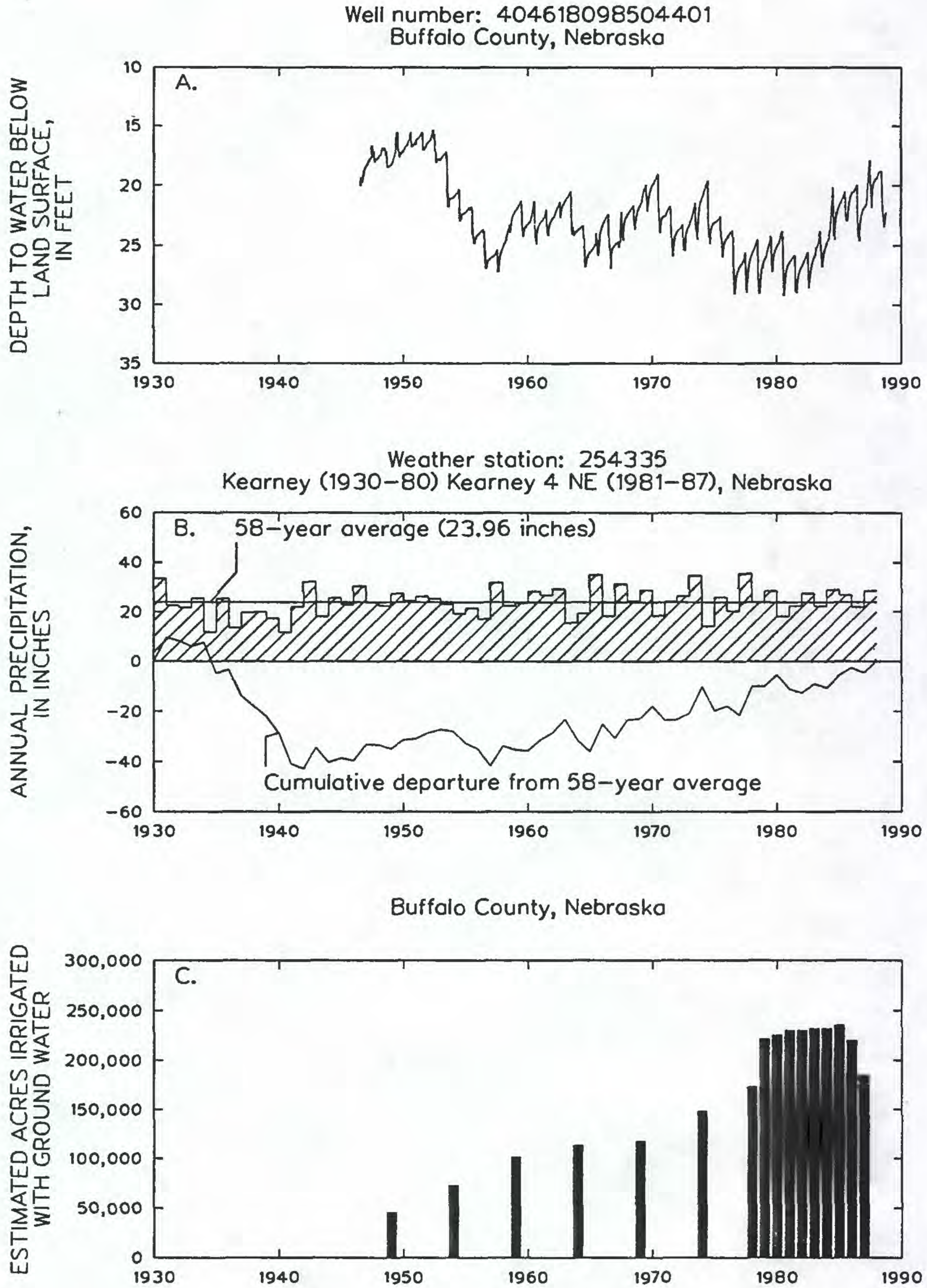



Figure 14.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Buffalo County, western Nebraska.

## COLORADO--WATER-LEVEL CHANGES AND PRECIPITATION, 1987

*Water-Levels Are Only Slightly Affected by Increased Precipitation in the High Plains of Colorado during 1987.*

The High Plains aquifer underlies about 14,900 square miles in eastern Colorado. The estimated pumpage from the High Plains aquifer in Colorado during 1985 was 788 million gallons per day (883,000 acre feet); about 99 percent of this water was used for irrigation of crops (Wayne Solley, U.S. Geological Survey, written commun., 1988).

A monitoring well network has been used to provide water-level data in the High Plains of eastern Colorado since 1970. Until 1984, the water levels were measured by personnel of the U.S. Geological Survey as part of cooperative programs with the Office of the Colorado State Engineer, the Colorado Water Conservation Board, Colorado State University, and local ground-water management districts. More recently, data have been collected by employees of the State and entered into the U.S. Geological Survey's ground-water site inventory (GWSI) computer data base through cooperative programs with the Colorado Geological Survey and the Office of the State Engineer. The network currently (1988) includes annual measurements from about 650 wells in the area north of the Arkansas River or latitude 38° N in Colorado and some measurements made on an irregular schedule south of latitude 38° N in Colorado. Much of the High Plains aquifer in the southern Colorado area has been dewatered and many of the wells have been deepened and are now completed in several aquifers. Recently, five continuous water-level recorders were added to the network to define seasonal and annual water-level fluctuations. This information will aid in relating annual measurements to seasonal water-level changes.

After declining in many areas until about 1980, water-level changes were mixed from 1980 through the nonirrigation season of 1987-88. The area-weighted water-level change in 546 wells that were measured in the nonirrigation seasons of 1986-87 and 1987-88 was a rise of 0.11 foot (fig. 15A). Water levels in about one-half of the wells declined; the greatest decline was about 8 feet. Water levels in the remaining wells rose; the greatest rise was about 6 feet. Only about 1 percent of the wells had water-level changes of more than 3 feet, and fewer than 4 percent of the wells had water-level changes of more than 2 feet. Few regional patterns of water-level change are discernible, with most areas having both minor rises and declines.

Precipitation in the Colorado High Plains was slightly greater than normal in 1987 (fig. 15B). The area-weighted departure was 2.57 inches greater than normal. This above-normal precipitation may have resulted in increased recharge and decreased irrigation pumpage, thereby modifying the long-term trend of declining water levels. Another contributing factor in the current cessation of large declines may be the enlistment of lands in the Conservation Reserve Program. About 750,000 acres of the approximately 1.8 million acres in Colorado that have been taken out of production due to this program through August 1988 are in counties partially overlying the High Plains aquifer. Even though most of that acreage was not irrigated, there may be some undetermined effect on recharge to and discharge from the aquifer.

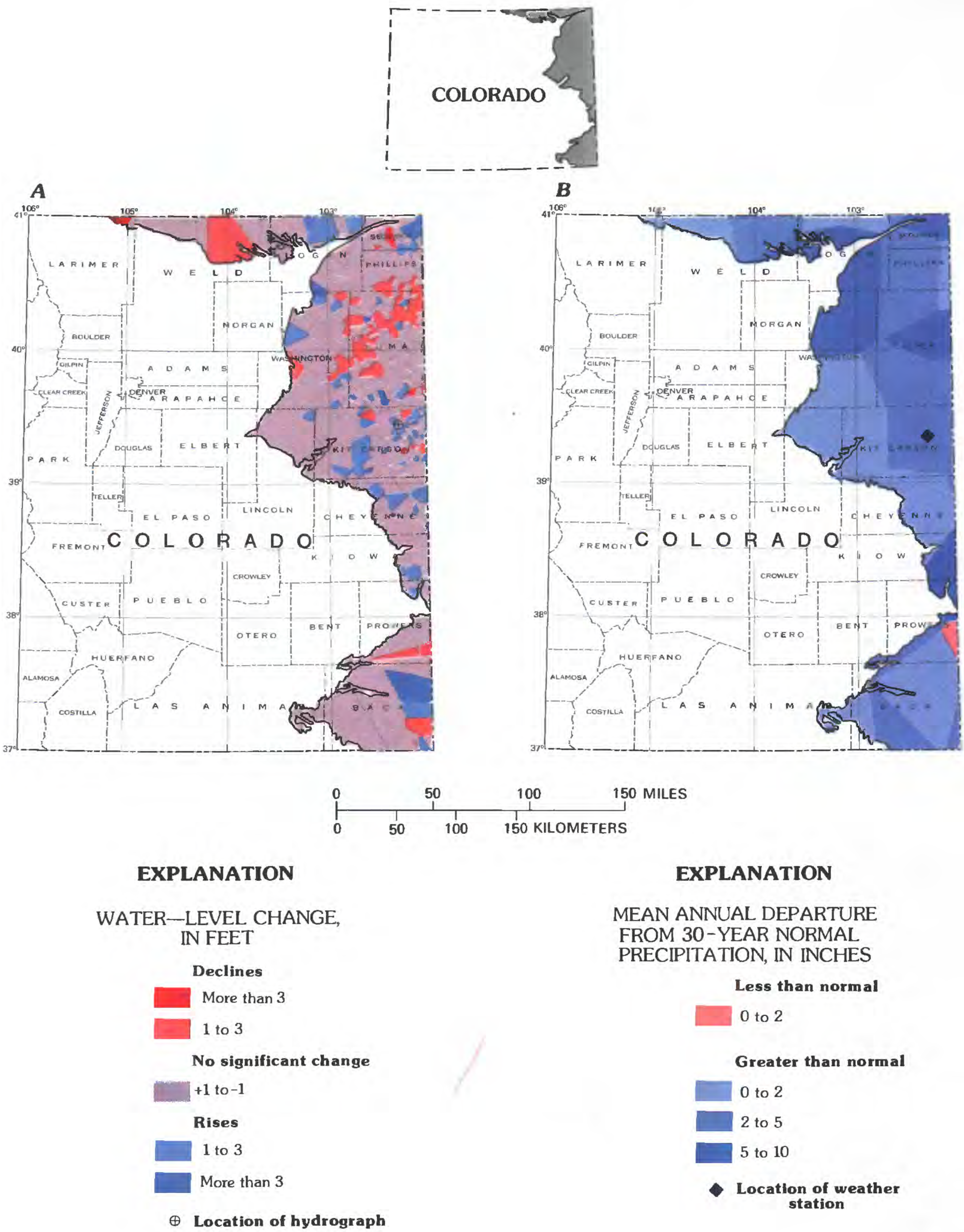



Figure 15.--A, Water-level changes in the High Plains aquifer in Colorado, nonirrigation season 1986-87 through nonirrigation season 1987-88; and B, Annual departure from 30-year normal precipitation in Colorado, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## COLORADO--REPRESENTATIVE EASTERN COLORADO CONDITIONS

*After Years of Continual Declines, Water Levels in the High Plains Aquifer of Kit Carson County Generally Stabilized after 1978.*

A long-term hydrograph for a well near Burlington, Colorado, is shown in figure 16A. The water-level changes in this well, which are typical of much of the Colorado High Plains, show large water-level declines through much of the 1960's and 1970's as irrigated acreages increased. Since about 1978, the irrigated acreage has fluctuated considerably, but is no longer increasing (fig. 16C). This stability of irrigated acreage and the generally greater than normal precipitation since 1977 (fig. 16B) is reflected in water levels that show decreased declines and some rises from 1978 through the mid-1980's. This general stability of water levels is typical of the trend in the Colorado High Plains. This follows the substantial declines that had been reported for about 50 percent of the High Plains aquifer in Colorado through 1980 (Borman, 1983).

The data used to prepare the hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Complete precipitation records were not available for 1962 and 1977; therefore, the average annual precipitation for the 56 complete years of record in the 1930-87 period was used for the missing years in the cummulative-departure computation. Estimates of acres irrigated with ground water in Kit Carson County were derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978. Data for 1980 through 1987 are from the Colorado Agricultural Statistics Service, which reports total irrigated acreage for some specific crops. These data were adjusted to include all crops irrigated by ground water.

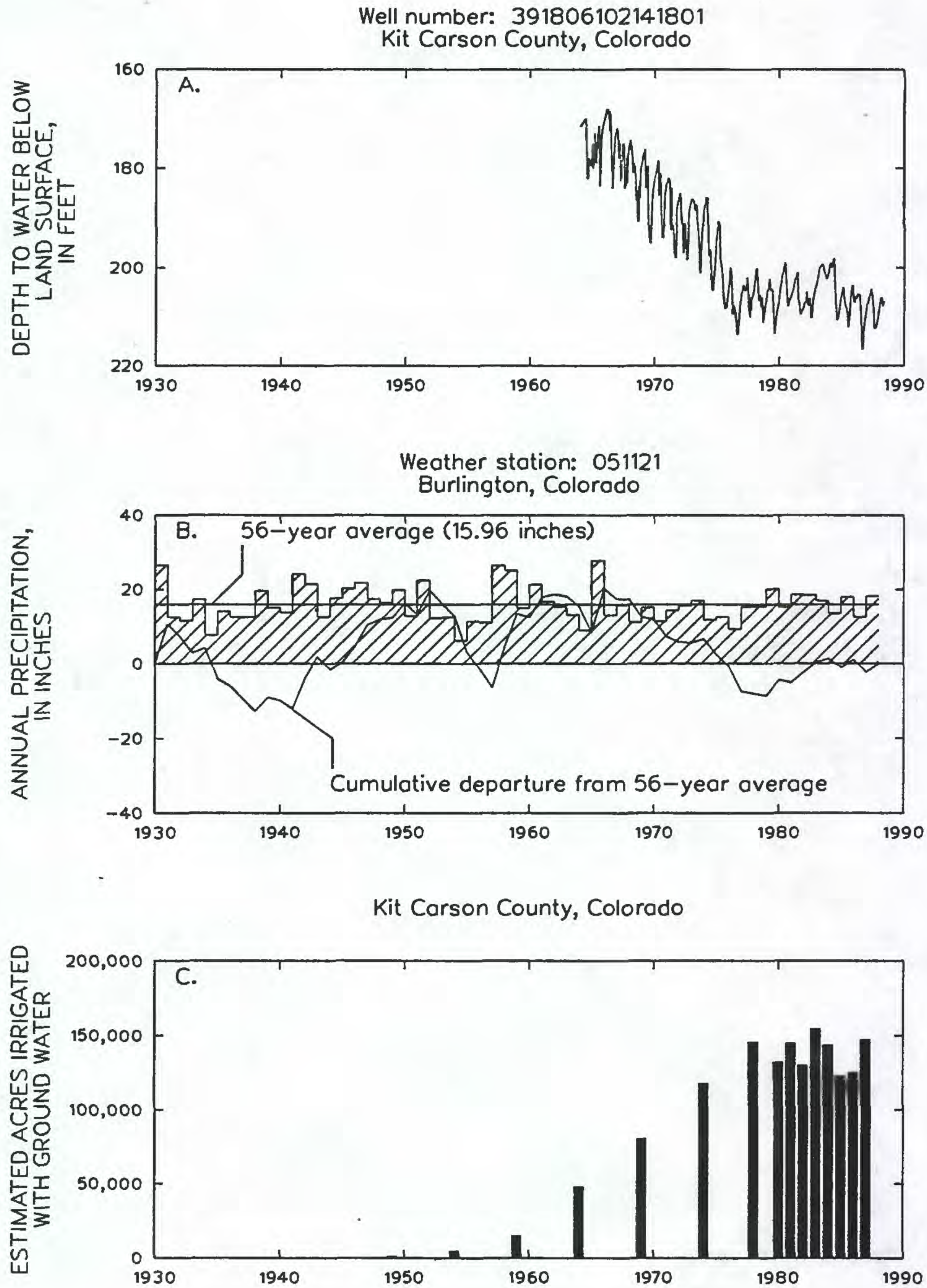



Figure 16.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Kit Carson County, eastern Colorado.

## KANSAS--WATER-LEVEL CHANGES, 1987

*Water-Level Changes in the High Plains Aquifer in Kansas Differed Markedly during 1987.*

The High Plains aquifer in Kansas underlies about 30,500 square miles of western and south-central Kansas. The number of irrigation wells has increased from less than 500 during 1940 to more than 20,000 in 1987. Estimates of pumpage from the High Plains aquifer were about 3,940 million gallons per day (4,416,600 acre-feet) during 1985 (Wayne Solley, U.S. Geological Survey, written commun., 1988). About 98 percent of this water was used for agriculture.

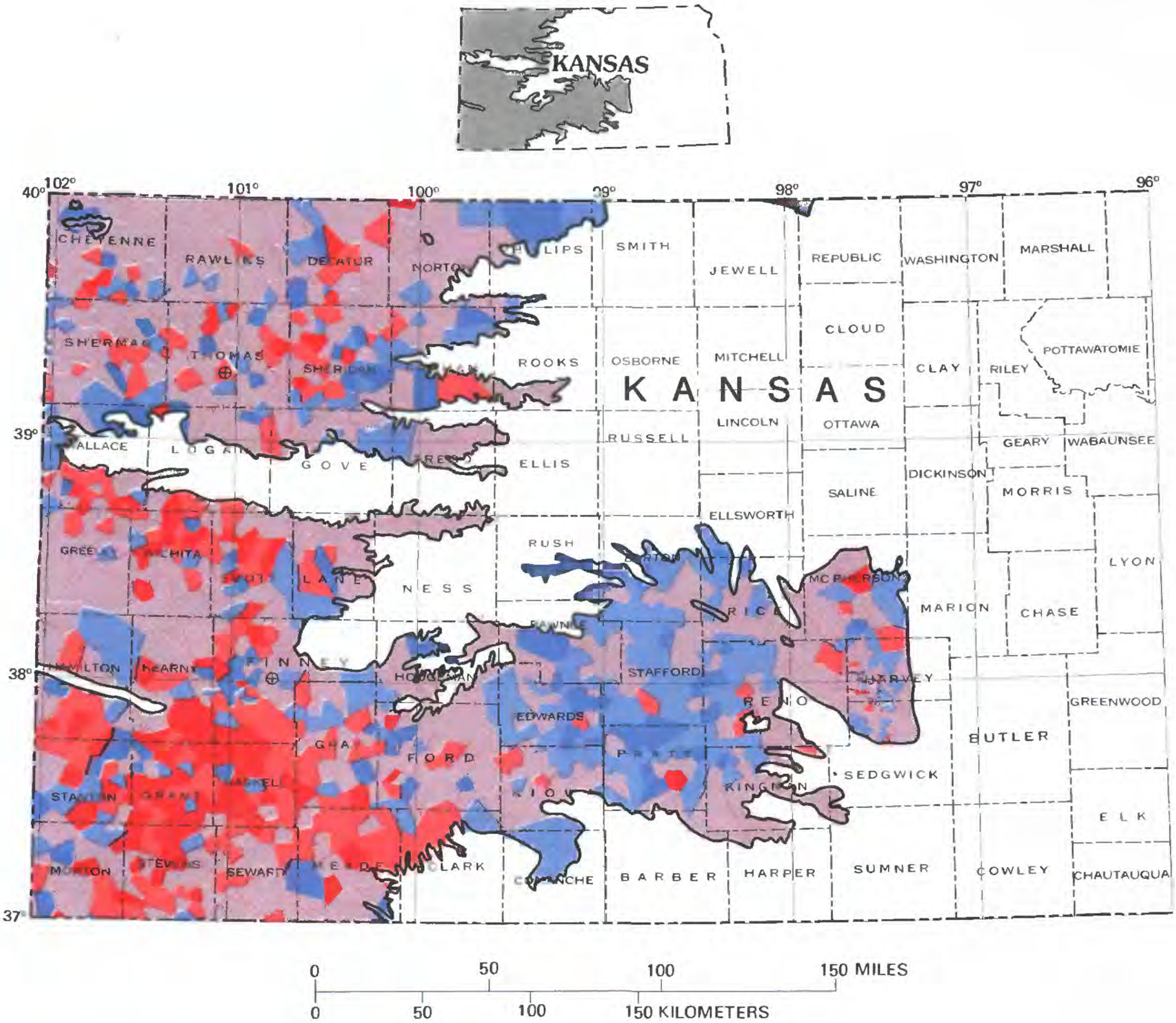
Water levels in the High Plains aquifer in Kansas are measured annually in a network of about 1,460 wells by personnel from the Kansas State Board of Agriculture and the U.S. Geological Survey. Support for this cooperative effort also is provided by the Kansas Geological Survey. Measurements are made in midwinter of each year when the effects of seasonal pumping for irrigation are minimal.

The water-level-change map (fig. 17) shows changes from nonirrigation season 1986-87 to nonirrigation season 1987-88 and is based on measurements from 1,389 wells. The area-weighted average water-level change during this period was a rise of 0.08 foot in the High Plains. In northwestern Kansas, the mean measured water level rose 0.1 foot (Pabst, 1988) although declines of more than 3 feet or rises of more than 3 feet occurred in isolated areas. In southwestern Kansas, the mean measured water level declined 0.7 foot (Pabst, 1988). The most substantial declines were in areas of intense irrigation-well development. In south-central Kansas, the mean measured water level rose 0.6 foot (Pabst, 1988); water levels rose more than 3 feet in several areas.

Through February 1988, about 1.5 million acres of irrigated and nonirrigated land have been taken out of production in the area underlain by the High Plains aquifer in Kansas as part of the Conservation Reserve Program. It is too early, however, to define the effects of this program on water levels in the aquifer. The total number of acres irrigated in the High Plains of Kansas decreased substantially from about 24 million acres in 1986 to about 20 million acres in 1987 (Kansas State Board of Agriculture, 1986, 1987).

As in other areas of the High Plains, improved irrigation practices, increasing energy costs, and a greater awareness of conservation practices have caused irrigators to decrease their ground-water withdrawals. Decreasing well yields and crop prices also may have caused some irrigators to cease or curtail their operations, resulting in slower rates or reversals of water-level declines in some areas underlain by the High Plains aquifer in Kansas.

The slower rates of water-level decline in the High Plains aquifer also may reflect better management of ground-water resources. Since the mid-1970's, five ground-water management districts have been organized in western and south-central Kansas. The boundaries of these districts conform primarily to the boundaries of the High Plains aquifer. Each district was required to develop a management program and could recommend regulations to the Chief Engineer (Kansas State Board of Agriculture, Division of Water Resources), who then could sanction policies and regulations related to the conservation and management of ground water. Examples of policies and regulations adopted within the districts include mandatory metering, well-spacing restrictions, water-use and water-wastage restrictions, and programs related to protecting the quality of ground water.




**EXPLANATION**

WATER—LEVEL CHANGE, IN FEET

**Declines**

More than 3

1 to 3

**No significant change**

+1 to −1

**Rises**

1 to 3

More than 3

⊕ **Location of hydrograph**

Figure 17.- Water-level changes in the High Plains aquifer in Kansas, nonirrigation season 1986-87 through nonirrigation season 1987-88.

## KANSAS--PRECIPITATION, 1987

*Precipitation Was Generally Greater than Average in the High Plains of Kansas during 1987.*

The High Plains aquifer in Kansas is replenished primarily by infiltration from precipitation. Hansen (in press) estimated that the average annual rate of potential natural recharge to the High Plains aquifer ranges from about 0.5 inch in extreme western Kansas where the average annual precipitation is about 16 inches to about 3 inches in the eastern part of south-central Kansas where the average annual precipitation is about 30 inches.

The slower rates of water-level decline and the water-level rises in the High Plains aquifer in Kansas in recent years are due, in part, to increased precipitation and, therefore, a decreased need for irrigation. The departure from normal precipitation in the High Plains of Kansas in 1987 is shown in figure 18. The area-weighted departure was 4.42 inches greater than normal. South-central Kansas, in particular, was substantially wetter than normal, with most of the area receiving 5 or more inches more than the normal precipitation of 26.28 inches. South-central Kansas also had the greatest average rise in water levels during 1987. Only five weather stations in western Kansas recorded less than normal precipitation during 1987. For 1981-87, the area-weighted departure from normal precipitation was 1.95 inches greater than normal for the entire High Plains in Kansas.

Precipitation during the first 6 months of 1988 in the High Plains of Kansas was about 1.75 inches less than normal. If this precipitation trend continues, ground-water pumpage might increase during the irrigation seasons of 1988 and 1989; consequently water-level declines might accelerate.

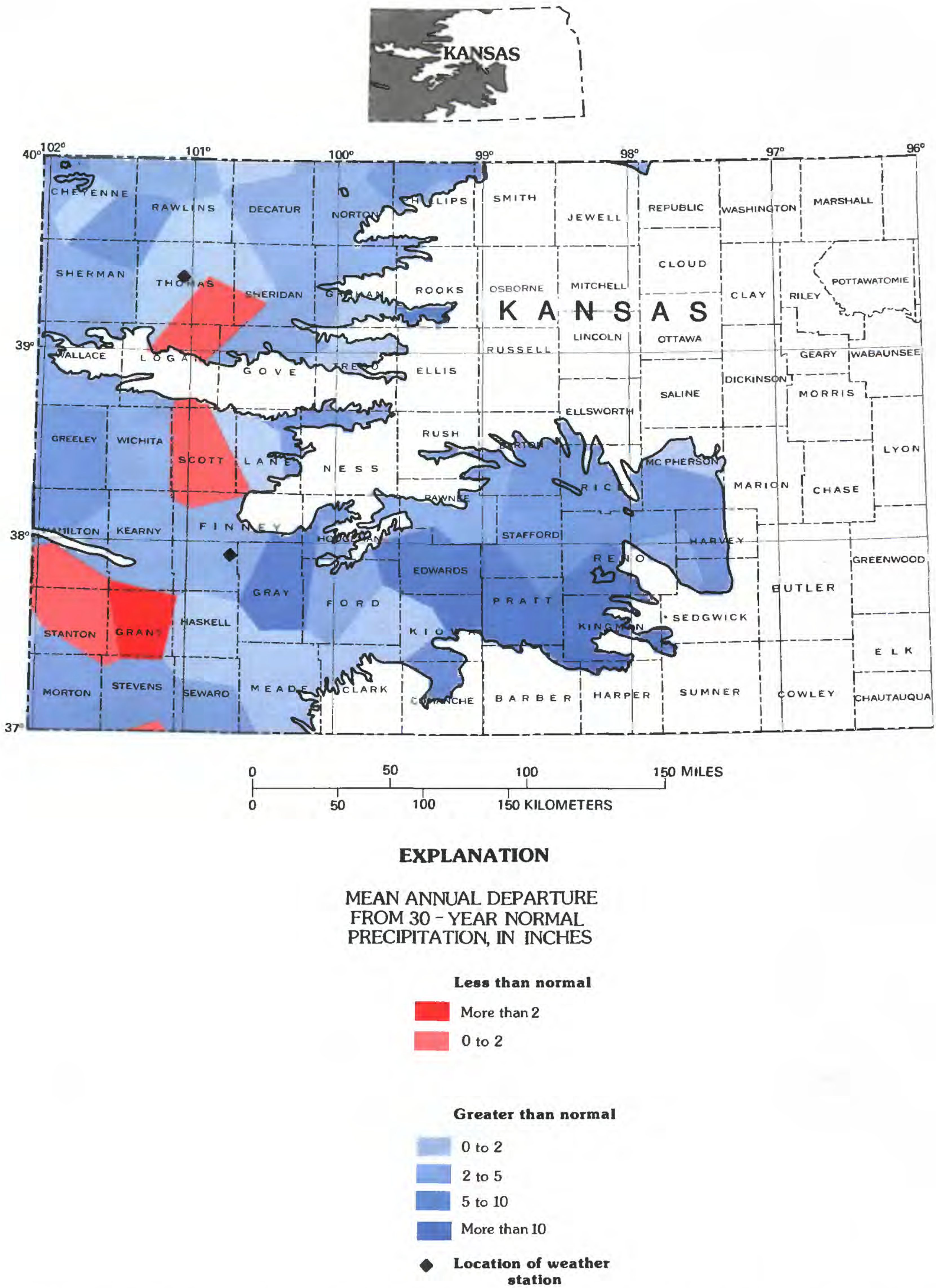



Figure 18.--Annual departure from 30-year normal precipitation in Kansas, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## KANSAS--REPRESENTATIVE NORTHWESTERN KANSAS CONDITIONS

*Ground Water Levels Continually Declined in Thomas County, but Slower after about 1981.*

As a result of the typical irrigation practices used in the High Plains of Kansas, which consist of pre-watering in the spring and irrigation in the summer, the water table commonly rises during the nonirrigation season, declines slightly in the spring, perhaps rises slightly during early summer, declines to its lowest annual level in late summer, and then again rises toward the previous high level during the next fall and winter. When pumpage exceeds any increase in recharge, the water table never fully rises to the height of the previous winter. The result is a continual removal of water from ground-water storage.

The hydrograph of the well in Thomas County (fig. 19A) shows a continual decline of water levels which corresponds to an increase in total acres irrigated following the drought of 1953-57 (fig. 19B and 19C). Many areas in the High Plains of Kansas experienced a rapid increase in the drilling of wells for irrigation during and after the 1953-57 drought. The decline in the water levels tended to stabilize from about 1981 to the mid-1980's in response to greater than normal precipitation and a decrease in the rate of increase in acres irrigated.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Kansas Department of Agriculture, Kansas Agricultural Statistics for 1980-87. The values of 200 acres in 1949 and 500 acres in 1954 are too small to show in figure 19C. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

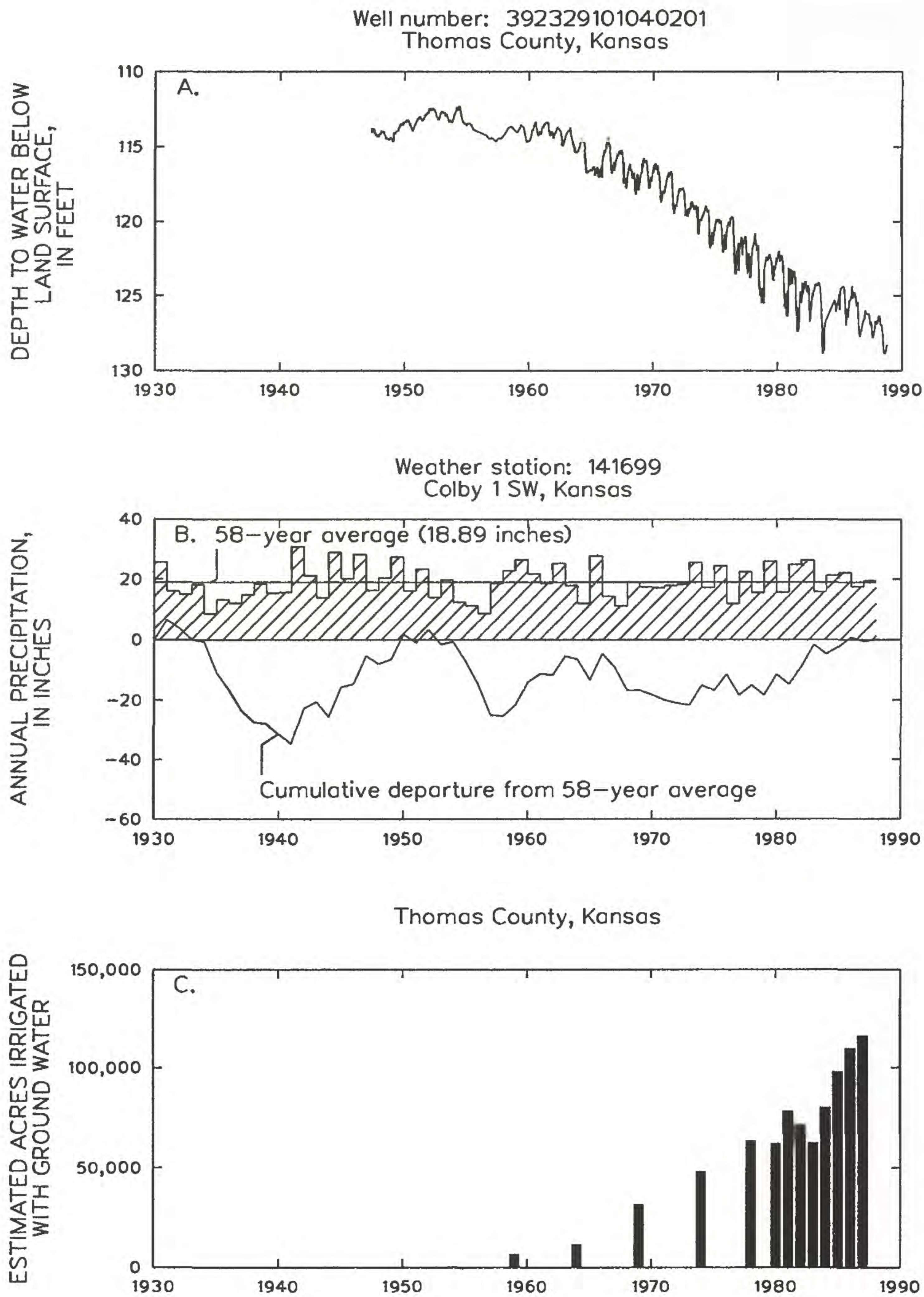



Figure 19.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Thomas County, northwestern Kansas.

## KANSAS--REPRESENTATIVE SOUTHWESTERN KANSAS CONDITIONS

*Despite Greater than Normal Precipitation and Stabilization in Acres Irrigated, Water Tables Continued to Decline, but Slower from 1983 through 1987.*

The hydrograph of the well in Finney County (fig. 20A) indicates an overall continual decline of water levels in response to the increase in total acres irrigated starting in 1949 (fig. 20C). The rapid increase in irrigation in Finney County started after World War II when large-capacity turbine pumps were introduced. Increases in natural recharge to and decreases in natural discharge from the aquifer in this area are greatly exceeded by the ground-water pumpage for irrigation; consequently, there is a continuing removal of ground water from storage. The lessening of the rate of water-level decline from 1983 through 1987 could be the result of the increase in precipitation (fig. 20B) and the decrease in the total acres irrigated from 1983 through 1987 (fig. 20C).

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Kansas Department of Agriculture, Kansas Agricultural Statistics for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

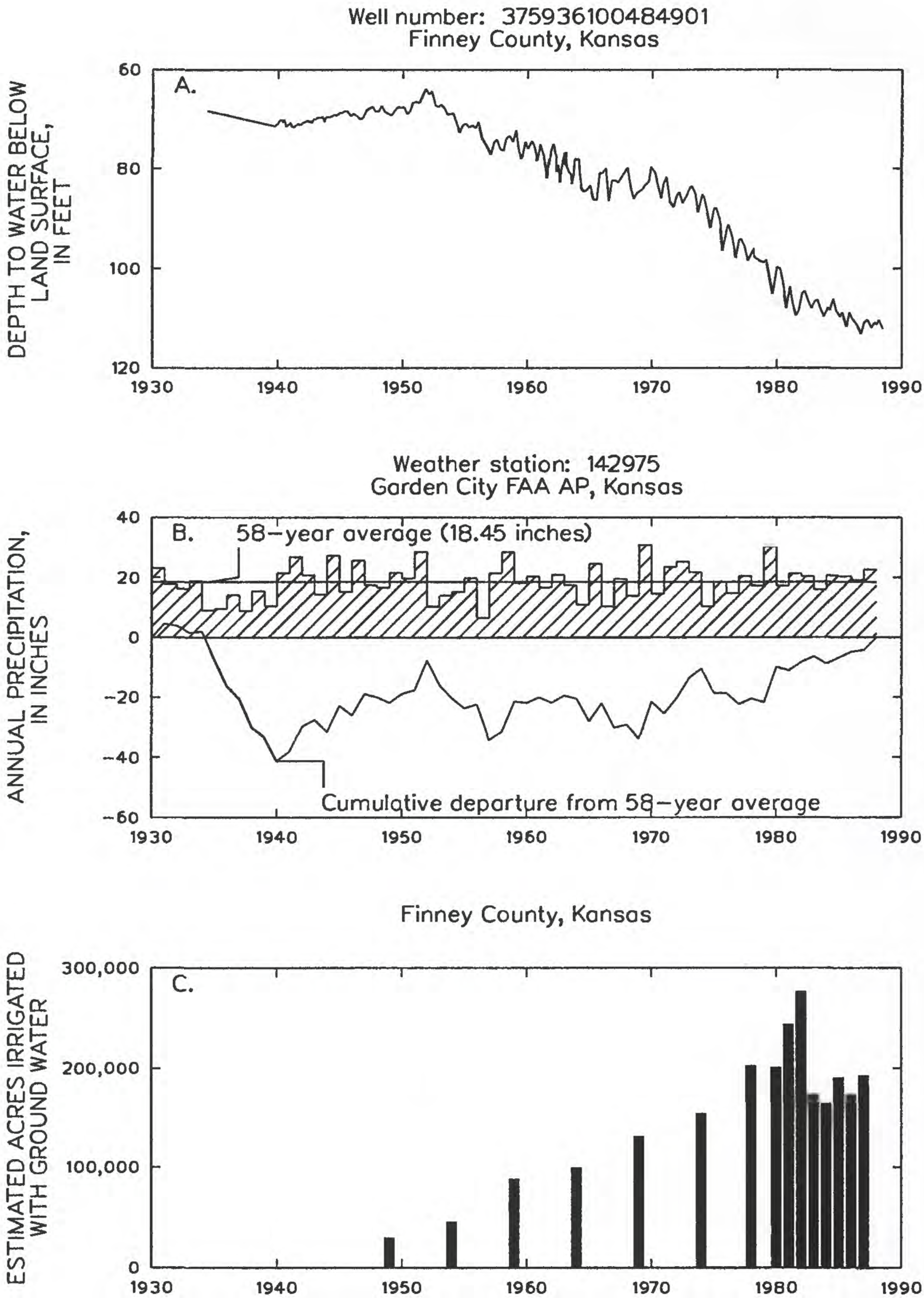



Figure 20.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Finney County, southwestern Kansas.

## NEW MEXICO--WATER-LEVEL CHANGES AND PRECIPITATION, 1987

*Water-Level Changes and Precipitation Were Variable during 1987.*

The High Plains aquifer underlies about 9,450 square miles in eastern New Mexico. The estimated pumpage from the High Plains aquifer during 1985 was 583 million gallons per day (653,000 acre-feet) (Roy Cruz, U.S. Geological Survey, oral commun., 1989). Irrigation for agriculture was the dominant use of this ground water.

Ground-water data in New Mexico are collected by personnel of the U.S. Geological Survey and the Office of the New Mexico State Engineer as part of a continuing Federal-State cooperative observation-well program. Mass water-level measurements (water-level measurements made in a large number of wells at about the same time) are made at 1-year and 5-year intervals to monitor water-level changes in the High Plains aquifer.

Only a few wells are measured each year in the northern High Plains area in New Mexico. Therefore, there are few data to use in preparing annual-change maps. In the southern High Plains area of New Mexico, where more wells are measured annually, annual changes in water levels are calculated and contoured by the U.S. Geological Survey, and maps for Curry, Roosevelt, and Lea Counties are published by the New Mexico State Engineer (Hudson, annual reports). These maps are used to determine the ground-water depletion allowed by the Internal Revenue Service.

Five of the six continuous water-level recorders used in the High Plains monitoring network were added to the observation-well program in 1988 to aid in defining seasonal fluctuations in water levels.

A net decline in water levels in irrigated areas of the High Plains aquifer has occurred since ground-water development began. Much of the decline was before 1980. The declines generally increase from west to east with the greatest declines along the New Mexico-Texas border.

From 1981 through 1987, water-levels rose in some areas and the rate of decline in other areas was less rapid after 1980. The water-level rises and less rapid rates of decline can be attributed to: (1) A decrease in irrigation requirements because of greater than normal precipitation; (2) a decrease in irrigated acreage, because of unfavorable agricultural economics and government incentives to reduce cultivated acreage; (3) a change in water-management practices; and (4) in some areas, to recharge by infiltration of streamflow and precipitation. Some recharge to the High Plains aquifer in northern New Mexico (central and southeastern Union, eastern Harding, and northern Quay Counties) may have been along losing streams because of increased precipitation and increased surface-water runoff to the streams. Precipitation in eastern New Mexico was greater than normal from 1981-87. The mean departure from normal precipitation, weighted by area, was 3.75 inches greater than normal.

In the northern New Mexico area of the High Plains aquifer, water-level data from wells measured in 1987 and 1988 indicated little change or moderate declines (fig. 21A). In central and southeastern Union, eastern Harding, and northern Quay counties, precipitation generally was less than normal during 1987 (fig. 21B).

Between the nonirrigation season of 1986-87 and the nonirrigation season of 1987-88, water levels rose in the High Plains aquifer in some of the areas with less irrigation development in parts of southern Quay, Curry, Roosevelt, and northern Lea Counties (fig. 21A). Some of the areas of decline indicated in the southern part of the New Mexico High Plains, primarily in Roosevelt and northern Lea Counties, are probably more localized than shown in figure 21A because the areal change is assigned using the Thiessen-polygon method, and the change in individual wells may not represent regional conditions. Precipitation was generally greater than normal in this southern area during 1987 (fig. 21B).

For the entire High Plains aquifer in New Mexico, the area-weighted water-level change from 1987 to 1988 was a rise of 0.15 foot. The area-weighted precipitation departure from normal during 1987 was 3.29 inches greater than normal. Precipitation continued to be greater than normal in most areas through the summer of 1988.

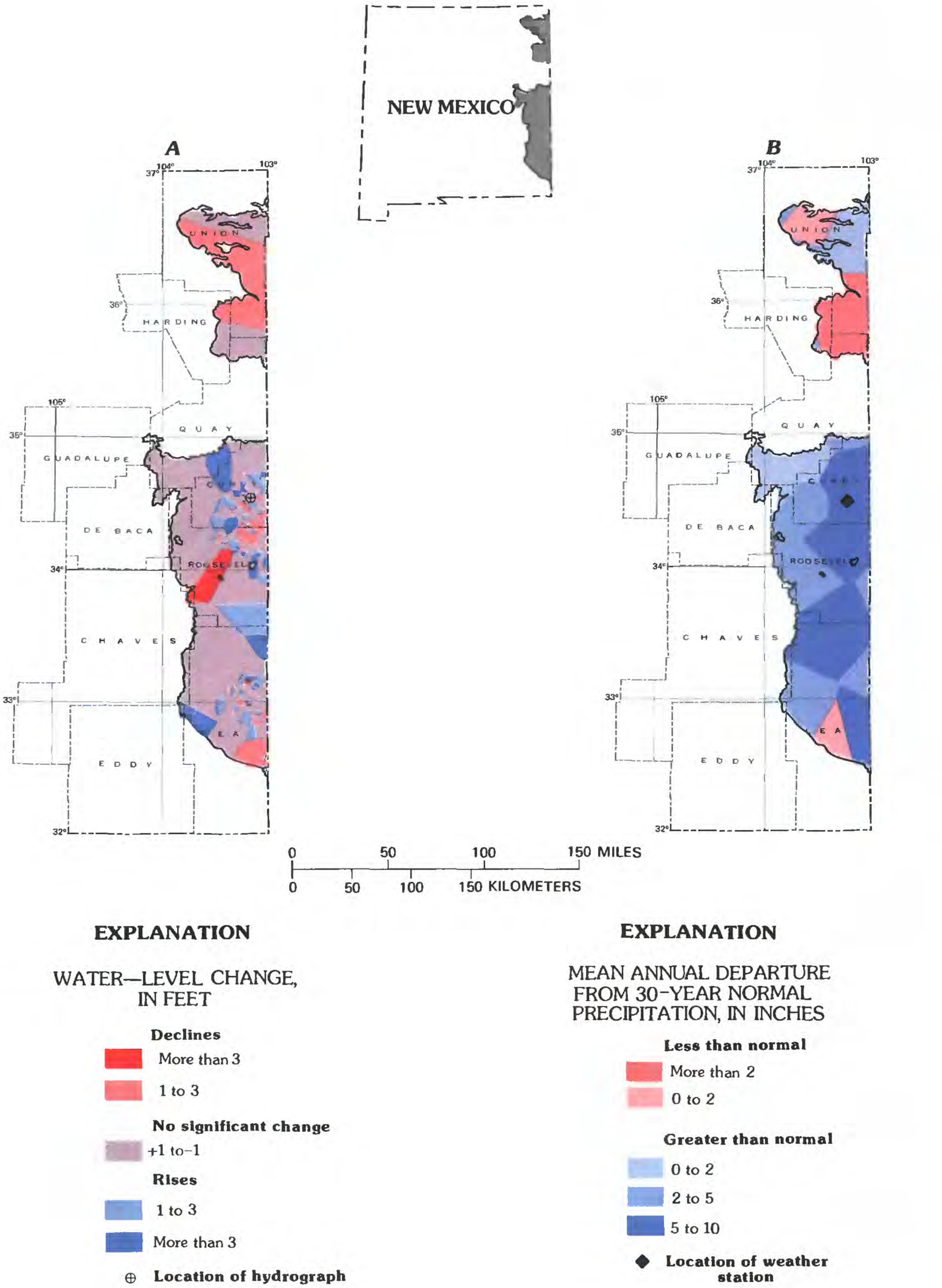



Figure 21.--A, Water-level changes in the High Plains aquifer in New Mexico, nonirrigation season 1986-87 through nonirrigation season 1987-88; and B, Annual departure from 30-year normal precipitation in New Mexico, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## NEW MEXICO--REPRESENTATIVE CONDITIONS IN EASTERN NEW MEXICO

*Rate of Water-Level Declines in the High Plains Aquifer Has Decreased in Curry County.*

The hydrograph (fig. 22A) showing the changes in water levels with time in an observation well in Curry County represents many water-level changes in the High Plains of New Mexico. Water levels in areas of irrigation development generally declined at an increasing rate until the late 1970's as irrigated acreage and ground-water withdrawals increased. The rate of decline has decreased during the 1980's due to the direct and indirect effects of greater than normal precipitation (fig. 22B) and a decrease in the acreage irrigated (fig. 22C).

Total declines from predevelopment through the nonirrigation season of 1987-88 are about 15 feet for wells near the observation well in Curry County (fig. 22A). Further to the east near the New Mexico-Texas border, however, water levels have declined about 80 feet. To the west, where irrigation is less developed, declines are less than 15 feet, and, in recent years, some water-level rises have been measured.

The water-level data are from the records of the U.S. Geological Survey. The records of annual precipitation are from the U.S. Department of Commerce, National Climatic Data Center. The estimated acres irrigated are from data for all crops irrigated by ground water and are obtained from the U.S. Department of Commerce, Census of Agriculture, for the 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the New Mexico State University Agricultural Experiment Station for 1980-87.

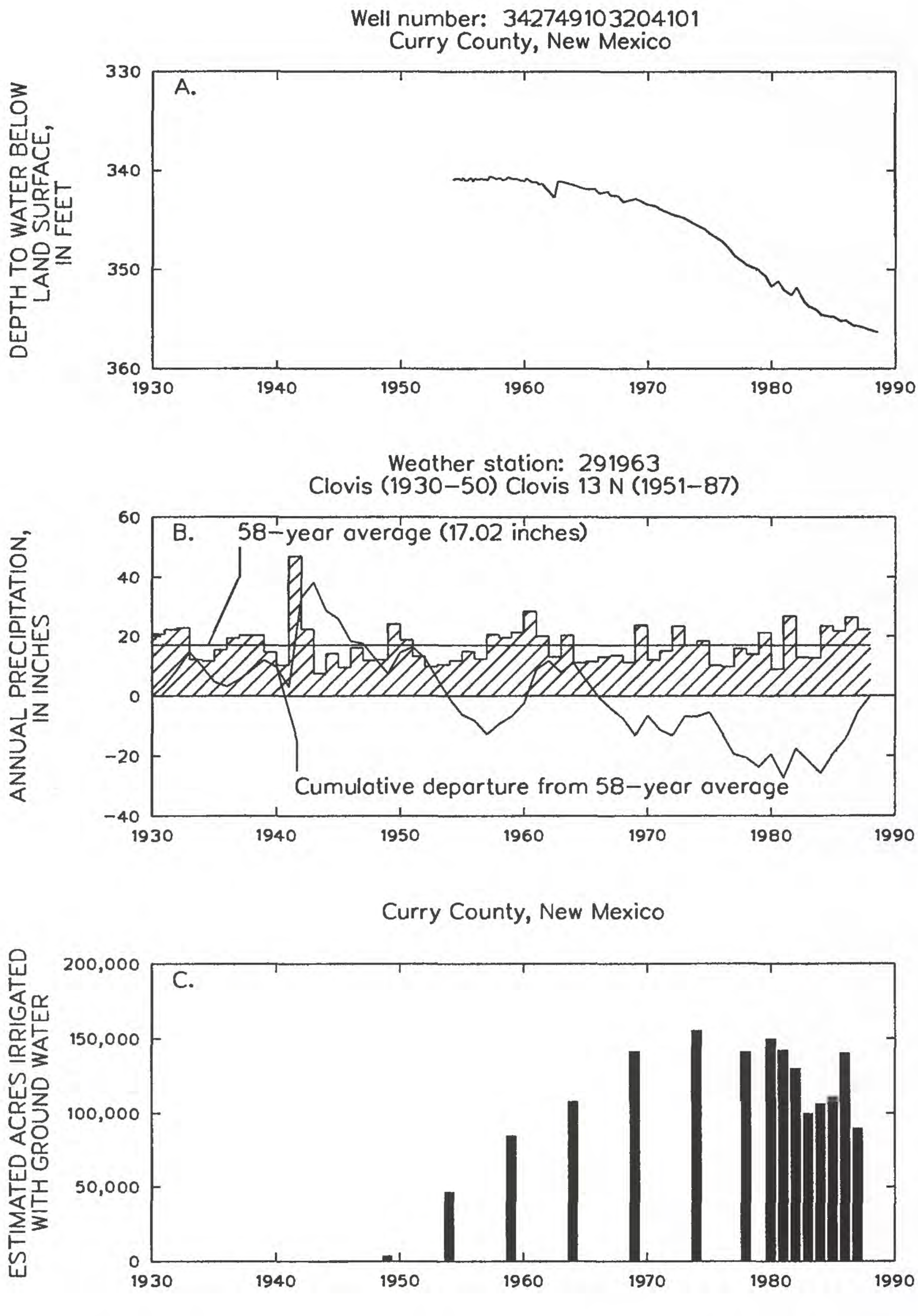



Figure 22.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Curry County, eastern New Mexico.

## OKLAHOMA--WATER-LEVEL CHANGES AND PRECIPITATION, 1987

*Water-Level Rises Were Common in the High Plains of Oklahoma in 1987 because of Increased Precipitation.*

The High Plains aquifer underlies about 7,350 square miles of western Oklahoma and the Panhandle. Water pumped from the High Plains aquifer in Oklahoma during 1985 is estimated to have been about 248 million gallons per day (278,000 acre-feet). Ninety-seven percent of this water was used for irrigation (Wayne Solley, U.S. Geological Survey, written commun., 1988).

Annual water-level measurements in the High Plains of Oklahoma are made cooperatively by the U.S. Geological Survey and the Oklahoma Water Resources Board. Each year about 400 wells are measured in January when water levels are assumed to have reached maximum recovery from the previous pumping season.

Water levels in the High Plains aquifer generally rose from January 1980 through January 1988, however, much of the rise was during 1987. Data from 350 wells measured in January 1980 and January 1988 are available. The water-level change, weighted by area, was a rise of 1.88 feet. From 1981 through 1987, the mean area-weighted departure from normal precipitation was 3.38 inches greater than normal.

The water-level change, weighted by area, for the 417 wells measured in January 1987 and in January 1988 was a rise of 0.80 foot. Water levels in nearly all wells measured in western Oklahoma rose, whereas water-level changes in the Panhandle were mixed (fig. 23A). Precipitation during 1987 was greater than normal throughout most of the High Plains in Oklahoma, particularly in western Oklahoma (fig. 23B). The area-weighted departure from normal precipitation for 1987 was 7.45 inches greater than normal. This greater than normal precipitation is reflected in water-level rises from January 1987 to January 1988 in large parts of the aquifer in Oklahoma.

During the first 9 months of 1988, moisture availability was greater than normal in the far western part of the State according to the Drought Severity Index of October 1, 1988 (National Oceanic and Atmospheric Administration and U.S. Department of Agriculture Joint Agricultural Weather Facility). This is in contrast to the conditions of deficient moisture for central and eastern Oklahoma. The effect of the greater than normal moisture for the first 9 months of 1988 on pumpage and water levels cannot be defined until after the January 1989 water-level measurements are compiled.

In general, irrigated acreage has decreased since the late 1970's. Increased fuel costs have caused irrigators to make more efficient use of fuel, particularly natural gas, with a consequent decrease in water pumped from the aquifer. In addition, some marginal crop lands were not irrigated and greater acreages have not been planted as part of the Conservation Reserve Program.

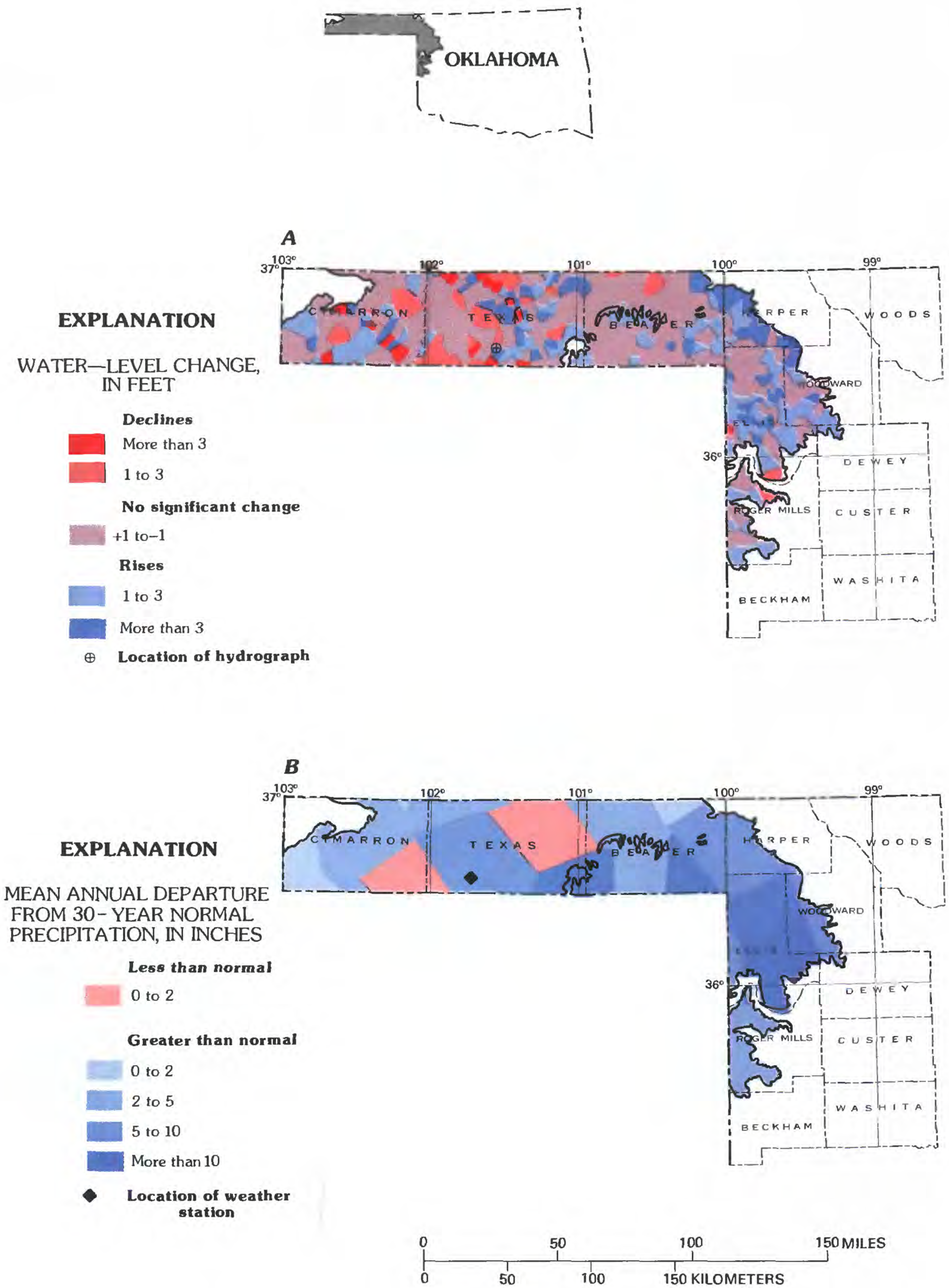



Figure 23.--A, Water-level changes in the High Plains aquifer in Oklahoma, nonirrigation season 1986-87 through nonirrigation season 1987-88; and B, Annual departure from 30-year normal precipitation in Oklahoma, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## OKLAHOMA--CONDITIONS IN THE PANHANDLE WHERE WATER LEVELS ARE DECLINING

*Variations in Precipitation Do Not Greatly Affect Water Levels in Texas County.*

Water-level changes were mixed in the High Plains aquifer in the Panhandle of Oklahoma during 1987. Water levels in some wells with a history of declines continued to decline, whereas in others, water levels rose during 1987. The hydrograph of an observation well in Texas County shows a continual water-level decline since about 1965 (fig. 24A), reflecting pumpage for irrigation from the High Plains aquifer. Variations in precipitation (fig. 24B) do not appear to greatly affect water levels in this observation well. The slope of the hydrograph steepens, beginning in the early 1970's, reflecting the increase in acres irrigated through 1982 (fig. 24C). This observation well is located on the southwestern edge of a large cone of depression south of Guymon in Texas County. Water levels in the center of the cone declined about 100 feet during 1940-80. A marked decrease in acres irrigated since 1982 and slight increases in precipitation may have caused a slight decrease in the rate of water-level decline during the last several years.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Oklahoma Department of Agriculture, Oklahoma Crop and Livestock Reporting Service for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

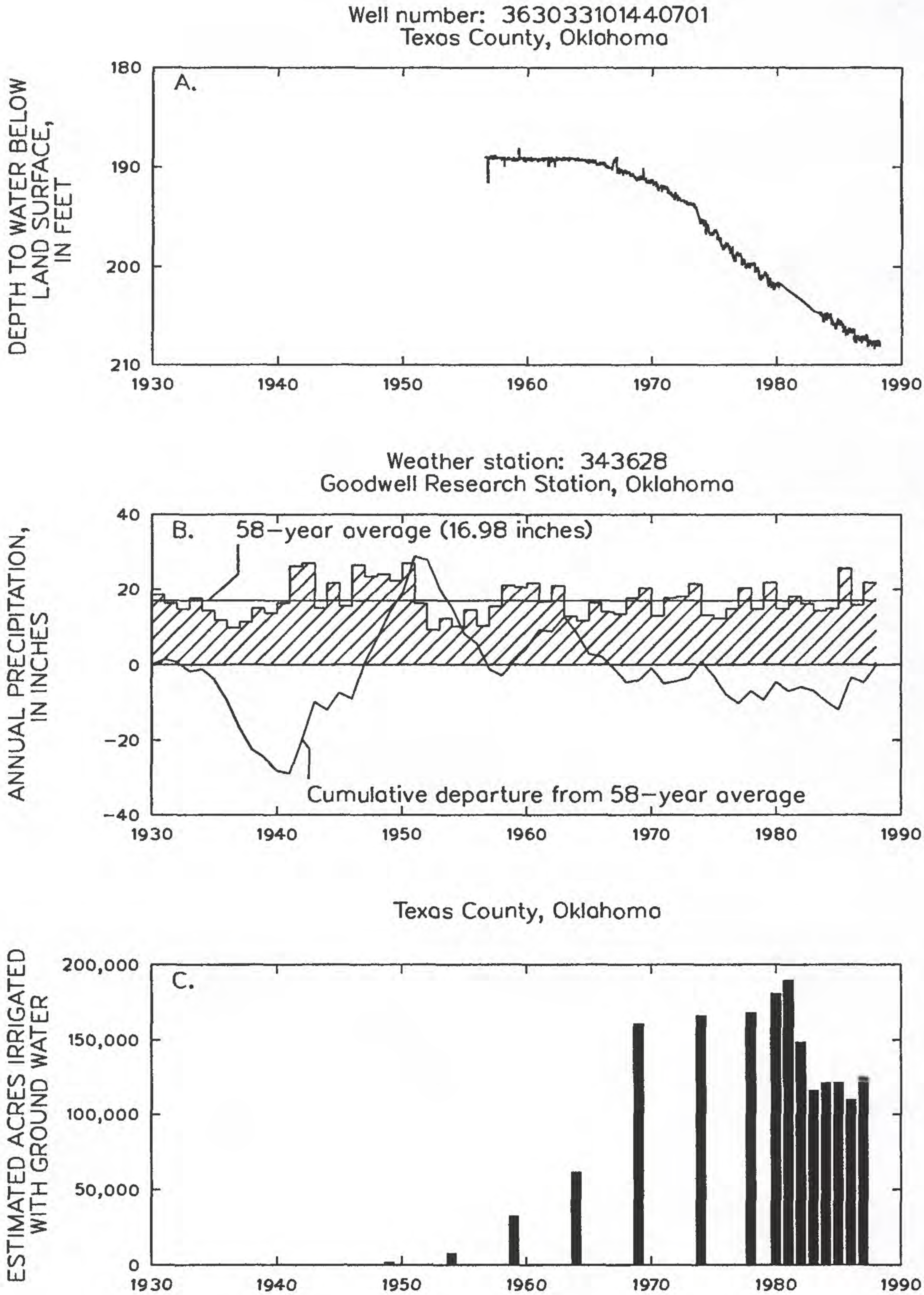



Figure 24.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Texas County, Oklahoma Panhandle.

## TEXAS--WATER-LEVEL CHANGES, 1987

*Long-Term Trend of Water-Level Declines Abated in Much of the High Plains of Texas during 1987.*

The High Plains aquifer underlies about 35,450 square miles of northwestern Texas including much of the Panhandle. During 1985, total estimated ground-water pumpage was 4,210 million gallons per day (4,719,300 acre-feet). Pumpage for irrigation or for other agricultural uses has dominated the ground-water use in the High Plains in Texas. An estimated 96 percent of ground water used has been for agriculture (Wayne Solley, U.S. Geological Survey, written commun., 1988).

The change in the ground-water levels between the nonirrigation seasons of 1986-87 and 1987-88 in the High Plains of Texas (fig. 25) was determined by computing the difference in yearly water-level measurements from 434 wells. The area-weighted change in water levels was a rise of 0.83 foot. This is a reversal of the average decline of about 0.7 foot per year during the 10 years from 1978 through 1987.

As expected, the changes in the 1987 water levels were not uniform throughout the High Plains. In the central area, where water-level changes were more uniform between a 3-foot rise and a 1-foot decline, water-level changes in individual wells most readily corresponded to the regional changes. In the northern and southern areas, water-level changes ranged between rises of more than 3 feet and declines of more than 3 feet in fairly close proximity. The most consistent rises in water levels have occurred in the southeastern part of the southern area where rises of more than 3 feet were common. Rises in water levels also have been measured in this area for the previous few years. The most consistent declines occurred in the central part of the northern area and were more than 10 feet in some wells.

Changes in water levels generally have reversed from a long-term and continual decline to a slight rise in 1985 and 1986, and to a more substantial rise in 1987. This change in the trend of water levels has been caused by a combination of changes in the pumping and recharge rates. Water-level rises measured in some wells probably are associated with recoveries of local cones of depression caused by decreased pumpage.

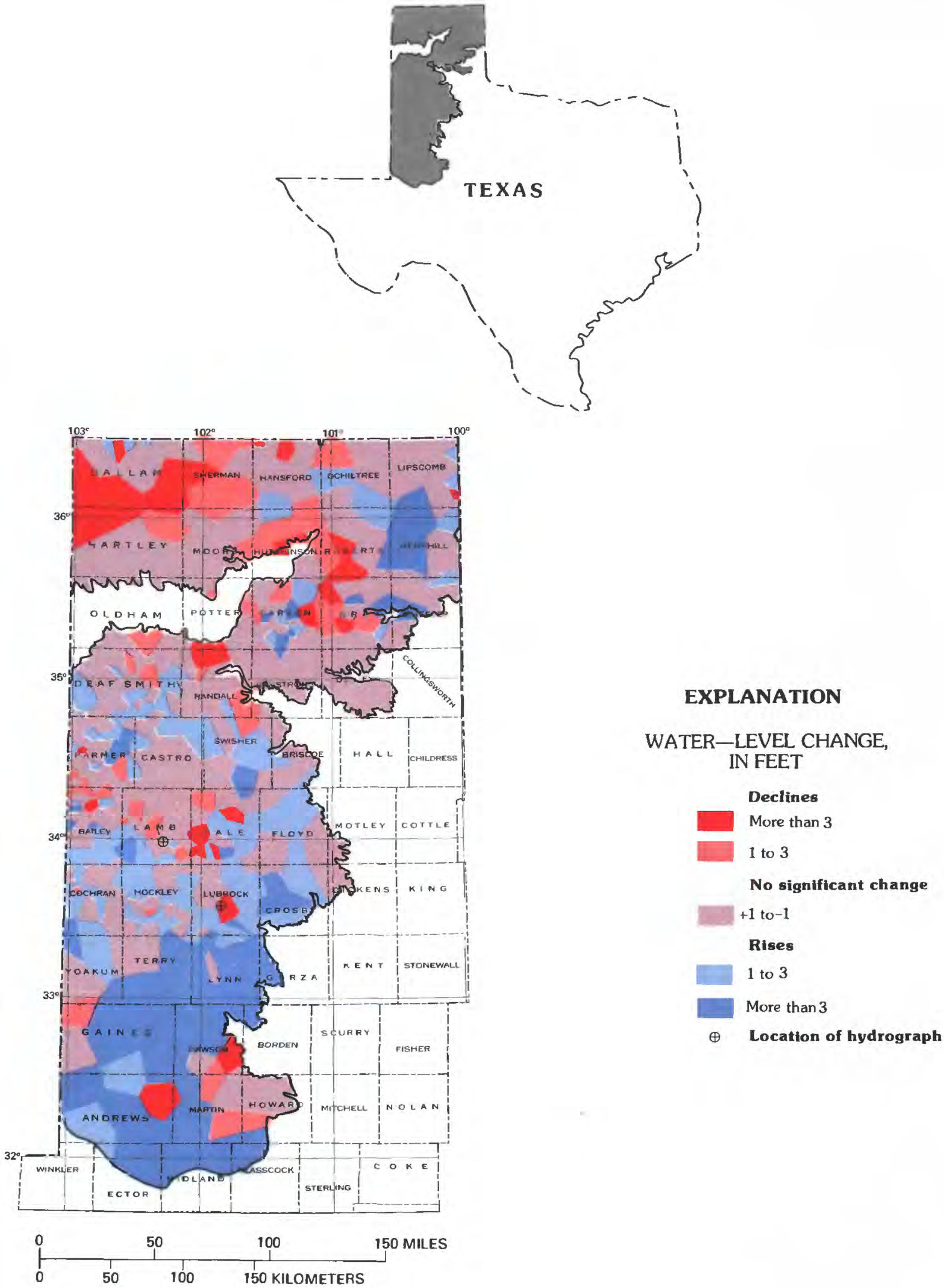



Figure 25.--Water-level changes in the High Plains aquifer in Texas, nonirrigation season 1986-87 through nonirrigation season 1987-88.

## TEXAS--PRECIPITATION, 1987

*During 1987, Precipitation Was Substantially Greater than Normal in Most of the High Plains of Texas.*

During 1987, precipitation in the High Plains of Texas was greater than the 30-year normal except for a few areas, primarily in the northwestern corner of the Panhandle (fig. 26). The greatest departures from normal were most common in the eastern part of the Panhandle and in parts of the central and southern areas where precipitation at many stations was from 5.0 to more than 10.0 inches greater than normal.

Ground-water recharge is comprised mostly of percolation of precipitation and irrigation water. Previous studies have determined that long-term average recharge rates from precipitation in the High Plains of Texas commonly are about 0.1 inch per year and locally are as much as 1.0 inch per year. This is equivalent to a change in the saturated thickness in the aquifer of about 0.1 to 1.3 feet. However, recharge from precipitation during the last few years may be substantially greater than the long-term average because of a combination of factors that include: unusually greater than normal precipitation, a distribution of precipitation during the year favoring recharge, flooding of areas beyond the normal boundaries of playa lakes where infiltration rates are greater, and local construction of pits and sumps in most of the playa lakes.

The deep percolation of applied irrigation water also can be a major source of recharge. Studies have determined that recharge consisting of applied irrigation water can range from 1 to 50 percent of the withdrawn water (Mackey, 1987). When the source of the irrigation water is ground water, the net withdrawals from the aquifer equal the volume pumped less the volume returned to the aquifer as recharge.

Because the unsaturated zone between the land surface and the water table may be several hundred feet thick and contain some beds that are almost impermeable, recharge percolating downward from the land surface may not reach the water table for many months or much longer. The proportion of water available at the land surface that reaches the water table differs for many reasons, but the soil conditions and the volume of irrigation water applied are two significant factors.

A cause-and-effect relation between changes in water levels and precipitation cannot be established without simultaneously considering the withdrawals of ground water, because the greatest effect on water-level changes in the High Plains aquifer in Texas is the withdrawal of ground water. The pattern and volume of ground-water withdrawals are complex and have changed substantially during the last decade. One of the factors has been the increase in irrigation efficiency by widespread improvement in water transfer and application practices. Thus, the volume of water that needs to be pumped for the same crop production is substantially less. Another factor is that crop production also has been substantially decreased because of: (1) Government programs that offer incentives to decrease acreage, such as the Conservation Reserve Program and the Payment In Kind Program; and (2) decreased prices for crops, and increased costs of energy, equipment, and loans. Another significant factor has been the greater than average precipitation that has greatly decreased the need for irrigation water. In fact, some acreage could not be planted every year because of flooding around playa lakes and in other low-lying areas.

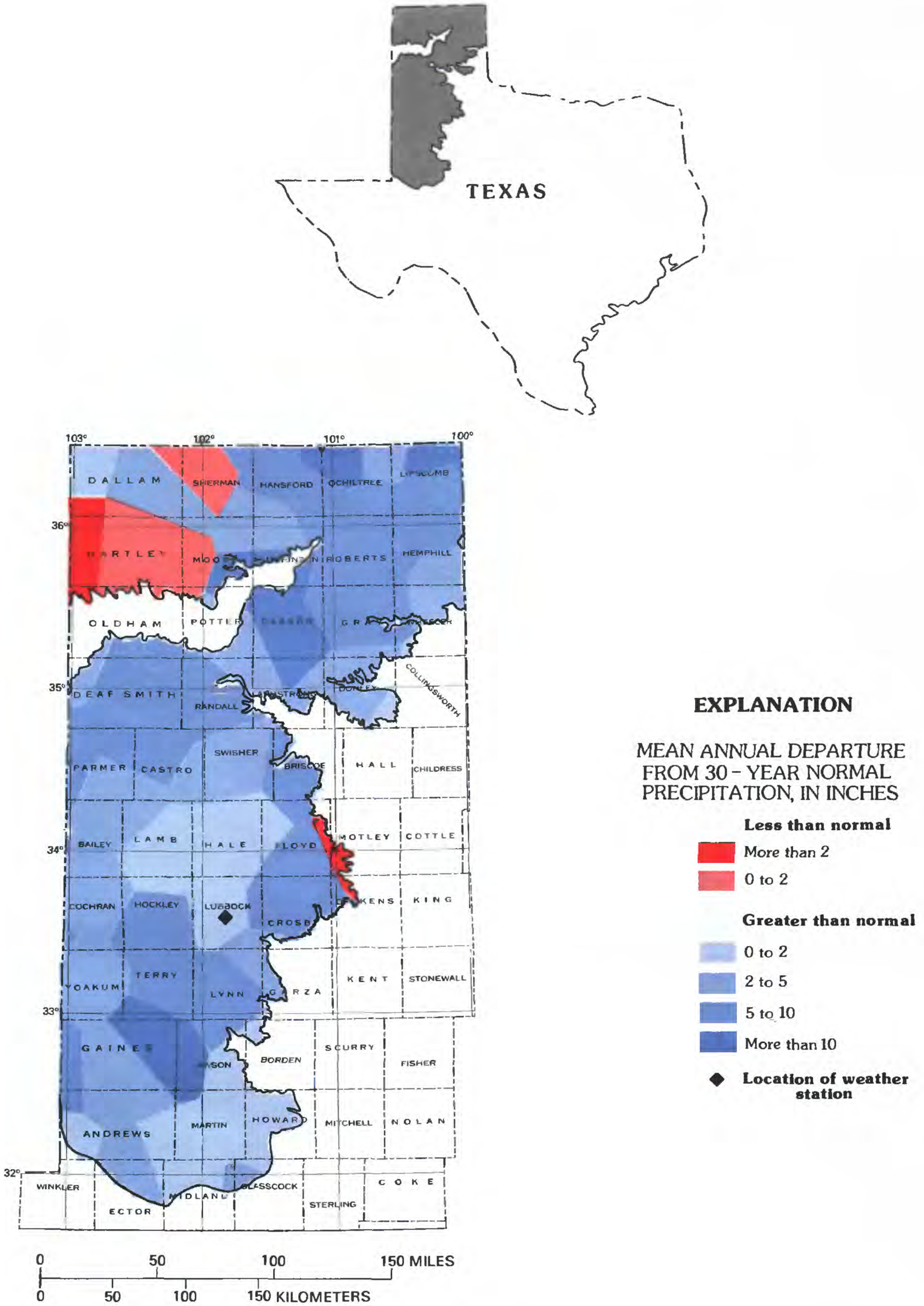



Figure 26.--Annual departure from 30-year normal precipitation in Texas, 1987. Source: U.S. Department of Commerce, National Climatic Data Center.

## TEXAS--REPRESENTATIVE CONDITIONS IN THE HIGH PLAINS

*Rate of Water-Level Decline in the High Plains Aquifer Decreased in the Mid-1980's in Lamb County.*

The volume of water withdrawn from the High Plains aquifer during a given year is primarily related to irrigated acreage and precipitation. However, crop type, soil type, method of water application, and irrigation efficiency also affect the volume of water that is withdrawn. Not only does the annual precipitation affect the volume of water that must be pumped to meet the requirements of a crop, but the timing of the precipitation is even more important. Therefore, the relation between irrigated acreage, precipitation, and resulting water withdrawn can only partly explain the fluctuations of water levels in the High Plains aquifer in Texas, as illustrated by the data from Lamb County.

Graphs showing water levels, annual precipitation and its cumulative departure from normal, and irrigated acreage for Lamb County are shown in (fig. 27). The data for Lamb County illustrate a typical pattern of water-level declines and changes in irrigated acreage in the High Plains of Texas. The water-level hydrograph (fig. 27A) shows a long-term gradual decline until the mid-1980's, when the rate of water-level decline decreased. The irrigated acreage was virtually constant during the 1960's, 1970's, and early 1980's but decreased in the mid-1980's (fig. 27C). Records from a weather station in nearby Lubbock show a 58-year average annual precipitation of 18.27 inches (fig. 27B). The area experienced a long period of less than average precipitation from the mid-1940's to the late 1950's. Precipitation during the 1960's, 1970's, and early 1980's was variable, but there was a general trend of greater than normal precipitation. Precipitation was substantially greater than the 58-year average since the mid-1980's. The only discernible relation between water levels and the other two components is for the mid-1980's, when the almost static water levels can be associated with greater than normal precipitation and a decrease in irrigated acreage.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Texas Agricultural Statistics Service for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

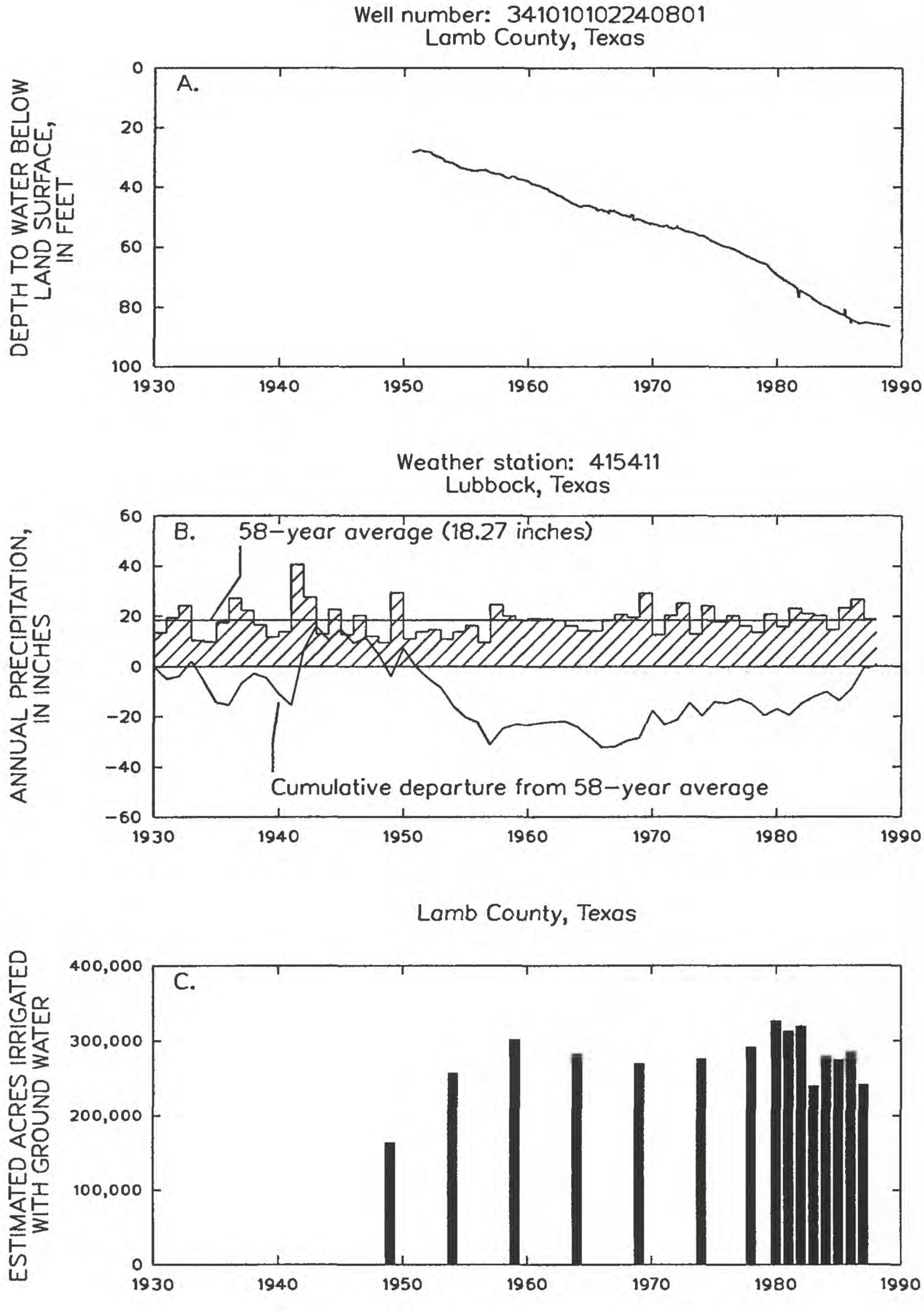



Figure 27.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Lamb County, northwestern Texas.

## TEXAS--UNUSUAL CONDITIONS IN LUBBOCK COUNTY

*Unusual Hydrologic Conditions in Lubbock County Have Resulted in Water-Level Rises.*

The data for Lubbock County (fig. 28) show an unusual pattern of water-level rises in the High Plains aquifer and changes in irrigated acreage. Since the late 1960's, water levels in the aquifer have risen about 40 feet (fig. 28A) and irrigated acreage has been decreased by about 50 percent (fig. 28C). The water-level rises are mostly attributed to the importation of municipal water supplies, some of which is used for landscape irrigation, and the drainage of stormwater runoff in the Lubbock metropolitan area to water-holding areas, such as pits and playa lakes. These practices have recharged the aquifer. Much of the decrease in irrigated acreage can be attributed to the expansion of the Lubbock metropolitan area. The greater than normal precipitation (fig. 28B) and the decrease in irrigated acreage are believed to have had a minor effect on the rising water levels.

The data used to prepare the well hydrograph are from the files of the U.S. Geological Survey. The annual-precipitation records are from the U.S. Department of Commerce, National Climatic Data Center. Estimates of acres irrigated with ground water are derived from data obtained from the U.S. Department of Commerce, Census of Agriculture for 1949, 1954, 1959, 1964, 1969, 1974, and 1978, and from the Texas Agricultural Statistics Service for 1980-87. The data, which include acres irrigated for selected crops, have been adjusted to include all crops irrigated by ground water.

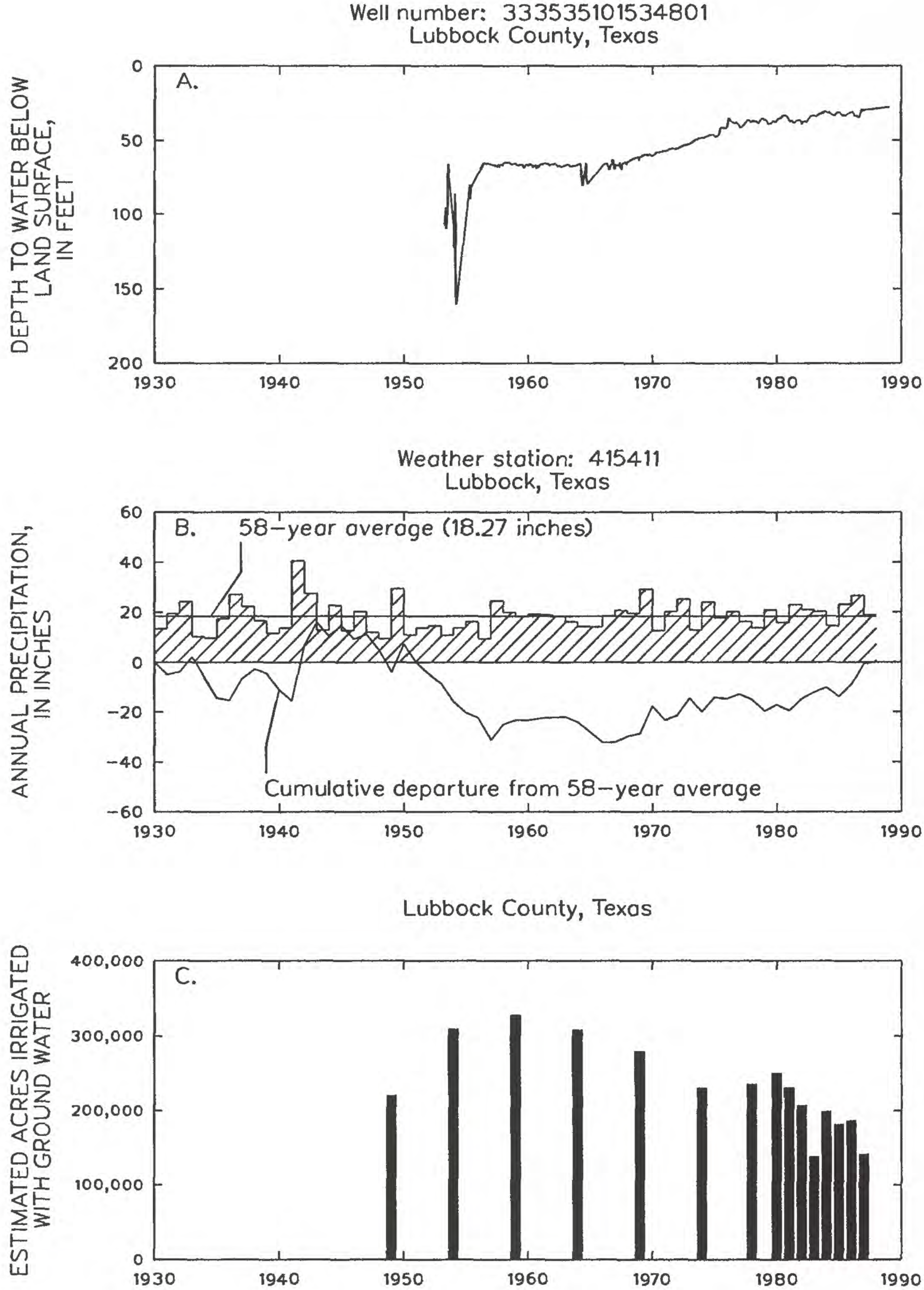



Figure 28.--A, Depth to water; B, Annual precipitation and cumulative departure from average; and C, Estimated acres irrigated with ground water--Lubbock County, northwestern Texas.



(p. 61 follows)

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