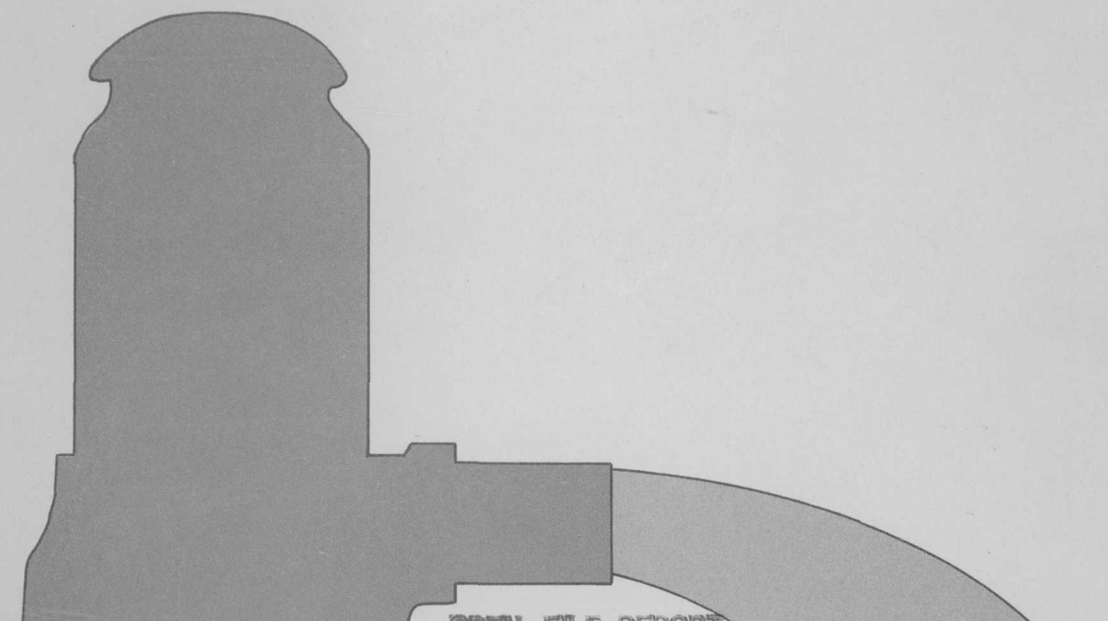
GROUND WATER

CIMARRON RIVER BASIN



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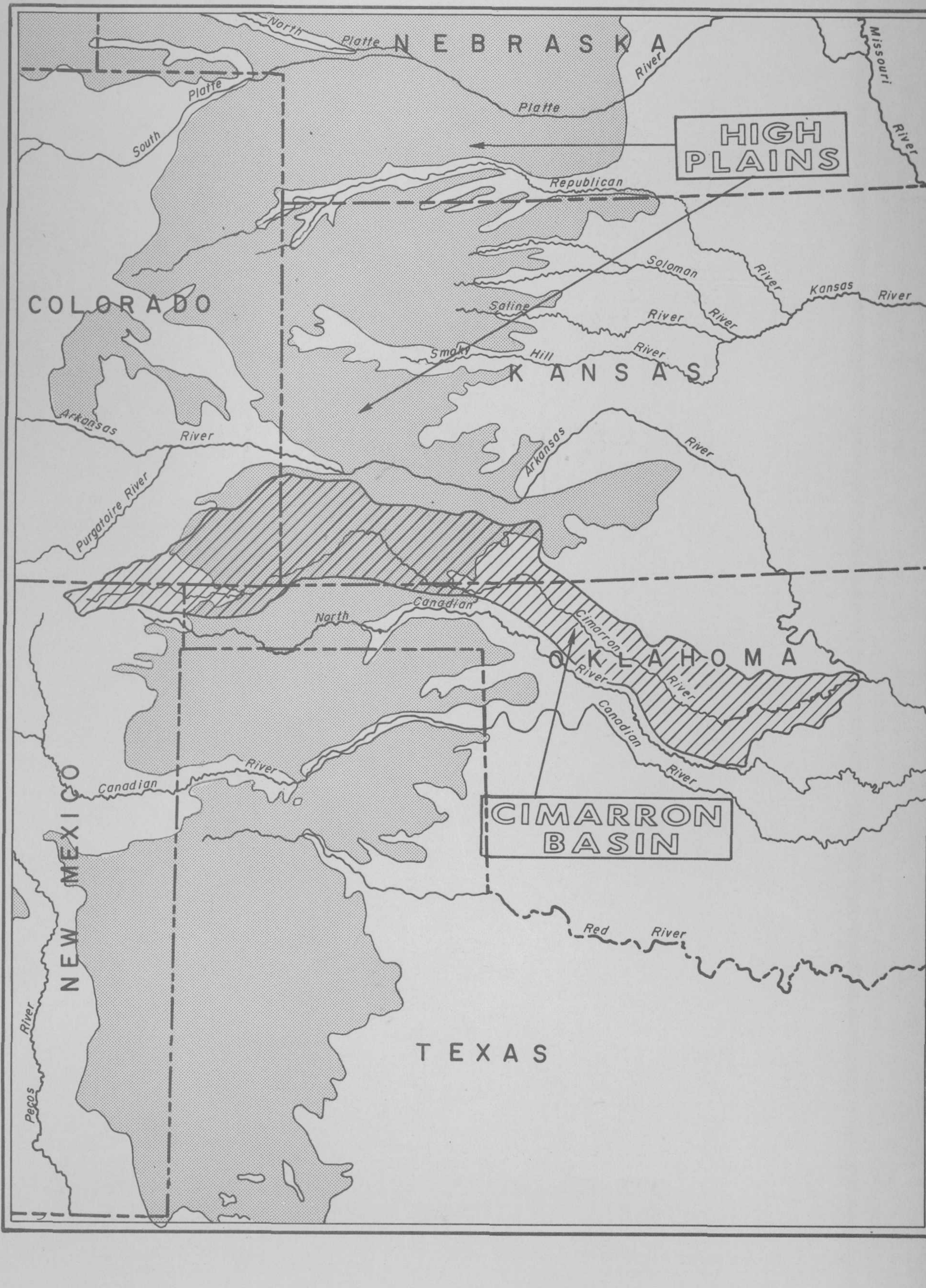
NEBRASKA
North Platte
South Platte
Platte
Platte River
Missouri River
HIGH PLAINS
Republican
Soloman River
Kansas River
Saline River
Smoky Hill River
COLORADO
KANSAS
Arkansas River
Purgatoire River
North Canadian
Cimarron River
OKLAHOMA
Canadian River
CIMARRON BASIN
NEW MEXICO
Red River
Pecos River
TEXAS

GROUND WATER IN THE CIMARRON RIVER BASIN

NEW MEXICO, COLORADO, KANSAS, AND OKLAHOMA

Prepared by the

U.S. Geological Survey--Water Resources Division

for the

U.S. Corps of Engineers--Tulsa District

Denver, Colorado

September 1966

GROUND WATER IN THE CIMARRON RIVER BASIN

NEW MEXICO, COLORADO, KANSAS, AND OKLAHOMA

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GROUND WATER IN THE CIMARRON RIVER BASIN,

NEW MEXICO, COLORADO, KANSAS, AND OKLAHOMA

INTRODUCTION

This report on ground water in the Cimarron River basin was prepared by the Water Resources Division of the U.S. Geological Survey at the request of the U.S. Corps of Engineers, Tulsa District, for inclusion in the Corps' overall report on the water resources of the basin. The report is an updating of the Cimarron Basin part of the report on the Arkansas, White, and Red River basins (Lohman and Burtis, 1953a) and includes more recently published data, as well as unpublished data in the files of the Geological Survey. These data are compiled by district offices of the Geological Survey in each State in cooperation with State and local agencies and with other Federal agencies. No new data were collected as a part of this investigation.

The report is primarily a map presentation, and the text is intended mainly to clarify and supplement the maps and to make them more understandable and usable. The report also presents some of the ground-water problems--both present and potential--and suggests some partial solutions. As the maps and text are of necessity highly generalized, the reader is referred to the more detailed reports for more precise information. (See Selected References.)

GEOLOGIC SETTING

For convenience of presentation in this report, the rocks that crop out in the Cimarron River basin are grouped into two general categories--consolidated deposits and unconsolidated deposits. The consolidated deposits include the older bedrock formations, consisting mainly of shale, limestone, sandstone, and basalt; the unconsolidated deposits include the younger surficial sediments, consisting mainly of sand, gravel, silt, and clay. The aquifers in the consolidated deposits are referred to as bedrock aquifers and those in unconsolidated deposits are called surficial aquifers.

The consolidated deposits include bedrock formations ranging in age from Pennsylvanian in the eastern part of the basin to Tertiary in the western part. Rocks of Pennsylvanian age crop out in an area extending eastward from eastern Payne County, Okla., to the confluence of the Cimarron and Arkansas Rivers. These rocks are overlain by rocks of Permian age, which underlie a large part of the basin, from eastern Payne County upstream to Meade County, Kans. Rocks of Triassic and Jurassic age are exposed mainly in southeastern Colorado, in the Oklahoma panhandle, and in northeastern New Mexico. Rocks of Cretaceous age crop out in many areas in the western part of the basin on both the east and west sides of the High Plains. The bedrock of Tertiary age includes the basalt flows of southeastern Colorado, northeastern New Mexico, and westernmost Oklahoma. The principal bedrock units (excluding the basalt) are listed in table 1, and the areas of bedrock outcrop are shown on plates 3 and 4.

The unconsolidated deposits include all the surficial sediments, which range in age from Tertiary to Recent. They include the sediments

Table 1.--Principal bedrock units cropping out in the Cimarron River basin (excluding basalt) 1/

New Mexico			Colorado			Kansas		Oklahoma		
Group	Formation	Member	Group	Formation	Member	Group	Formation	Group	Formation	Member
Cretaceous rocks										
Colorado	Niobrara Formation Carlile Shale Greenhorn Limestone Graneros Shale		Colorado	Niobrara Formation Carlile Shale Greenhorn Limestone Graneros Shale		Colorado	Greenhorn Limestone Graneros Shale	Colorado	Greenhorn Limestone Graneros Shale	
	Dakota Sandstone			Dakota Sandstone			Dakota Sandstone		Dakota Sandstone	
	Purgatoire Formation	Kiowa Shale Cheyenne Sandstone		Purgatoire Formation	Kiowa Shale Cheyenne Sandstone		Kiowa Shale Cheyenne Sandstone		Purgatoire Formation	Kiowa Shale Cheyenne Sandstone
Jurassic rocks										
	Morrison Formation Entrada Sandstone			Morrison Formation Entrada Sandstone					Morrison Formation Exeter Sandstone	
Triassic rocks										
Dockum			Dockum				Unnamed	Dockum		
Permian rocks										
							Big Basin Formation 2/ Day Creek Dolomite Whitehorse Sandstone	Whitehorse	Quartermaster Formation Cloud Chief Formation	
									Rush Springs Sandstone Marlow Formation	
						Nippewalla	Dog Creek Formation Blaine Gypsum Flowerpot Shale Cedar Hills Sandstone 3/ Salt Plains Siltstone 3/ Harper Siltstone	El Reno	Dog Creek Shale Blaine Gypsum Flowerpot Shale	
									Hennessey Shale Garber Sandstone Wellington Formation	
								Chase Council Grove Admire		
Pennsylvanian rocks										
								Pontotoc	Vanoss Formation	
									Ada Formation Lecompton Limestone Vamoosa Formation	
								Ochelata	Tallant Formation Barnsdall Formation Wann Formation	

1/ Units containing principal aquifers are underscored. 2/ Of O'Connor (1963). 3/ Of Cragin (1896).

of Tertiary age that underlie the High Plains and that range in thickness from a featheredge to more than 700 feet. They also include the alluvium and terrace deposits of the Cimarron River, which range from a maximum thickness of about 50 feet in the upper reaches to nearly 100 feet in the eastern part of the basin.

GROUND WATER

OCCURRENCE

Bedrock Aquifers

The bedrock aquifers are found principally in the Vamoosa Formation, in the Garber and Wellington Formations, and in the Rush Springs Sandstone--all of Permian age; in rocks of the Dockum Group of Triassic age; and in the Cheyenne Sandstone or equivalents and Dakota Sandstone of Cretaceous age. The bedrock aquifers differ from the surficial aquifers in that they generally lie at greater depth, they are more difficult to drill, they contain water that generally is under artesian head, they commonly contain more highly mineralized water, and they generally are recharged at a slower rate. These differences commonly result in more costly development, more rapidly declining water levels, and less suitable quality of water.

The occurrence of water under artesian head can be both an advantage and a disadvantage. When an artesian aquifer is penetrated by a well, the water will rise in the well to a level above the point at which it was tapped--thus reducing the pumping lift and, hence, the cost of pumping. The rise may amount to only a few feet, or it may be tens or hundreds of feet. In the Walsh area of Baca County, Colo., for example, water commonly will rise more than 300 feet in wells tapping the Cheyenne Sandstone Member of the Purgatoire Formation and locally will flow at the ground surface.

Some of the differences between water-table and artesian aquifers are illustrated in figure 1. In figure 1A, the well penetrates a

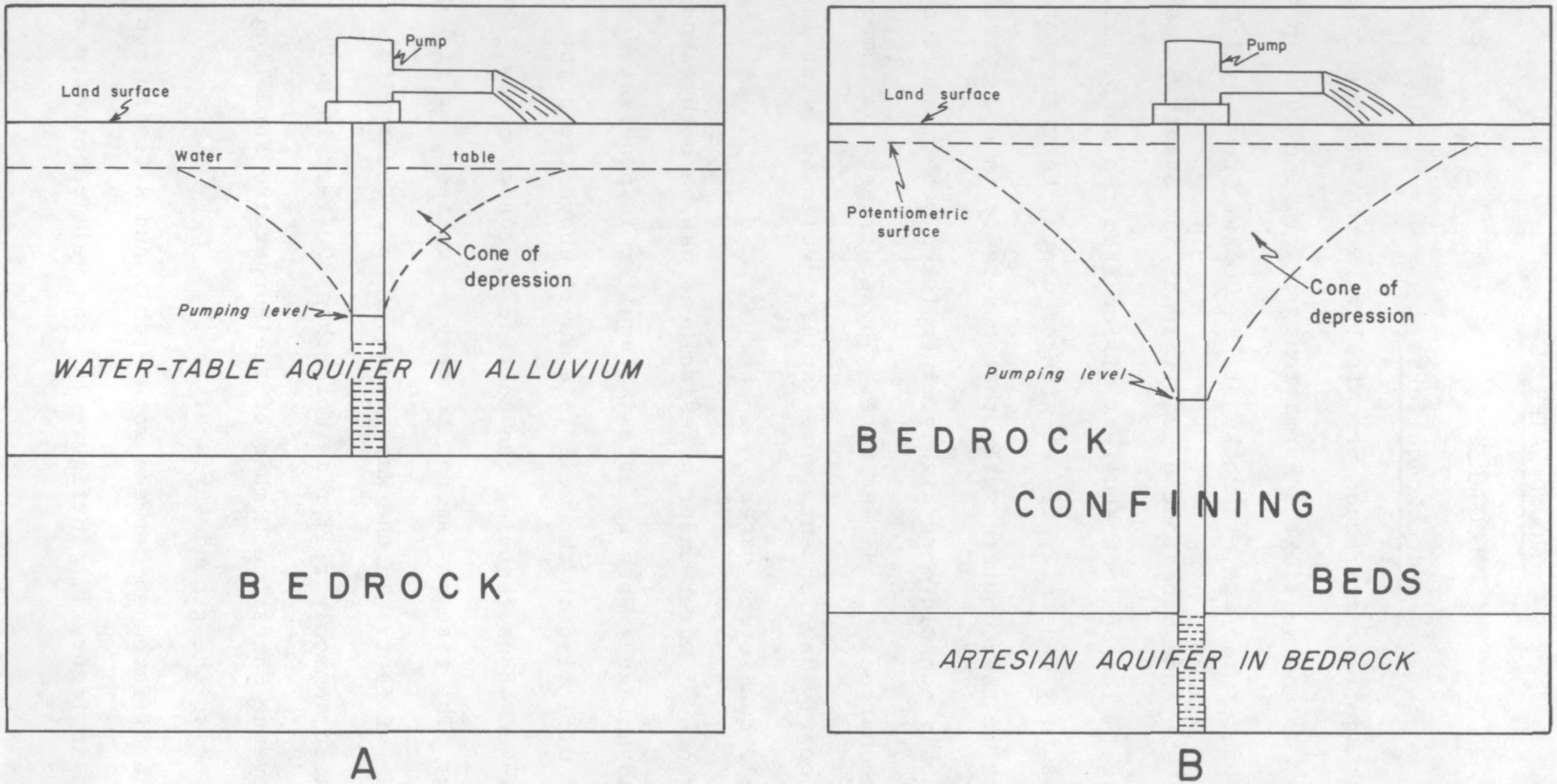

Figure 1.--Diagrammatic sections illustrating water-table and artesian conditions.

water-table aquifer in unconsolidated materials above bedrock. As the well is pumped, the aquifer is partly unwatered within the cone of depression. The amount of water released by gravity drainage of a cubic foot of saturated material under water-table conditions is a measure of its specific yield; that is, if it yields 0.20 cubic foot of water, its specific yield is 20 percent. The specific yield of sand and gravel, for example, commonly is between 15 and 25 percent.

In figure 1B, the well starts in bedrock and penetrates bedrock all the way through the artesian aquifer. The water rises in the well almost to the land surface and to a level that coincides with an imaginary surface known as the potentiometric surface. This surface represents the level to which water in tightly cased wells tapping the artesian aquifer will rise. When the well is pumped, an imaginary cone of depression is developed around the well in the bedrock.

As long as the pumping level in a well in an artesian aquifer remains above the top of the aquifer, the water is derived entirely from compression of the aquifer and expansion of the water--the sediments comprising the aquifer are not drained, and the aquifer remains full. When the pumping level extends below the top of the aquifer, it changes from artesian to water-table, a cone of depression develops within the aquifer (as in figure 1A), and drainage of the aquifer begins. The coefficient of storage of an artesian aquifer expresses the quantity of water released from storage in a vertical column of the aquifer of unit cross section as the result of a unit decline in head. The storage coefficient of an artesian aquifer commonly is in the order of magnitude of 0.0001 to 0.00001. The average storage coefficient of the Cheyenne Sandstone

Member in Baca County, as indicated by several flow tests, is about 0.0005.

As the specific yield of a water-table aquifer generally is many times as great as the storage coefficient of an artesian aquifer, the water levels in wells tapping a heavily pumped artesian aquifer will decline at a very much greater rate than in a water-table aquifer with an equivalent amount of pumping. On cessation of pumping, water levels in artesian wells may recover rapidly, but the continued development of and pumping from artesian aquifers is commonly accompanied by rapidly declining water levels. Once the water level recedes to the top of the aquifer, however, the aquifer ceases to be artesian, and the water level declines much more slowly as the aquifer is drained. If an artesian aquifer is at great depth, the pumping lift may exceed economic limits before the drainage of the aquifer begins.

Vamoosa Formation

The aquifer in the Vamoosa Formation may have a greater potential for development than any other bedrock unit in the Oklahoma part of the Cimarron Basin. It crops out in a narrow north-south band extending from Osage County to Seminole County and is an important aquifer in this and nearby areas. In the Cimarron Basin, it crops out in Pawnee and Creek Counties and lies at shallow depths in eastern Payne and Lincoln Counties (fig. 2). Yields from the formation within the Cimarron Basin range from a few to 100 gpm (gallons per minute). Wells producing about 150 gpm have been reported south of the Cimarron Basin, in Seminole County. Numerous small towns and industries obtain water from wells in the Vamoosa Formation. Yields as large as 100 gpm from wells 300 to 550 feet

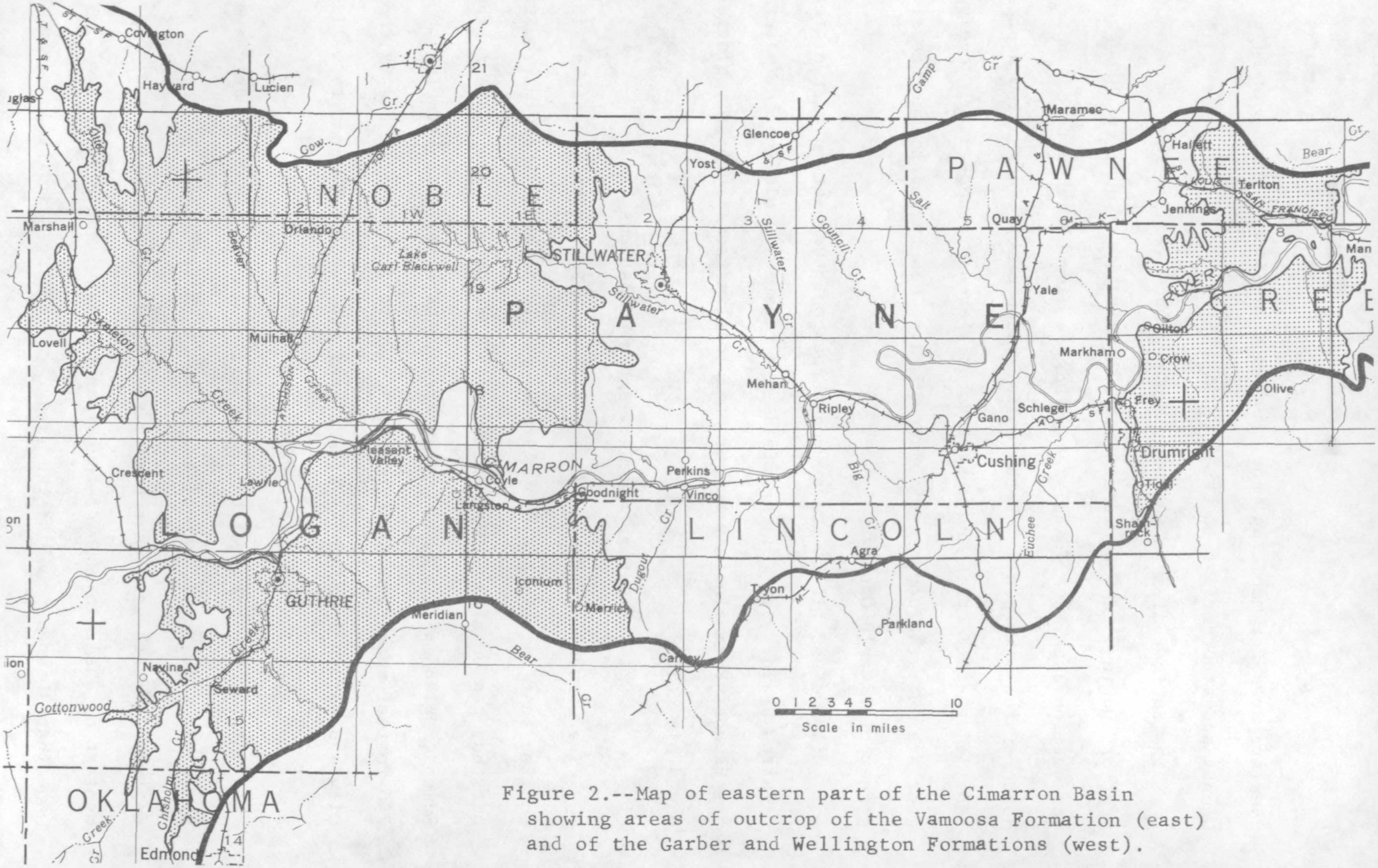

Figure 2.--Map of eastern part of the Cimarron Basin showing areas of outcrop of the Vamoosa Formation (east) and of the Garber and Wellington Formations (west).

deep are used for municipal and industrial needs at Cushing in Payne County and at Drumright in Creek County.

The aquifer dips to the west and becomes saline a short distance west of Cushing. The water differs considerably in quality throughout the outcrop area, and locally has a high sodium-bicarbonate content. North of the Cimarron River the saline water occurs at shallow depths, and yields are lower. The most favorable areas for potential development are near the southeast corner of Payne County and the northeast corner of Lincoln County.

Oil and gas fields are common throughout the eastern part of the Cimarron Basin. Some of the fields are relatively old; hence, water in the Vamoosa Formation may be polluted locally from improperly plugged or cased oil wells.

Garber and Wellington Formations

The Garber Sandstone and the Wellington Formation contain a single aquifer that is not tapped by large-capacity wells in the Cimarron Basin but that has been developed extensively just outside the basin in the Edmond, Oklahoma City, and Norman areas, where wells penetrating 400 to 750 feet of shale and sandstone yield 100 to 250 gpm. In the Oklahoma City and Norman areas there are several hundred large-capacity wells, and locally the aquifer is approaching full development.

The outcrop areas of these formations in the Cimarron Basin are principally in Noble, Payne, and Logan Counties (fig. 2); they dip westward beneath younger formations. The aquifer contains a high percentage of shale in much of the Cimarron Basin, where it generally yields less than 10 gpm to wells; the larger yields are near the southern boundary of the basin. A few small towns in the basin have obtained small supplies from the aquifer; however, prospects for water for other than domestic and stock uses generally is not favorable because of the low specific capacities of the wells and because of the occurrence of salt water in the lower part of the aquifer.

Rush Springs Sandstone

The Rush Springs Sandstone is not tapped by large-capacity wells in the Cimarron Basin, and it is present only in parts of Harper, Woods, and Woodward Counties (fig. 3). Most of the wells drilled in this formation are in Caddo County and adjacent areas south of the Cimarron Basin where yields of 200 to 400 gpm are common. The development of water supplies from the Rush Springs in the Cimarron Basin for more than stock and domestic supplies does not appear promising because the water-bearing sand becomes progressively finer-grained northwestward from the Caddo County area. In Woodward County, for example, the Rusn Springs Sandstone is almost as fine grained as the underlying Marlow Formation, and at the Oklahoma-Kansas border the stratigraphic equivalent of the Rush Springs is primarily a shale unit. A few small communities pump very limited amounts of water from the Rush Springs for public supplies.

Rocks of Triassic Age

Fine-grained sandstones believed to be a part of the Dockum Group of Triassic age underlie the western part of the basin and are reported to yield water to irrigation wells in Morton and Stanton Counties, Kans., and Baca and Prowers Counties, Colo. The aquifer generally is tapped as a supplemental source of water by wells that are also screened opposite

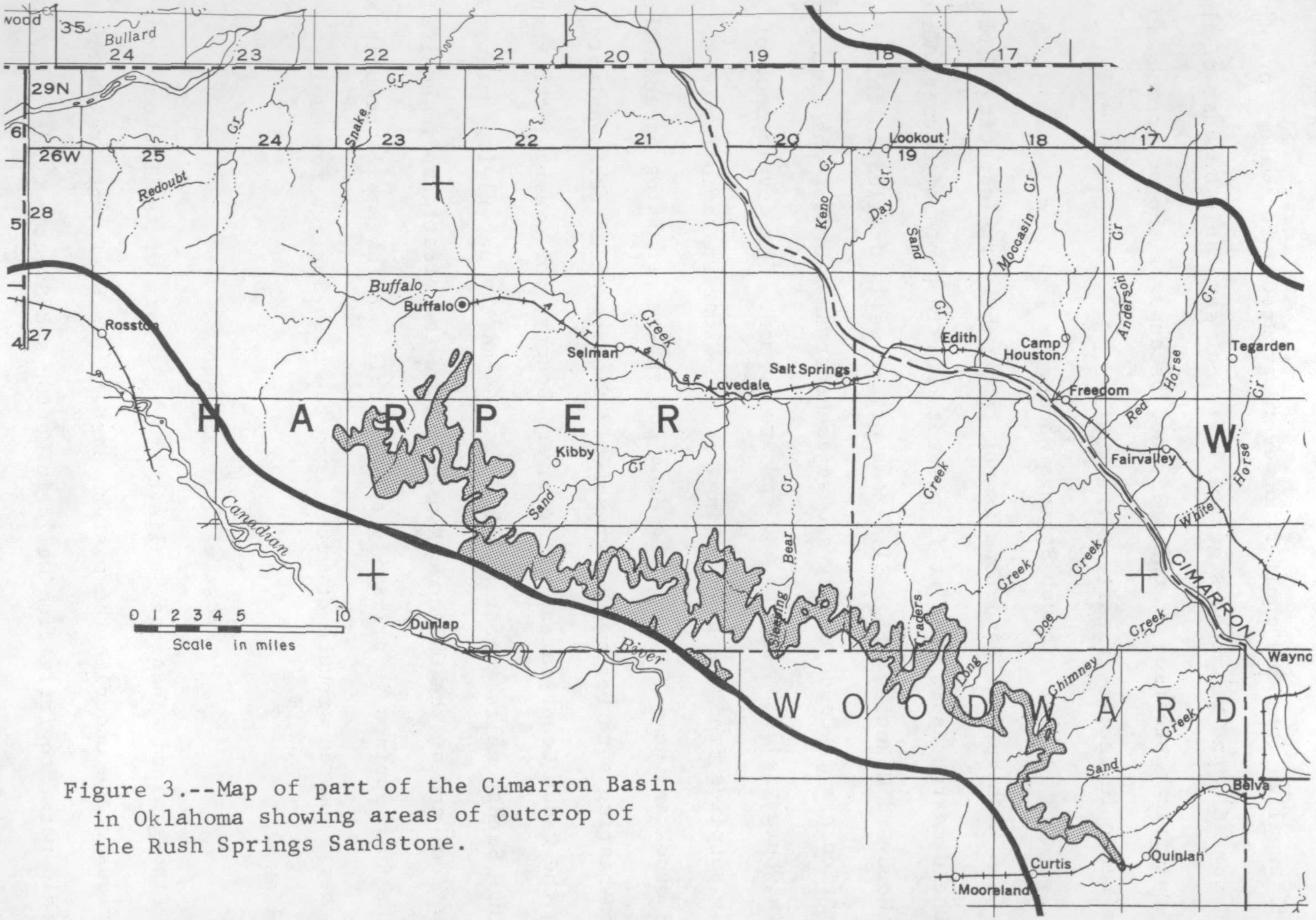

Figure 3.--Map of part of the Cimarron Basin in Oklahoma showing areas of outcrop of the Rush Springs Sandstone.

additional overlying aquifers. The amount of water taken from Triassic rocks by a multiple-screen well generally is not known but probably is only a few hundred gallons per minute. One well in Stanton County is screened opposite both the Triassic rocks and the Cheyenne Sandstone; its yield is reported to be 1,000 gmp.

Water from Triassic rocks ranges widely in chemical quality--locally it is reported to contain more than 1,000 ppm (parts per million) total dissolved solids. The water is hard, but apparently no deleterious effects from its use have been reported.

Rocks of Triassic age do not appear to have potential for large-scale development. The sandstones are fine grained in most places; hence, the yields of wells usually are not large. As the water in these rocks generally is under artesian head, the water levels are likely to decline rapidly. Because the rocks generally constitute the lowest aquifer containing potable water and commonly lie at considerable depth, the cost of drilling discourages development.

Where Triassic rocks are the only source of water or where overlying aquifers are not sufficiently productive for the use intended, the Triassic rocks are an important potential source of supply. By tapping this and other aquifers with multiple-screen wells, many farmers are now developing adequate supplies of water for irrigation in areas where no single aquifer is sufficiently productive to warrant development. This system tends to solve the problem of water quality by allowing the mixing of water of poor quality that in some areas might not otherwise be usable with water of good quality, so that the end product is usable. The system also creates problems by allowing the uncontrolled movement of water through wells between aquifers having different artesian heads and different water quality.

The Triassic rocks are believed to pinch out eastward in Morton and Stanton Counties, Kans., and Texas County, Okla.; hence, their potential for development is limited to the westernmost part of the basin. Their greatest potential is in those areas where they are overlain by other bedrock aquifers, such as those in the Cheyenne Sandstone or equivalents and the Dakota Sandstone, and perhaps also where they are overlain by surficial aquifers.

Cheyenne Sandstone or Equivalents

The basal unit of Lower Cretaceous rocks in the Cimarron Basin has commonly been called the Cheyenne Sandstone or the Cheyenne Sandstone Member of the Purgatoire Formation; locally, it has been assigned other names. For simplicity, it is referred to in this report as the Cheyenne Sandstone or equivalents. The Cheyenne is exposed in the Cimarron Basin along canyon and mesa walls at many places in northeastern New Mexico, southeastern Colorado, and western Oklahoma. In many of these areas it is largely drained and will yield little or no water to wells.

The Cheyenne is buried beneath both bedrock formations and unconsolidated deposits in a large area in central and eastern Baca County, in southeastern Prowers County, and in much of southwestern Kansas--largely within the High Plains section of the Cimarron Basin. The formation pinches out toward the south and southeast, and the approximate limit of its extent is shown on plate 4. Its thickness ranges from less than 50 feet in parts of Union County and western Baca County to more than 100 feet in northeastern Baca County, and in western Morton County.

In much of its extent beneath the High Plains it is fully saturated with water that is under artesian head and that is of good quality.

The Cheyenne Sandstone or equivalents is a fine- to coarse-grained friable sandstone containing pebbles or lenses of conglomerate in the lower part. Where the sandstone is fine grained, moderately well cemented, and poorly sorted, it will yield only small quantities of water to wells--perhaps only enough for domestic and stock use. Where it is soft, friable, poorly cemented, of uniform grain and perhaps also fractured, it may yield more than 3,000 gpm to properly constructed wells. Thus, it is not unusual to observe a well failure only a few hundred yards from a large-capacity well--both tapping the aquifer in the Cheyenne.

Water in the Cheyenne is generally of moderately good quality and is suitable for irrigation and many other uses. Analyses of 11 samples in Baca County indicated a range in total dissolved solids from 222 to 637 ppm and a range in hardness from 172 to 379 ppm. On the basis of percent sodium and specific conductance, the samples were all considered good to excellent for irrigation. Pattern diagrams of representative samples are shown on plate 5.

Although the Cheyenne has long been known as an artesian aquifer in many parts of the Great Plains and was the source of water for the flowing wells in the Walsh area of Baca County, it was not tapped by large-capacity wells for irrigation until 1947 when a well yielding nearly 3,000 gpm was completed in northeastern Baca County. Because of adequate precipitation and abundant crops, only 24 irrigation wells had been completed in the county by 1951. The years of drought in the early 1950's and in the 1960's caused greatly increased drilling activity, with the result that there were more than 600 irrigation wells in the county in 1965 (fig. 4). Although reliable data are not available, it is estimated that about 75 percent of these wells obtain all or part of their water from the Cheyenne Sandstone or equivalents. The Cheyenne also furnishes part of the supply for many multiple-screen wells in the Cimarron Basin--particularly in Baca and Prowers Counties and in several areas in western Kansas. These wells commonly penetrate the unconsolidated Tertiary and Quaternary sediments in the Dakota Sandstone as well as the Cheyenne. A few also tap the underlying aquifer in the Triassic rocks.

The potential for additional development of water from the Cheyenne is great, but there is danger that the water levels will decline rapidly until they reach the top of the aquifer, and it ceases to be artesian. The water levels should then decline much more slowly while the aquifer is being unwatered by gravity drainage. Records on file in the Geological Survey indicate that water levels in the Walsh area have declined as much as 120 feet since 1946 (fig. 5), and that most of the old artesian wells have ceased flowing. As the aquifer lies at a depth of more than 400 feet in parts of this area, the pumping lifts may become excessive before the rate of decline is reduced significantly.

The recharge to the Cheyenne probably is at a very slow rate; hence, the large-scale withdrawals in Baca County are coming largely from storage. Locally, however, recharge may be more rapid as indicated by the significant water-level rises near Edler in Baca County (fig. 5). These rises probably were the result of the large storms of 1965. Wherever the aquifer is at a depth sufficiently small to permit unwatering, much

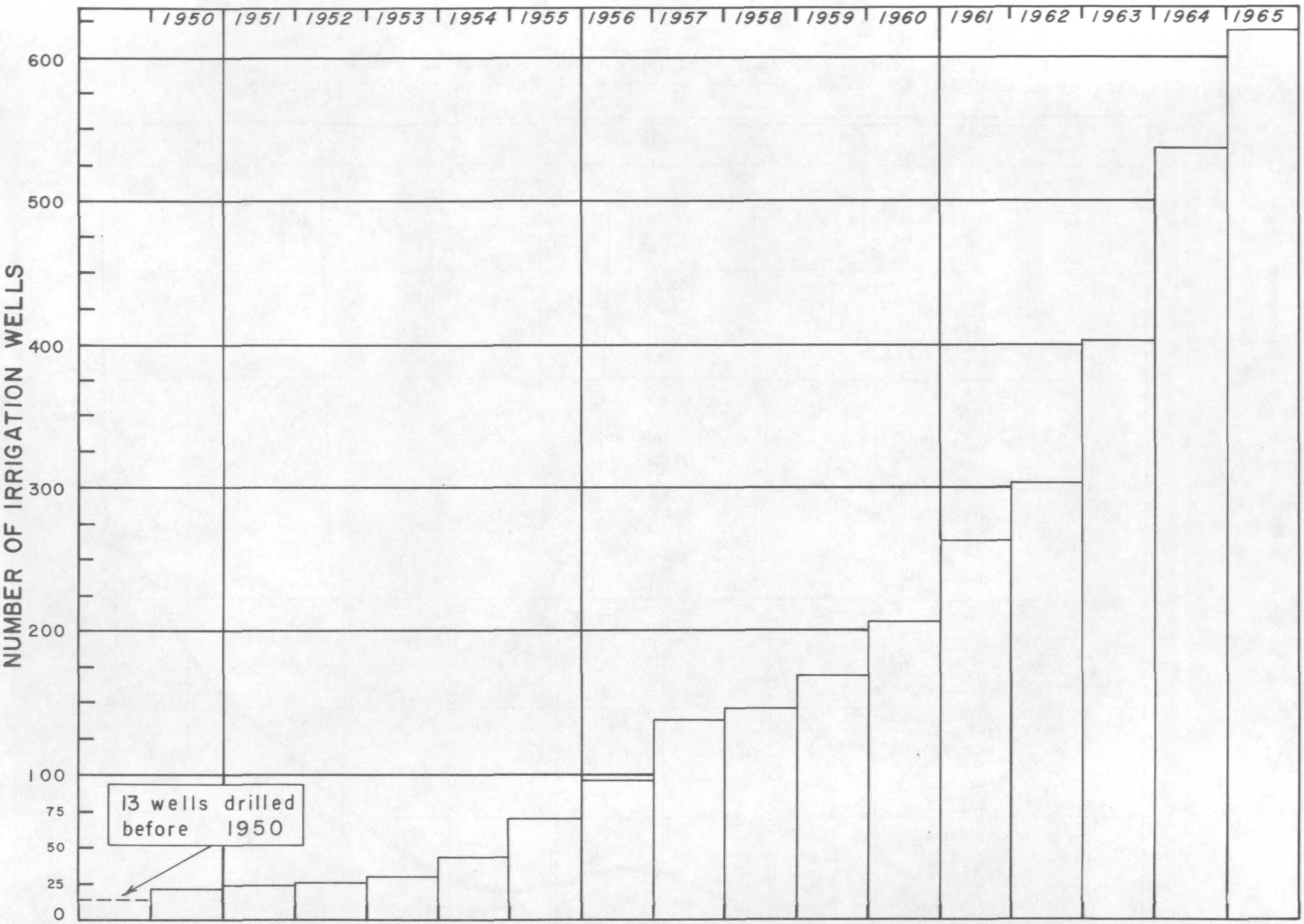

Figure 4.--Cumulative total number of irrigation wells in Baca County, Colo. (Data from McConaghy and Colburn, 1964, and from records of the Colorado State Engineer.)

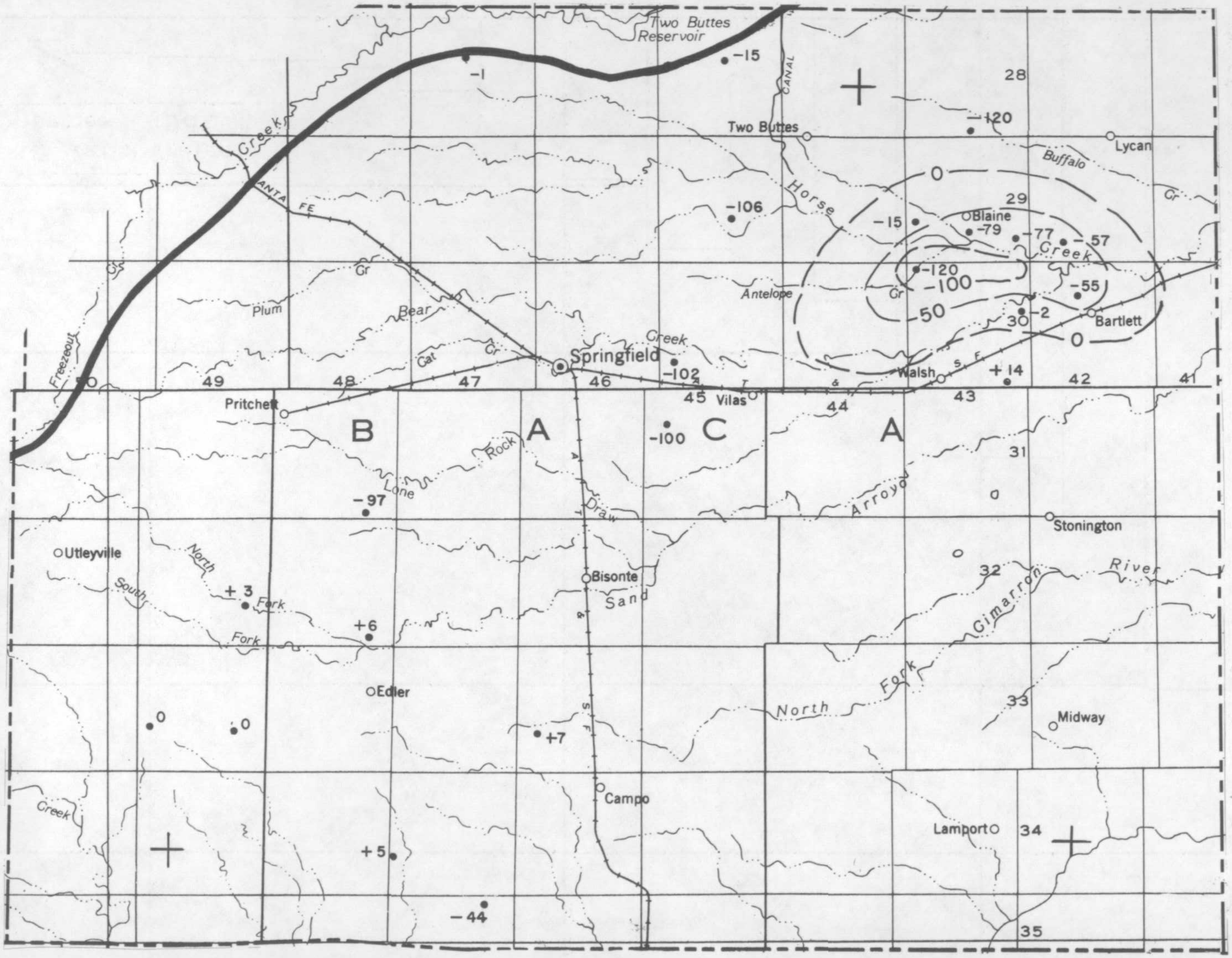

Figure 5.--Map of Baca County, Colo., showing net changes in water level, in feet, between 1949 and 1966 in wells penetrating the Cheyenne Sandstone Member of the Purgatoire Formation.

additional water may be obtained by slow drainage from the overlying shale; data on that potential source of water are lacking. Accurate data on the amount of water that is in storage in the Cheyenne are also lacking.

An estimate of the water that is theoretically in storage in the Cheyenne or equivalents can be made by the use of several assumptions. If it is assumed that the average artesian head is 200 feet above the top of the aquifer and that the average storage coefficient is 1×10^{-4}, then the aquifer will release less than 15 acre-feet of water per square mile as the head declines to the top of the aquifer. If it is also assumed that the aquifer has an average thickness of 75 feet and an average specific yield of 15 percent, it will theoretically yield about 7,200 acre-feet of water per square mile by gravity drainage. Not all this water can be recovered, however, for as the water level declines within the aquifer, the thickness of saturation decreases, and well yields decrease accordingly.

The Cheyenne may have an average coefficient of transmissibility that is considerably less than that of the surficial aquifers, although definitive data are not available. Tests of artesian wells tapping the Cheyenne indicated that the coefficient of transmissibility of the aquifer in Baca County probably is less than 25,000 gallons per day per foot and that the underflow through a 1-mile section of the aquifer was less than 1 million gallons per day with the hydraulic gradients prevailing at the time of the tests.

Dakota Sandstone

The Dakota Sandstone, of Early Cretaceous age, lies above the Cheyenne and is separated from it by the Kiowa Shale or equivalents.

The Dakota crops out in the Cimarron Basin over wide areas in Union, Las Animas, Baca, and Cimarron Counties and in numerous small areas elsewhere in the western part of the basin. It extends beneath the cover of unconsolidated deposits in the High Plains and pinches out toward the south and southeast, as shown on plate 4.

The Dakota Sandstone generally is largely drained in the highly dissected areas in the westernmost part of the Cimarron Basin; where covered extensively by younger deposits--particularly the unconsolidated deposits of the High Plains--it is in most places fully saturated with water of usable quality.

The Dakota ranges in thickness from a featheredge, where it pinches out beneath the cover of unconsolidated deposits in the High Plains, to nearly 200 feet where it has been undisturbed by erosion. Throughout much of the High Plains, where it is the first bedrock formation encountered beneath the unconsolidated deposits, its thickness ranges from 75 to 125 feet and averages about 100 feet.

The water in the Dakota has a wider range of chemical quality than water in the Cheyenne. In 23 samples from the Dakota that were analyzed during a study of ground water in Baca County, the total dissolved solids ranged from 132 to 5,120 ppm; however, more than half the samples contained between 200 and 500 ppm of dissolved solids. Water from the Dakota commonly contains too much iron for satisfactory domestic use, and some of it contains enough fluoride to cause mottling of tooth enamel. There have been no reports of deleterious effects from using the water for irrigation, perhaps because much of the water from the Dakota that is used for irrigation is pumped by multiple-screen wells and is mixed with other water that generally is of better quality. Some water from the Dakota is known to have a high percentage of sodium and if used for irrigation without mixing with other water, could have an adverse effect on crops grown on fine-grained, poorly drained soils.

The Dakota Sandstone is known throughout much of the Great Plains as a source of water for flowing artesian wells. Although no wells tapping the Dakota are known to flow in the Cimarron Basin, the water may rise a few feet to several hundred feet above the top of the sandstone, thus reducing the pumping lift of hundreds of domestic and stock wells that tap the sandstone within the basin. The Dakota was not developed extensively by large-capacity wells in the Cimarron Basin until the recent expansion of irrigation in Baca County. About 15 percent of the irrigation wells in Baca County obtain all or part of their supplies from it. Wells tapping the Dakota alone generally will yield only 50 to 100 gpm, although yields as large as 300 gpm have been reported. Water from the Dakota is withdrawn for irrigation mainly in Baca County, but also in parts of southwestern Kansas. In these areas the Dakota generally furnishes only a part of the supply withdrawn by multiple-screen wells.

Water levels in the Dakota Sandstone have declined over a large area in northeastern Baca County where development has been most extensive--the maximum recorded decline was 125 feet in a well between Springfield and Two Buttes (fig. 6). Elsewhere in the county, large water-level rises have been measured. Some rises probably are the result of recharge from above-normal precipitation in 1965, although some of the measurements may be in error because of flooding of the wells during the

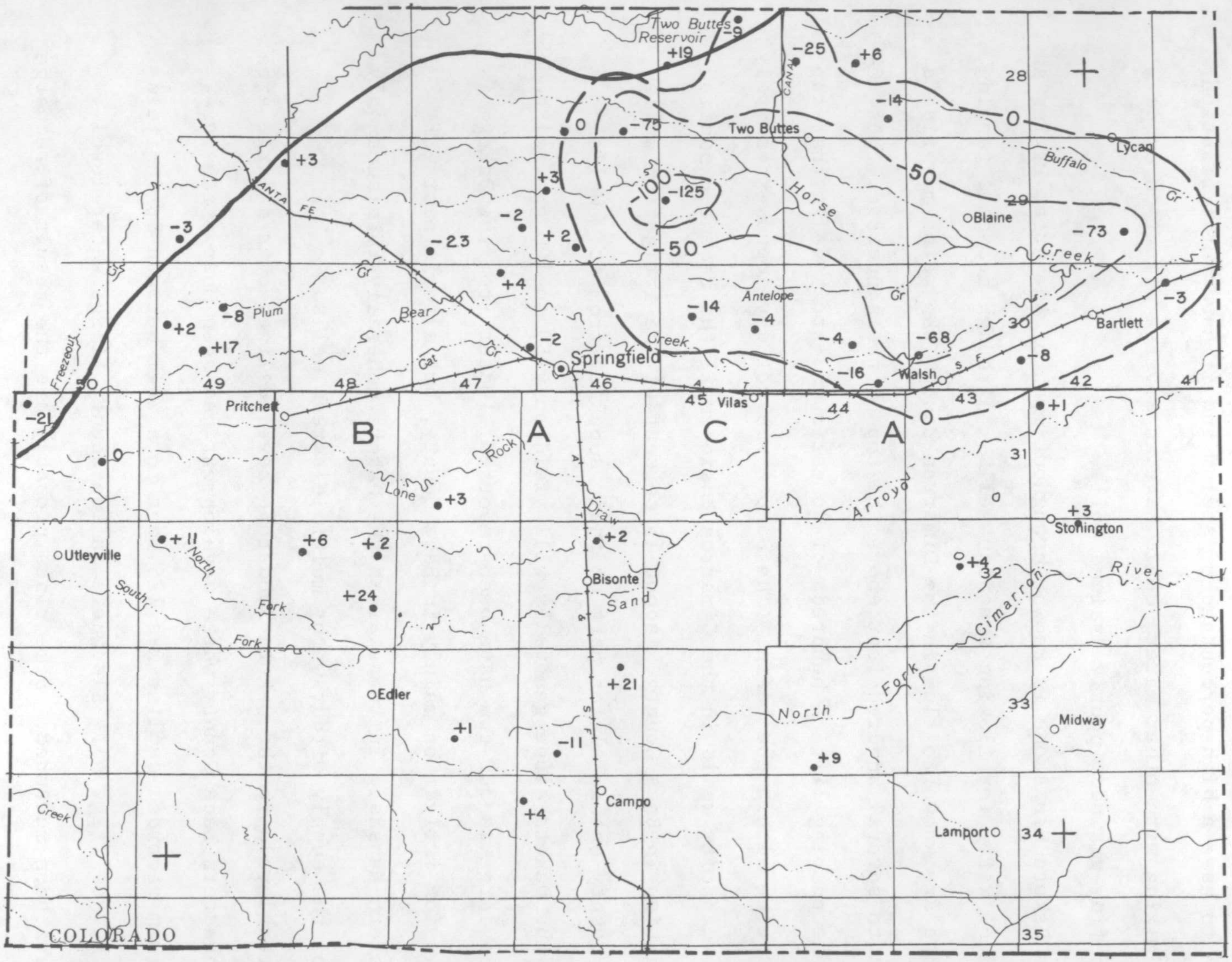

Figure 6.--Map of Baca County, Colo., showing net changes in water level, in feet, between 1949 and 1966 in wells penetrating the Dakota Sandstone.

storms or because of water cascading into the well from perched zones to the regional zone of saturation.

The Dakota Sandstone has a potential for much more development because it has a relatively large amount of water in transient storage. Large-scale development probably will be slow in some areas because the formation lies at considerable depth, generally yields relatively small quantities of water to wells, locally contains water of poor quality, and is overlain by more productive aquifers in much of its area of distribution beneath the High Plains. The Dakota may have considerable potential as a supplemental source of water where the overlying formations will not yield enough water for the use intended, or where the overlying aquifers are seriously depleted. By the time the overlying aquifers are depleted, it may be economically feasible to pump water from the Dakota on a large scale.

Large-scale development of water from the Dakota will, in places, be accompanied by rapidly declining water levels because the water is under artesian head. As the rate of recharge to the Dakota generally is very low, the development will be essentially a mining operation. Estimates of the amount of water theoretically recoverable from the Dakota can be made in the same manner as for the Cheyenne (p. 19) by assuming an artesian head 100 feet above the top of the aquifer, a storage coefficient of 1×10^{-4}, a thickness of 150 feet, and a specific yield of 10 percent. Where the Dakota is immediately overlain by unconsolidated water-bearing materials, as it is in much of the High Plains area north of the Cimarron River, there is little or no artesian head, and the theoretically recoverable storage can be estimated by assuming an average thickness of 100 feet and a specific yield of 10 percent. Under these conditions the aquifer would yield about 6,400 acre-feet per square mile by gravity drainage.

Surficial Aquifers

The surficial aquifers in the Cimarron Basin are of two general types--(1) the thick deposits of sand, silt, gravel, clay, and caliche of Tertiary and Quaternary age that underly the flat, gently eastward-sloping surface of the High Plains, and (2) the much thinner deposits, which consist largely of sand and gravel but which also contain silt and clay, that underlie the terraces and flood plains throughout the basin. For simplicity, they are referred to as the "High Plains deposits" and the "alluvial deposits" in this report, although both are of alluvial origin. The High Plains deposits underlie most of the Cimarron Basin from western Baca and Cimarron Counties to eastern Meade and Beaver Counties. They reach a maximum thickness of more than 700 feet in south-eastern Stevens County where the lower 600 feet is saturated with water. They yield large quantities of water of good quality to wells for irrigation (pl. 5), public supply, and other uses. The alluvial deposits underlie the flood plains and terraces of the Cimarron River and its larger tributaries throughout the basin. Together with the High Plains deposits, they form a single aquifer where the valley crosses the High Plains; east and west of the High Plains the alluvial deposits overlie bedrock and are commonly the only dependable source of large quantities of usable water.

Water in the surficial aquifers generally is under water-table conditions, although locally an artesian head is developed where there are alternating sequences of coarse-grained and fine-grained sediments. Small artesian heads are common in the High Plains deposits, which are said to be under semi-artesian conditions. Water in the alluvial deposits is almost everywhere under water-table conditions.

Origin and Movement of Water

Water in the surficial aquifers is derived almost entirely from local precipitation. In the High Plains, where precipitation averages about 20 inches annually, the long-term annual recharge from precipitation is believed to be less than 1 inch. Locally, under favorable conditions of infiltration, such as along ephemeral streams, in upland depressions, and in areas of sand dunes, the recharge may be considerably greater. The significant water-level rises in parts of Baca County, as shown on plate 5, probably reflect a high rate of recharge in areas of sandy soils as a result of the unusually large storms of 1965. Marine and Schoff (1962, p. 52) estimated the average annual recharge in part of Beaver County to be almost 4 inches. Recharge to the alluvial deposits in the lower reaches of the basin, where the annual precipitation exceeds 30 inches, may be as much as 25 percent of the precipitation.

The water-table contour map (pl. 1) shows the general direction of movement of the unconfined water in the Cimarron Basin. In the upper part of the basin--principally above the south line of Meade County--the contours represent the water table in the surficial aquifers; in the lower part of the basin--mainly below Meade County--the contours represent the water table in both the surficial aquifers and the adjacent bedrock formations.

The water table in the surficial aquifers and in part in the adjacent bedrock, slopes gently eastward from an altitude of more than 4,000 feet in western Baca County to less than 800 feet at the east end of the basin. From Seward County eastward, the Cimarron River becomes increasingly entrenched below the general regional level of the water table beneath the adjacent upland with the result that the contours are deflected sharply upstream and the ground water moves toward the river as well as generally downvalley.

Depth to Water

The depth to water in the surficial aquifers in the Cimarron Basin ranges widely--from less than 50 feet along the flood plains of the Cimarron River and its tributaries to more than 200 feet in parts of the High Plains (pl. 2). From southern Clark and Comanche Counties to the eastern end of the basin, the depth to water in the alluvial deposits and in the adjacent bedrock is almost everywhere less than 50 feet--only on the higher terraces does the depth exceed 50 feet.

In the High Plains, the water table generally is much deeper than in the valleys east and west of the plains. It was less than 50 feet below land surface in some upland areas in western Grant County and eastern Stanton County before heavy pumping for irrigation began; it is now (1966) more than 100 feet in some of that area. The depth to water in a large area in eastern Baca and northwestern Morton County is less than 50 feet, but the water table is discontinuous in the surficial deposits in part of the area or is in the underlying bedrock. The depth to water is more than 200 feet in a large area in western Haskell and northeastern Grant Counties and in some parts of Baca County.

In southwestern Baca County, where the water table in the surficial deposits is discontinuous, the depth to water locally exceeds 300 feet.

Thickness of Saturation

The saturated part of the surficial deposits is the interval between the water table and the base of the saturated deposits; it is commonly called the "saturated thickness." For a given permeability, the greater the saturated thickness of a material, the greater the transmissivity and, hence, the more productive the aquifer. The map showing the thickness of saturation of the unconsolidated materials (pl. 3) is useful for delineating those areas having the greatest potential for development and for estimating the quantity of theoretically recoverable water in storage.

The water table beneath the High Plains is a relatively smooth, eastward-sloping surface (pl. 1), but the bedrock surface on which the surficial aquifers were deposited has been extensively eroded and is highly irregular. If data were adequate, a detailed map showing thickness of saturated surficial materials would display highly irregular contours. The contours on plate 3 are relatively smooth and generalized because data are not adequate for more precise delineation of the saturated thickness.

The map shows that the thickness of saturated surficial deposits in the High Plains before heavy pumping began ranged from a featheredge in many places to more than 600 feet in southeastern Stevens County. The greater saturated thicknesses and, therefore, most of the stored water is beneath southwestern Kansas, but much water is also stored in parts of Prowers, Baca, Cimarron, Texas, and Beaver Counties.

The saturated surficial deposits both east and west of the High Plains underlie principally the flood plains and terraces. The thickness is generally less than 50 feet in Union and Cimarron Counties and generally less than 75 feet east of Gray and Meade Counties. Locally, the thickness of saturation in the eastern part of the basin is reported to be as much as 85 feet.

Water in Storage

Vast quantities of ground water are in storage in the surficial aquifers in the Cimarron Basin--largely beneath the High Plains (pl. 3). The amount of water cannot be determined precisely with the data now available, although it can be roughly estimated. The difficulties in determining the storage are caused mainly by the wide range in texture and sorting--both vertically and laterally--of the surficial deposits. The texture changes so much within short distances laterally that the cost of determining these changes precisely by test drilling would be prohibitive.

In much of the High Plains the unconsolidated sediments consist of alternating zones of widely differing textures with the result that water in coarse-grained materials underlying fine-grained materials may be under artesian head, and the specific yield of the materials cannot be determined precisely by the relation of the amount of water withdrawn to the decline in head. The aquifer is a complex hydrologic system with widely differing heads. Although the aquifer is believed to have an overall specific yield of about 15 percent, its storage coefficient has been found to be as low as 0.0001 where it is under artesian head. A water-level decline of 1 foot in an area of 1 square mile in which the specific yield is 15 percent will release nearly 100 acre-feet of water from storage; the same decline over the same area with a storage coefficient of 0.0001 will release less than 1 acre-foot of water from storage.

If the artesian heads are ignored and the aquifer is assumed to have a specific yield of 15 percent, then the acre-feet of water theoretically recoverable from any area can be estimated by multiplying the area, in square miles, by the thickness of saturation, in feet, by 100. The volume of water thus determined does not represent the amount that can be pumped; to drill enough wells to drain all the water from the aquifer is not economically feasible. In addition, as the water levels are lowered by pumping, the saturated thickness decreases, the well yields decrease, and the pumping lifts increase--thus pumping for irrigation becomes impractical or uneconomical before the water in the aquifer can be exhausted.

If it is assumed that all but 50 feet of the saturated material could be drained by pumping, then the amount of ground water that theoretically could be pumped from storage (in acre-feet) can be estimated by multiplying the area (in square miles) in which the thickness of saturation exceeds 50 feet by the average thickness (in feet) of saturation in excess of 50 feet by 100. By planimetering the intervals of saturation on plate 3, it was determined that in an area of about 5,000 square miles, the amount of water that theoretically could be pumped from storage if the water table were lowered to within 50 feet of the base of the aquifer is 112 million acre-feet. (See table 2.)

The amount of water in storage beneath the flood plains and terraces east and west of the High Plains is believed to be comparatively small.

Table 2.--Estimated recoverable water in storage in the High Plains deposits of the Cimarron Basin 1/

Interval of saturated thickness (ft.)	Average saturated thickness (ft. -50 ft.)	Area (sq. mi.)	Storage (acre-feet)
50 - 100	25	836	2,090,000
100 - 150	75	555	4,162,500
150 - 200	125	255	3,187,500
200 - 250	175	333	5,827,500
250 - 300	225	552	12,420,000
300 - 350	275	631	17,352,500
350 - 400	325	862	28,015,000
400 - 450	375	586	21,975,000
450 - 500	425	168	7,140,000
500 - 550	475	79	3,752,500
550 - 600	525	54	2,835,000
More than 600	575	55	3,162,500
Total			111,920,000

1/ Based on estimated specific yield of 15 percent.

By planimetering the areas shown on plate 3, and by assuming an average thickness of 35 feet and a specific yield of 20 percent, the ground water in storage is estimated to be about 150,000 acre-feet in Union and Cimarron Counties and about 9 million acre-feet in the eastern part of the basin.

Chemical Quality of the Water

Pattern diagrams illustrating the chemical quality of water from representative wells tapping surficial aquifers in the Cimarron Basin are shown on plate 5. Water from the High Plains deposits is of uniformly good quality throughout the plains and generally is rated good to excellent for irrigation. The water generally contains between 200 and 500 ppm of dissolved solids and commonly has a hardness between 150 and 300 ppm. The water commonly is used for municipal supply without treatment (other than chlorination), although most residents use home water softeners to reduce the hardness. Locally, fluoride concentrations are higher than desirable.

Water in the unconsolidated sediments beneath the terraces and flood plains generally is more highly mineralized than water in the High Plains sediments (pl. 5). The water commonly is treated for municipal use, but it generally is satisfactory for irrigation. Locally, it is highly mineralized and is essentially unusable. For details of water quality in the Cimarron Basin, the reader is referred to the publications listed at the end of this report.

Growth of Irrigation

Most of the irrigation wells tapping the surficial aquifers in the Cimarron Basin have been drilled since 1940; the greatest development was after 1950. Although records for the entire basin are not available, the increases in irrigated acreage and in the quantity of water applied in the Kansas part of the basin have been recorded by the Kansas Water Resources Board and are shown in table 3. The irrigated acreage in 1965 was almost 450,000, and the annual application of water during 1963-65 averaged about 760,000 acre-feet.

During the compilation of this report, estimates of the total number of irrigation wells were made for each township within the basin, and the results are shown on plate 5. The data indicate that there are more than 2,500 irrigation wells in the basin, of which about 90 percent obtain water from surficial aquifers.

The most concentrated development of irrigation from wells has been in Grant and Stanton Counties and adjacent areas--generally referred to as the Grant-Stanton area. Less than 10 irrigation wells were in use in that area in 1940; more than 700 wells discharged about 508,000 acre-feet of water to irrigate about 236,000 acres in that area in 1965. (See fig. 7.) The development in Beaver County also has been rapid. In 1952, 18 wells supplied water for the irrigation of 613 acres of land; by 1959, 78 wells supplied water for the irrigation of 11,520 acres.

Comparatively little water has been pumped from wells tapping the surficial aquifers beneath the terraces and flood plain of the Cimarron River. Four irrigation wells have been reported on the flood plain in Union County, and several wells have been drilled on both the terraces and flood plain in the eastern part of the basin.

Table 3.--Growth of Irrigation in the Cimarron Basin, Kansas

Year	Acres irrigated	Average rate of application (acre-feet per acre)	Total water applied (acre-feet)
1950	35,290	1.70	60,000
1951	41,310	1.75	72,300
1952	47,840	1.94	92,700
1953	58,240	2.00	116,300
1954	92,450	1.98	183,300
1955	159,840	2.10	335,700
1956	222,320	2.51	558,200
1957	251,610	2.05	515,000
1958	275,500	1.74	480,500
1959	310,800	1.71	532,300
1960	311,800	1.70	530,900
1961	319,800	1.76	563,900
1962	336,400	1.81	610,500
1963	345,200	2.06	712,700
1964	381,100	2.33	887,200
1965	446,100	1.52	679,100

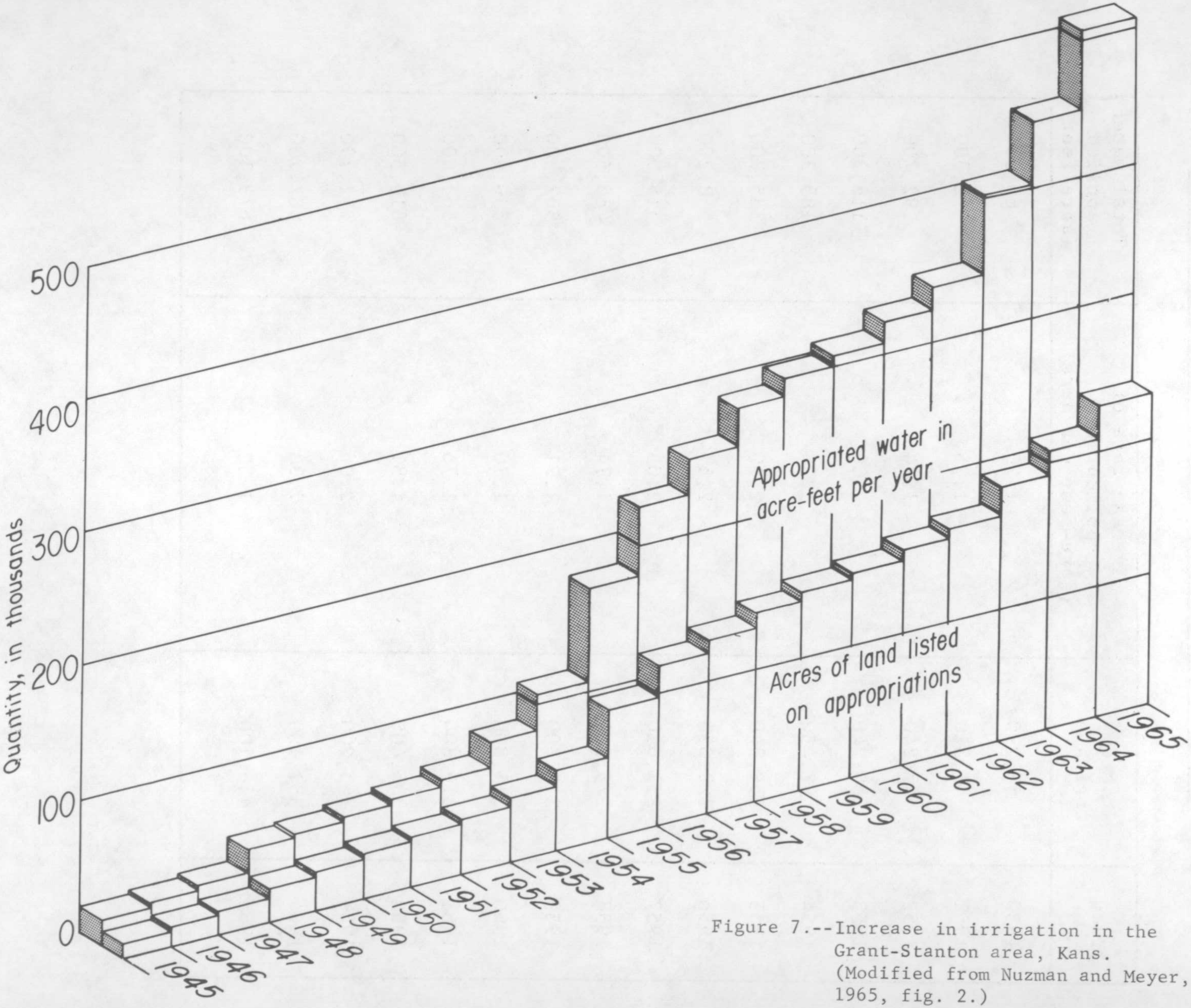

Figure 7.--Increase in irrigation in the Grant-Stanton area, Kans. (Modified from Nuzman and Meyer, 1965, fig. 2.)

Changes in Water Level

The contours on plate 5 indicate the net change in water level in the High Plains deposits in the Cimarron Basin from the period before extensive pumping began until 1966. The areas of most serious decline are, in general, those that have had the greatest concentration of irrigation wells for the longest period of time. The earliest large-scale development of irrigation from wells in the High Plains deposits of the Cimarron Basin was in the Grant-Stanton area; the large-scale development in Baca County is comparatively recent and involves principally the bedrock aquifers.

Declines of water levels in the Grant-Stanton area had reached new records at the time of annual water-level measurements in January 1965; locally they exceeded 100 feet. After the record-breaking storms of 1965, a significant rise appears to have taken place in water levels in parts of the cone of depression as indicated by figure 8. The net decline as of January 1966, as shown on plate 5, also indicates an improvement over the previous year, as the maximum decline was less than 80 feet. Reports of water-level trends during the 1966 pumping season indicate that the water table in some parts of the Grant-Stanton area is establishing new record lows and, hence, that the water-level measurements made in January 1966 may not have reflected the true picture of the water table at that time.

Water in the Grant-Stanton area is produced from multiple aquifers in the High Plains deposits. The upper aquifer locally was depleted very quickly, and many wells then were drilled through the underlying fine-grained sediments into a deeper aquifer of sand and gravel.

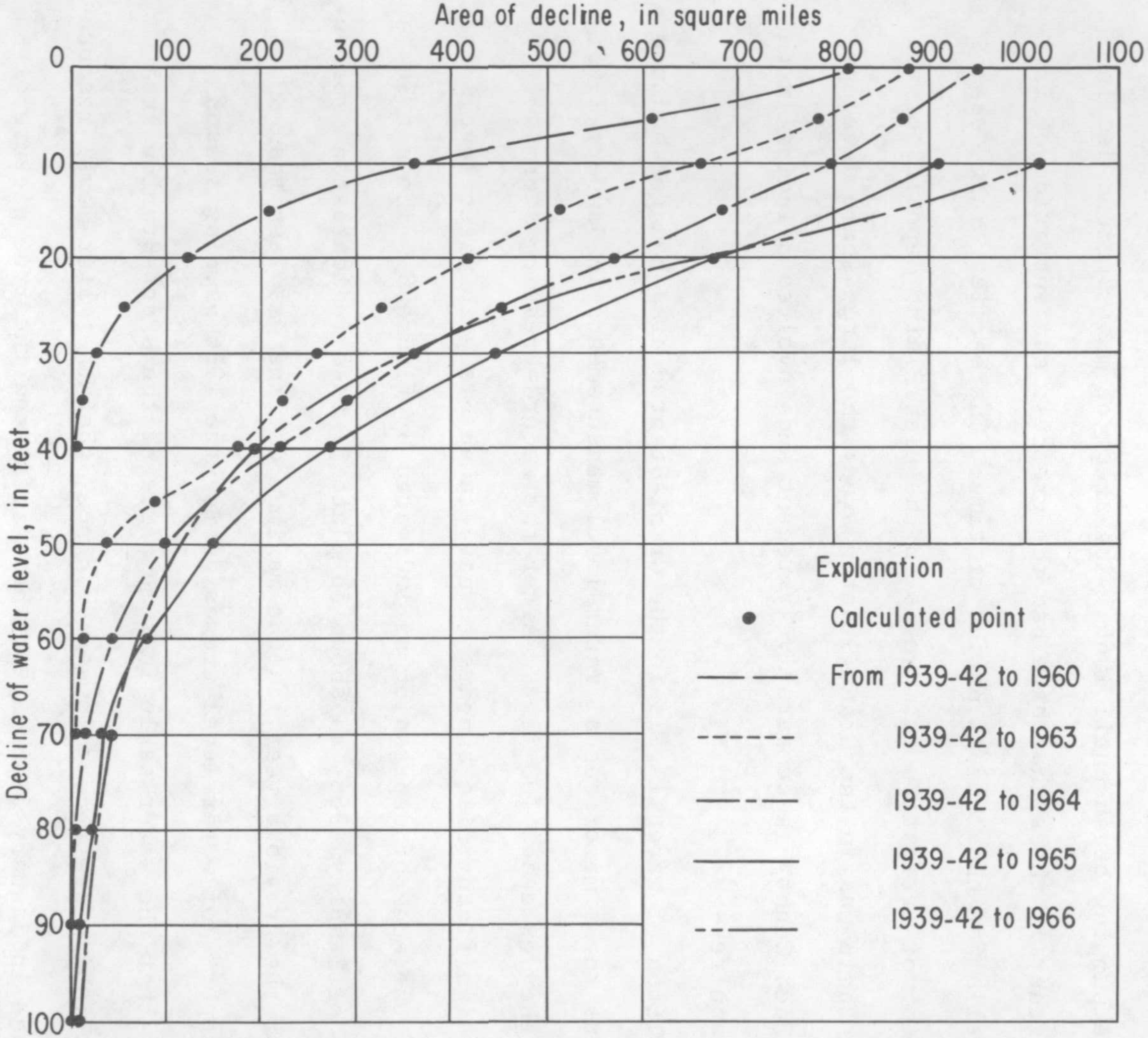

Figure 8.--Areal decline of water levels in the Grant-Stanton area, Kans. (Modified from Nuzman and Meyer, 1965, fig. 5.)

The maps showing net decline of water level have been based on annual measurements of the water levels in essentially all irrigation wells in the area (Nuzman and Meyer, 1965) because it was not possible to select observation wells producing from a single horizon. The contours on plate 5 were based on measurements made in irrigation wells. The State and Federal agencies involved in water studies in this area are now (Sept. 1966) reevaluating their observation-well program with the aim that future reports will contain net decline maps that are representative of a single-aquifer system rather than a multiple-aquifer system.

The water-level rises recorded in the Grant-Stanton area between January 1965 and January 1966 may reflect rapid recharge to the upper perched aquifer rather than to the more extensively developed deeper aquifer, and some erroneous measurements may have resulted from the cascading of water in the multiple-screen wells from the perched aquifer to the lower aquifer. If this is proved correct by the results of the January 1967 selected observations, then the contours on plate 5 present an overly optimistic picture of the problem of water-level decline in the Grant-Stanton area.

Significant water-level rises in wells tapping the surficial aquifer have been noted in several other parts of the Cimarron Basin (pl. 5). Water levels appear to have risen in large areas in southern Baca County since the late 1950's--locally as much as 24 feet. Other appreciable rises were measured in Cimarron and Beaver Counties and in northwestern Stanton County. These rises probably reflect unusually heavy local recharge as a result of the unusually large storms of 1965.

Potential Yield of Wells

The yield of a well depends upon the thickness and permeability of the water-bearing materials, the degree of penetration of these materials by the well, the diameter of the well, the efficiency of the well screen, the efficiency of the pump, and other factors. Because of the wide range in these factors, there is no accurate way in which to predict the yield of a well. If certain assumptions are made, however, it is possible to make generalized estimates of potential well yields that are useful to water planners.

If it is assumed that the sites for irrigation wells are selected by proper test drilling, that the wells are drilled to the specifications generally used by successful irrigation-well drillers in the area, that pumping equipment of customary efficiency is used, that the wells penetrate the entire aquifer and reach bedrock, and that the permeability of the aquifer is uniform, then the yield of a well tapping the surficial aquifers will be governed by the thickness of saturated material. In practice, this does not happen because the surficial aquifers have a heterogeneous texture and range widely in permeability. A well tapping a coarse gravel in an area where the thickness of saturation is less than 50 feet may yield more water than a well tapping finer-grained materials of much greater saturated thickness.

Plate 4 shows the estimated yield of wells penetrating the unconsolidated deposits in the Cimarron Basin. Although the map is not accurate in detail, it does reflect in a broad way the general availability of water to properly constructed wells. Highest potential yields are available in the High Plains part of the Cimarron Basin, where there are large areas in which properly constructed wells can be expected to yield more than 500 gpm. Yields of 50 to 500 gpm may be expected near the margins of the High Plains and on the flood plain and terraces of the Cimarron River--both east and west of the High Plains.

POTENTIAL DEVELOPMENT

The extent to which the aquifers in the Cimarron Basin can be developed not only depends on the available supply but also is a management problem that is governed to a large extent by State water laws and by economics. The total amount of ground water in storage in the Cimarron Basin is tremendous--perhaps as much as 140 million acre-feet in the surficial aquifers alone. The storage represents an accumulation over a long period of time at a slow rate of recharge that ranges from less than 1 inch annually over much of the western part of the basin to perhaps 8 inches in the more humid eastern part.

Ground water is in transient storage in the aquifers, but it moves very slowly; hence, it is not uncommon for an aquifer to be greatly overdeveloped in one area (in relation to the perennial supply) and essentially undeveloped in nearby areas. This is illustrated by the cones of depression in the water table shown on plate 5 and on figures 5 and 6. If perennial supply is considered the principal criterion for development, then most of the aquifers of the Cimarron Basin (particularly in the western part) are already overdeveloped; if not, then there are large quantities of ground water in storage that are available for long-term development as one would develop any other mineral deposit.

Bedrock Aquifers

The bedrock aquifers have undergone rapid development in the past 10 years--particularly in Baca County (fig. 4). Although individual aquifers may not be highly productive, wells are now being drilled to great depths and are being screened opposite all water-bearing intervals with the result that new lands are being irrigated in areas where irrigation previously was not considered economically feasible. How many more areas in the Cimarron Basin can be developed in this manner is not known, but large areas in Baca and Prowers Counties, and smaller areas in Cimarron and Union Counties appear to have potential for such development. Where the bedrock has been dissected by the Cimarron River and its tributaries, such as in southwestern Baca, southeastern Las Animas, northwestern Cimarron, and much of Union County, the bedrock probably is largely drained of water and has little potential for large-scale development.

One of the greatest potential sources of undeveloped ground water in bedrock is in the High Plains section where the Dakota Sandstone, the Cheyenne Sandstone or equivalents, and the rocks of Triassic age underlie surficial aquifers. (See plate 4 for the limits of the Dakota and Cheyenne.) In those areas--particularly in southwestern Kansas--adequate supplies generally have been available in the surficial aquifers, and the bedrock aquifers have remained essentially untapped. A few wells recently have been constructed so that they produce water from both the surficial and bedrock aquifers, and it is anticipated that many more wells of this type will be constructed as the water levels continue to decline in the surficial aquifers. In the areas lying between the western limit of saturation of the High Plains deposits (pl. 3) and the eastern limits of the Dakota and Cheyenne (pl. 4), there may be more than 16,000,000 acre-feet of water in storage in the Cheyenne or equivalents (assuming an average thickness of 75 feet and an average specific yield of 15 percent) and about 23,000,000 acre-feet in the

Dakota Sandstone (assuming an average thickness of 100 feet and an average specific yield of 10 percent).

Surficial Aquifers

The surficial aquifers in the High Plains section of the Cimarron Basin have already been developed extensively--particularly in the Grant-Stanton area. However, large areas in the High Plains remain undeveloped as indicated by the areas of relatively few irrigation wells shown on plate 5, and the potential yields shown on plate 4. The extent of additional development will depend on many factors, including types of soil, pumping lifts, crop prices, and management decisions as to how rapidly the aquifer should be depleted. As the recharge in the High Plains is very low (probably less than 1 inch annually), and as the average annual application of water to irrigated crops is about 23 inches (based on data in Kansas), it is obvious that only a very small fraction of the land can be placed under irrigation without exceeding the perennial supply. As a mining operation, however, much more ground water can be developed.

The surficial aquifer along the flood plain and terraces of the Cimarron River west of the High Plains--mainly in Union County--probably can be developed further. Although the recharge from precipitation probably is very low, the aquifer has hydraulic connection with the river and, hence, can be recharged by stream losses when the water table is lowered. The conjunctive use of surface water and ground water in this area should tend to stabilize the supply and permit additional development.

The surficial aquifer beneath the flood plain and terraces of the Cimarron River east of the High Plains is only slightly developed (pl. 5). From Woods County, Okla., eastward to the confluence with the Arkansas River, the surficial deposits have considerable potential for development of large-capacity wells. Although the thickness of saturated materials is much less than in the High Plains, yields of 50 to 500 gpm can be obtained from properly constructed wells in may places (pl. 4). As the aquifer in most places is hydraulically connected to the river, it can be used conjunctively with the surface-water supplies. In addition, the increased precipitation toward the east end of the basin results in greatly increased recharge and a greatly increased perennial supply to the aquifer. With proper management, the aquifer can be developed extensively without exceeding the perennial supply.

PROBLEMS RESULTING FROM DEVELOPMENT

The principal problems caused by the development of ground-water supplies in the Cimarron Basin are concerned with declining water levels--a natural consequence of widespread development in areas of low recharge and in aquifers that are under artesian head. The rapid declines in water levels in Baca County are largely the result of declining artesian heads. The declines can be expected to continue at a rapid rate until the water levels reach the top of the aquifer and the much slower process of gravity drainage begins. In some places, pumping lifts may become economically excessive before that situation develops.

The extensive declines of water levels in the Grant-Stanton area are partly the result of unwatering the aquifer but locally have been amplified by the presence of multiple aquifers, some of which are partly under artesian head. The first wells in the area obtained water from aquifers that were in the upper part of the High Plains sediments and that were in places perched above the regional water table. These aquifers were under water-table conditions but locally were relatively thin. With concentrated development for irrigation, the upper aquifers were depleted rapidly in some areas, and discharges declined. To obtain adequate supplies, new wells were drilled and old wells were deepened through the underlying, partly confining sediments into deeper lying aquifers that were under artesian or semi-artesian head. The water levels then declined rapidly for a short period because of the low artesian storage coefficient. Gravity drainage was later reestablished in many areas, but the rate of decline, although diminished, has remained serious. As the levels continue to decline, the deeper aquifers, including those in the bedrock formations, are likely to be brought into production.

Local problems of water quality may also result from the development of ground-water supplies, although none have been called to the attention of the writers. The recent practice of developing multiple-screen wells by drilling through and perforating opposite all water-bearing units (principally in bedrock) will result in widespread mixing of water of differing quality from the various bedrock aquifers. Although the end product pumped from the well may be suitable for irrigation, the indiscriminate movement of water between aquifers through multiple-screen wells over a long period of time may have a deleterious effect on the water in some aquifers with the result that the water may become unfit for many uses other than for irrigation.

PARTIAL SOLUTION OF PROBLEMS

The most serious ground-water problem in the Cimarron Basin appears to be the extensive decline of water levels with pumping. There is really no cure for the problem because recharge in the High Plains is almost negligible and because the extraction of ground water is primarily a mining operation. Management of the ground-water supplies by the controlled spacing of wells, by the limitation of pumpage, and by other means will result in better distribution of withdrawals and perhaps will prolong the life of the supply, but these are determinations that must be made by State governments, and they will, no doubt, differ from State to State, even though the aquifers are interstate in extent.

If additional supplies of surface water can be developed in the upper Cimarron Basin, the bedrock and surficial aquifers could perhaps be recharged through wells. Experiments in the High Plains of Texas and elsewhere, however, indicate that problems of sediment content, water incompatability, and air entrainment generally have prevented this method from becoming economically feasible. Recharge by channel infiltration might locally alleviate the problem in the surficial aquifers. Water-level records in parts of the Cimarron Basin indicate significant amounts of recharge along ephemeral streams after periods of flood. Retention dams to hold and retard the flood flows and, hence, to allow the flood water more time to infiltrate might be of considerable help in parts of the Grant-Stanton area. Even under the most favorable conditions, however, the amount of water that could be added to the aquifers by means of artificial recharge probably would represent a very small proportion of the total annual overdraft from the aquifer--perhaps less than 5 percent.

There appears to be no solution to the problem of mixing water of differing quality through multiple-screen wells. These wells are being developed mainly in areas where a single aquifer is not sufficiently thick or permeable to supply the water needed; hence, two or more aquifers must be tapped to obtain the desired supply. The problem in newly developed areas can be avoided only by strict State regulation of drilling; the problem in areas already extensively developed probably is beyond solution.

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