Geology and Ground-Water Resources of Yuma County, Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-J

Prepared in cooperation with the Colorado Water Conservation Board

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By WILLIAM G. WEIST, Jr.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF YUMA COUNTY, COLORADO

By William G. Weist, Jr.

ABSTRACT

Yuma County has an area of 2,383 square miles and in 1950 had a population of 10,827. It consists largely of relatively flat plains and undulating sand-dune areas but locally is cut by shallow valleys and, in the southeast and east-central parts, by deep canyons. The climate is semiarid to subhumid, and the average annual precipitation is about 17 inches. Farming and ranching are the principal occupations in the county.

The oldest rocks exposed in Yuma County are those of the Upper Cretaceous Pierre shale, which crops out in the eastern part of the county along the North Fork of the Republican River, the Arikaree River, and their tributaries. The Ogallala formation of Pliocene age, the principal aquifer, overlies the Pierre shale in much of the county. In the upland the older rocks are covered by Peorian loess or by Pleistocene to Recent sand dunes. The major stream valleys contain Pleistocene and Recent alluvium which forms the other important aquifer in the county.

The depth to ground water, which ranges from zero at water-table springs and seeps to about 250 feet in the north-central part of the county, is shown by a depth-to-water map. The report also contains maps showing by contours the shape and slope of the water table and of the surface of the Pierre shale. Maps show also the depth to the Pierre shale and the thickness of saturated water-bearing material in the county.

The Ogallala and alluvium are recharged principally by infiltration of precipitation within the area. They are recharged substantially also by percolation from intermittent streams and depressions, and by underground movement from adjacent areas to the south and west. Ground water is discharged from the county by underflow into adjacent areas to the east and north, by evaporation and transpiration in areas where the water table is shallow, by seepage into perennial streams, and through wells and springs.

Most of the wells in Yuma County were drilled, but a few were dug. Of the more than 600 wells inventoried about 100 are used for irrigation. Conditions are favorable throughout most of the county for additional development of water from wells for irrigation without affecting the flow of streams.

Ground water in Yuma County is moderately hard and some contains concentrations of silica too great for some industrial uses, but it is suitable for most

other uses. The average concentration of fluoride is about 1 ppm (part per million). Nitrate concentrations are below the danger level, and all the water tested was of good quality for irrigation.

Tabulated data presented in a separate report by Weist in 1960 include records of 615 wells, chemical analyses of the water from 27 wells, the results of aquifer tests made on 25 wells, and logs of 147 test holes, water wells, and seismograph shotholes. The logs include those from 34 test holes drilled as part of this investigation.

INTRODUCTION

Ground water is one of the principal natural resources of Yuma County, because nearly all water supplies in the area are obtained from wells and springs. There is, therefore, a need for an adequate understanding of ground water in order to facilitate its safe development.

Purpose and scope of the investigation—An investigation of the geology and ground-water resources of Yuma County, Colo., was begun in July 1956 as a part of the program of ground-water investigations being made in Colorado by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board. The project was aimed toward determining the origin, movement, and availability of ground water for domestic, stock, industrial, irrigation, and municipal supplies.

Location and extent of the area.—Yuma County is in the easternmost part of Colorado, between lat 39°34′ and 40°26′ N. and long 102°03′ and 102°47° W. (fig. 1). The county contains 70 townships and has an area of 2,383 square miles.

Previous investigations.—The geology and ground-water resources of Yuma County were described briefly by Darton (1905) in his report on the underground-water resources of the Great Plains. Cardwell (1953) included Yuma County in his report on the development of irrigation wells in the Kansas River basin in eastern Colorado. A report on the geology and ground-water resources of the Frenchman Creek drainage basin (Cardwell and Jenkins, 1963) includes part of Yuma County.

The geology of the area around Wray was described in detail by Hill and Tompkin (1953). Detailed studies of three prospective damsites in the county were made by the U.S. Bureau of Reclamation and the Corps of Engineers of the U.S. Army during 1947.

No comprehensive studies of the geology and ground-water resources of Yuma County had been made previous to this investigation. Detailed studies have been made of the geology and ground-water resources of several nearby areas, including Kit Carson County, Colo. (Chase, G. H., written communication, 1960), Wallace County, Kans. (Elias, 1931), Cheyenne County, Kans. (Prescott, 1953a), and Sherman County, Kans. (Prescott, 1953b).

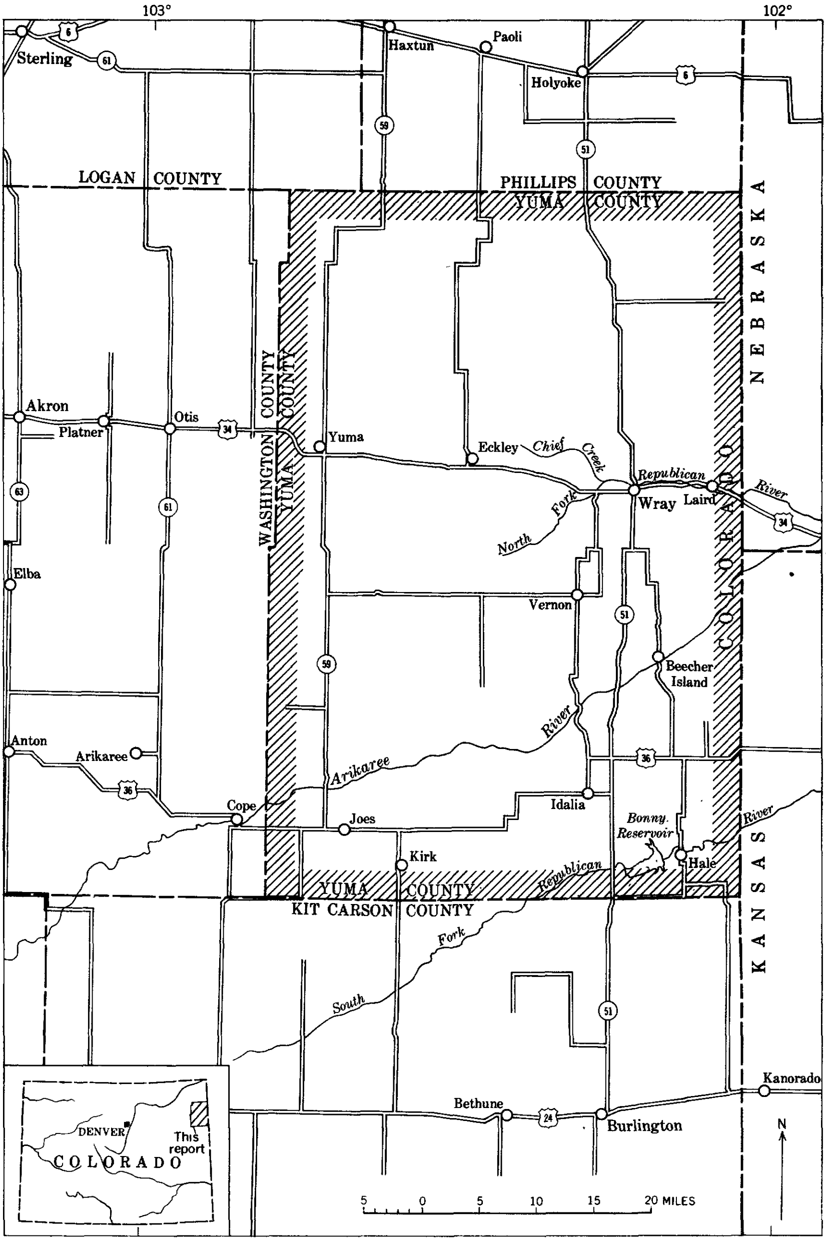

FIGURE 1.—Index map of Yuma County, Colo., and vicinity.

Methods of investigation.—The fieldwork for this report was done during July–October 1956, June–October 1957, and June–August 1958. The writer was assisted by R. E. Dickson from July 1956 to September 1956 and from July 1957 to September 1957, and by A. C. Utter during the first half of July 1958. Records of more than 600 wells were obtained during the investigation. The depth of and the depth to water in most of the wells were measured. Reported depths and reported water levels of the other wells were obtained from well owners, tenants, and drillers. Data on the character and thickness of water-bearing materials, the yield and drawdown of wells, and the general quality of the water were obtained from the same sources.

Samples of water were collected from 27 wells in the area and were analyzed in the laboratory of the U.S. Geological Survey at Denver, Colo., to determine their mineral content.

Thirty-four test holes were drilled in strategic areas where little or no subsurface information was available. Cuttings from the test holes were collected and studied by the writer. More than 500 additional logs of wells, test holes, and seismograph shotholes were obtained from well owners, drillers, and oil companies.

Aquifer tests were made on several of the irrigation wells to compute the coefficients of transmissibility, permeability, and storage of the aquifers.

The geologic formations, except the Pierre shale, were mapped by field observations and from aerial-photograph diapositives by means of a multiplex projector. The Pierre shale was mapped in the field by use of aerial photographs; the outcrop pattern was transferred to the base map by means of a Saltzman projector. The geology of the area along the North Fork of the Republican River was taken, with minor changes, from the map prepared by Hill and Tompkin (1953).

Other field data were compiled on county maps prepared by the State Highway Department and transferred to the base map, which was prepared from high-altitude aerial photographs by the Topographic Division of the U.S. Geological Survey and modified by H. E. McGovern and the writer. The wells shown on plate 4 were located within the sections by means of an odometer and their positions should be accurate to within 0.1 mile. The altitudes at the wells and test holes were determined by a level crew headed by V. M. Burtis.

Well-numbering system.—Wells described in this report are numbered according to their location within the Federal system of public-land subdivision. (See fig. 2.) The first letter of a well number indicates the quadrant of the meridian and base-line system in which the well is located. The quadrants are identified by capital letters, beginning with A in the northeast quadrant and proceeding counterclockwise. All the wells in this report are in the northwest (B) or southwest (C) quadrants of the Sixth principal meridian and baseline system. The township in which a well is located is indicated by the first numeral of the well number, the range by the second numeral, and the section by the third numeral. The lowercase letters that follow the section number indicate the position of the well within the section; the first letter indicates the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section, or 10-acre tract. The letters a, b, c, and d are assigned in a counter clockwise direction, beginning in the northeast quadrant. If

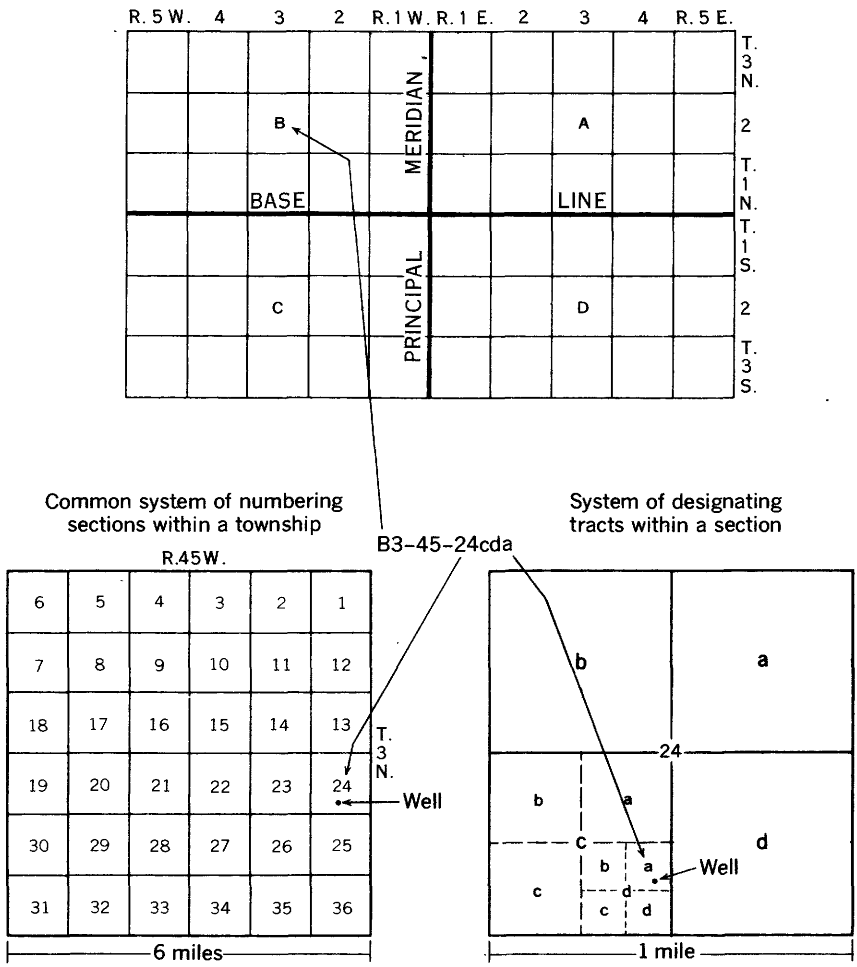

FIGURE 2.—Sketch showing system of numbering wells in Colorado.

2 or more wells are located within the same 10-acre tract, they are distinguished by numerals following the lowercase letters.

Acknowledgments.—The writer gratefully acknowledges the cooperation of the residents of Yuma County who allowed their wells to be measured, especially those whose wells were used for aquifer tests. Thanks go particularly to Amer Lehman, Byron Mitchell, and John Clark, Jr., who kept the writer informed of new wells being drilled, enabling him to get samples of well cuttings. The writer was fortunate to get many logs of wells, test holes, and seismograph shotholes. For most of these he is indebted to the following drillers and organizations: Canfield Drilling Co., Fred Hilt and Sons, Wrape and Payne, Charles Fastabend, Elbert Zion, U.S. Soil Conservation Service, U.S. Bureau of Reclamation, Corps of Engineers, U.S. Army, California Co., Texas Co., Ohio Oil Co., Lion Oil Co., Phillips Petroleum Co., Shell Oil Co., Pan American Oil Co., and Carter Oil Co.

GEOGRAPHY

Topography and drainage.—Yuma County lies entirely within the High Plains section of the Great Plains physiographic province. The topography ranges in altitude from about 4,430 feet in the southwest corner to about 3,400 feet near where the North Fork of the Republican River leaves the county. The total relief, therefore, is about 1,030 feet.

The surface of Yuma County consists of a nearly flat plain, slightly dissected by small intermittent streams and rather deeply dissected in the eastern half by both forks of the Republican River, the Arikaree River, and some of their tributaries (fig. 3). In parts of the county, particularly in the northeast quarter and the southwest quarter north of the Arikaree River, the relatively flat topography is broken by low, undulating sand dunes (fig. 4). The flat area underlain by the unconsolidated deposits contains many broad shallow depressions which are filled with water after heavy rains to form temporary lakes and ponds (figs. 5 and 6).

Yuma County is drained by the North Fork of the Republican River, the Arikaree River, and the South Fork of the Republican River, all of which are tributary to the Kansas River. Northwestern Yuma County is drained by Red Willow Creek, which loses its identity among the sandhills in the northeastern part of the county.

Climate.—The climate of Yuma County is semiarid to subhumid. The heaviest rains fall during the growing season, which at Wray normally extends from May 7 to September 28 (fig. 7). The mean annual precipitation in Yuma County ranges from 16 inches in the northwest to 20 inches in the southeast. The recorded mean annual precipitation, in inches, at the principal weather stations in Yuma County is as follows: Yuma, 16.18; Wray, 17.20; and Bonny Dam, 20.40. The annual precipitation at Yuma and Wray is shown in figure 8.

The temperature in Yuma County generally is high during summer days; but, owing to the high altitude, the relatively low humidity, and the moderate winds, the summer nights are generally comfortable. The cold winters are broken by periods of moderate weather. The mean annual temperature, as recorded at Wray, is 51.0° F. The highest average monthly temperature is 76.4°F in July and the lowest is 27.8°F in January (fig. 7).

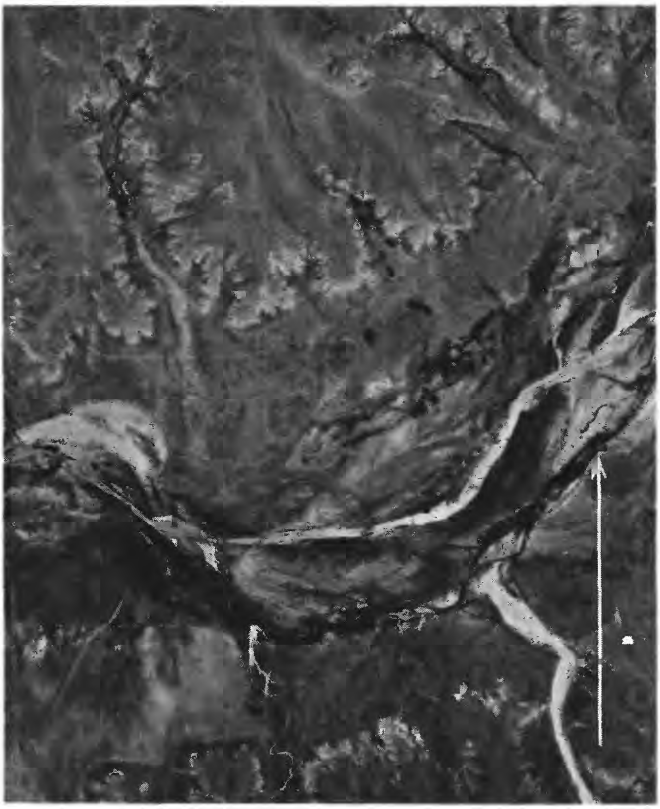

FIGURE 3.—Aerial photograph showing well-developed drainage along the Arikaree River in eastern Yuma County. North arrow is half a mile long. Photograph by U.S. Department of Agriculture.

Mineral resources.—The principal mineral resources of Yuma County are sand, gravel, and caliche (called gyp or gyp rock), which are quarried extensively for use as road metal.

Although several unsuccessful oil-test holes have been drilled in Yuma County, the area has not been tested thoroughly and additional drilling may be expected. Some natural gas was produced for a while near Beecher Island.

Population.—According to the 1950 census, Yuma County's population was 10,827, a decrease of 10.5 percent since the 1940 census. Wray, the county seat and largest town in the county, had a population of 2,198 in 1950. The population of other settlements in the county in 1950 was as follows: Yuma, 1,908; Eckley, 295; Laird, 165; Joes, about 100; Kirk, about 100; Vernon, about 75; and Idalia, about 72.

FIGURE 4.—Aerial photograph showing sand-dune area north of Wray. Note lack of a drainage system. North arrow is half a mile long. Photograph by U.S. Department of Agriculture.

Agriculture.—For many years livestock was the principal agricultural product of Yuma County, but with the rapid development of modern farm machinery, farming practices, and drought-resistant plants, much more of the land is now devoted to the cultivation of crops. Yuma County had more cropland in 1954 than at any other time in its history. The following table shows reported acreages for 1954:

	Acres
Pastureland	893, 660
Cropland	369, 500
Corn	64, 350
Sorghums	78, 650
Wheat	150, 000
Other grains	49, 000
Hay	27, 500

FIGURE 5.—Aerial photograph showing flat upland area underlain by the Peorian loess and having poorly developed drainage. North arrow is half a mile long. Photograph by U.S. Department of Agriculture.

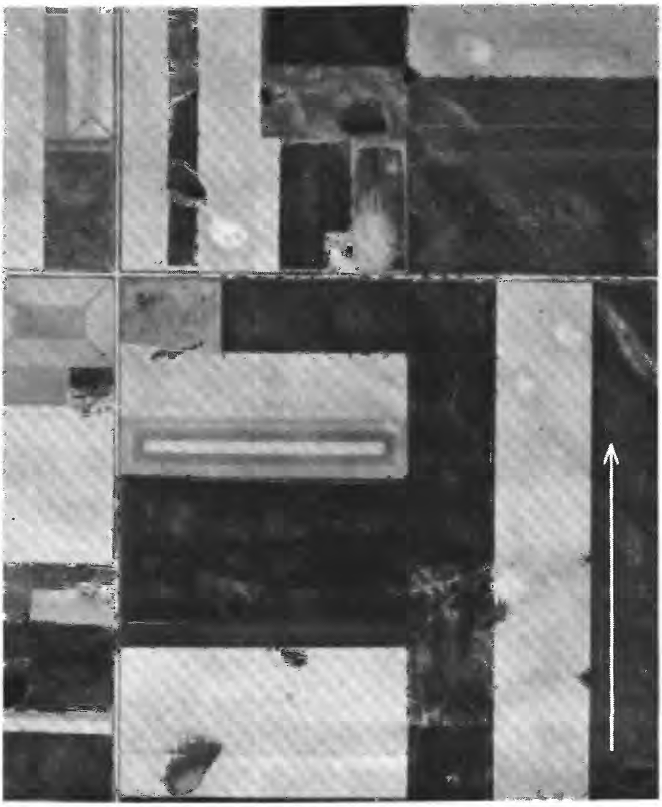

FIGURE 6.—Aerial photograph showing upland area underlain by the Ogallala formation and having poorly developed drainage. North arrow is half a mile long. Photograph by U.S. Department of Agriculture.

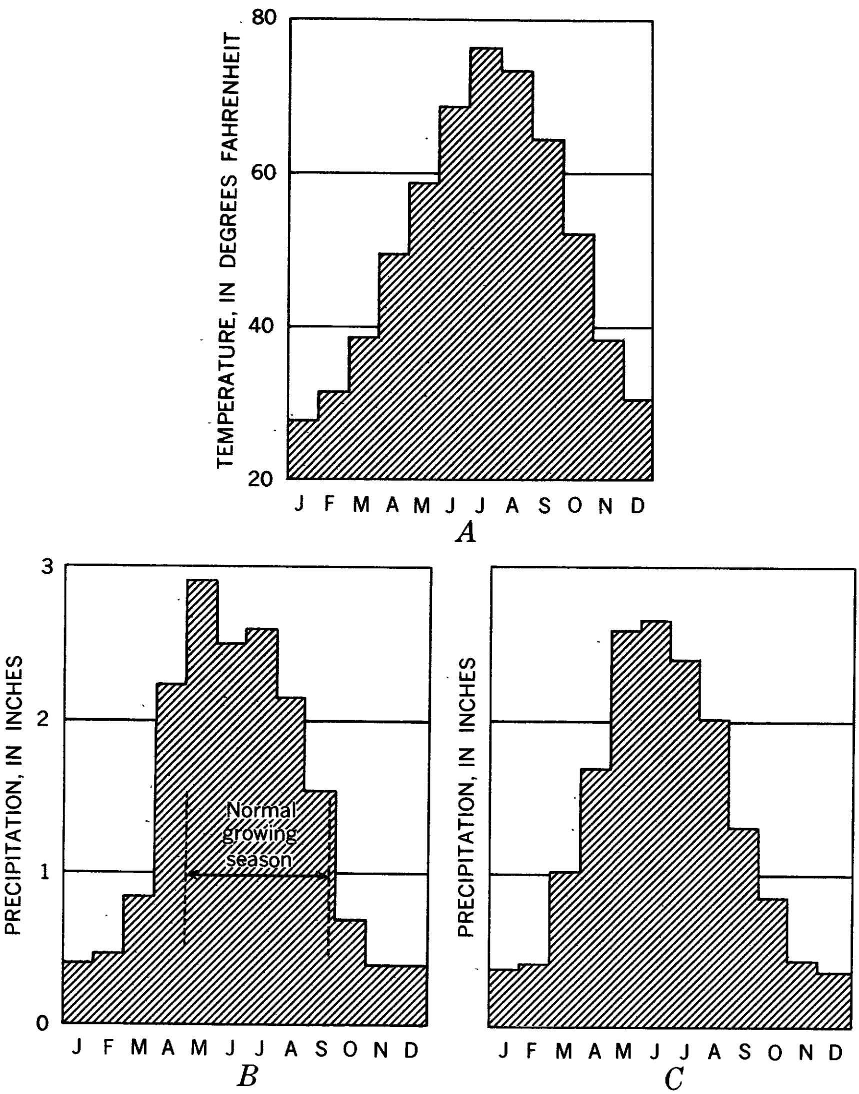

FIGURE 7.—Average monthly precipitation and temperature in Yuma County. *A*, Temperature at Wray; *B*, Precipitation at Wray; *C*, Precipitation at Yuma.

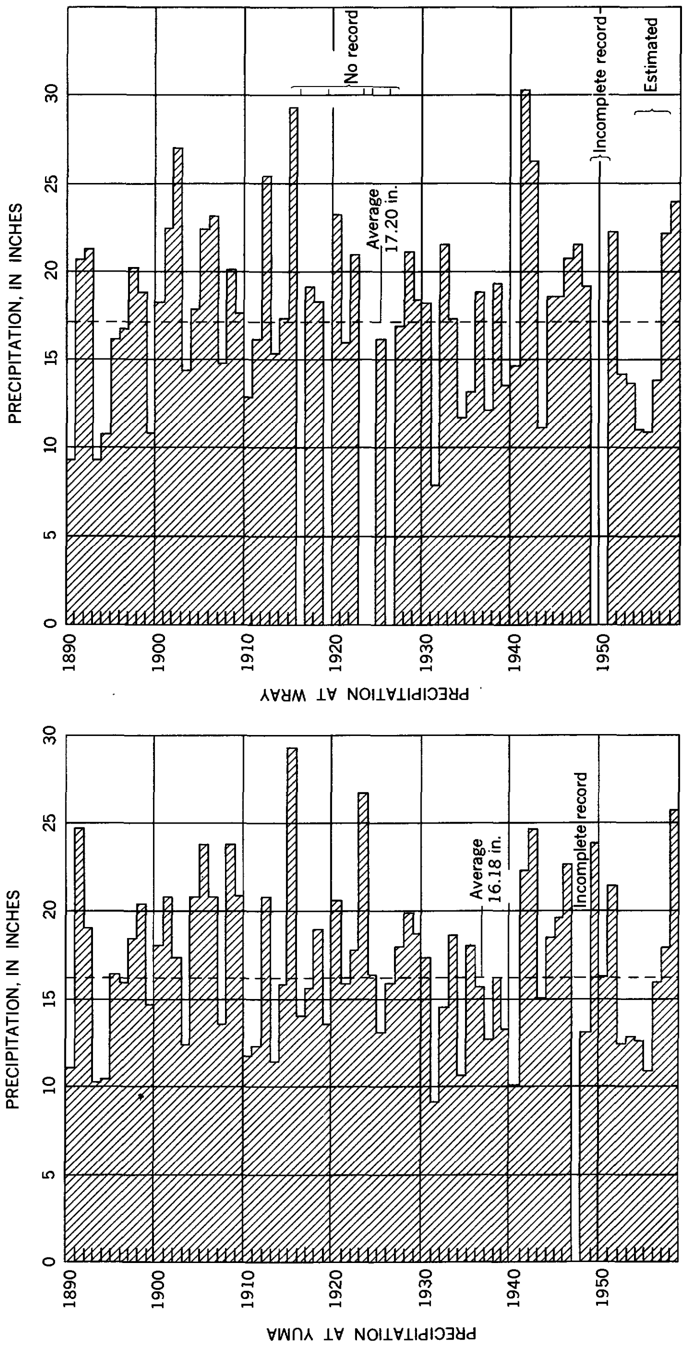

FIGURE 8.—Annual precipitation at Wray and Yuma, Yuma County.

The irrigated acreage was 5,100 in 1954, and it had nearly doubled by 1958.

Transportation.—Yuma County is served by the Chicago, Burlington and Quincy Railroad, whose main line goes through Yuma, Eckley, Wray, and Laird. The Continental Bus Co. serves communities on U.S. Highways 34 and 36. The paved roads in the county are U.S. Highways 34 and 36 and State Highways 51 and 59. A network of unpaved graded roads serves the principal agricultural areas. The county is not served by commercial air transportation.

GENERAL GEOLOGY

SUMMARY OF STRATIGRAPHY

Rock units exposed in Yuma County are of sedimentary origin and range in age from the Upper Cretaceous Pierre shale to Recent alluvium. The Pierre shale is exposed only along the North Fork of the Republican River and the Arikaree River in the eastern part of the county (pl. 1). The Tertiary period is represented by the Pliocene Ogallala formation. The White River group of Oligocene age may occur in the subsurface of northwestern Yuma County, but the evidence for its occurrence is not conclusive.

The Pleistocene is represented in the area by the Grand Island(?) and Sappa(?) formations and the Peorian loess. The Grand Island(?) and Sappa(?) formations are exposed in gravel pits in the north-central part of the county and have been recognized in many auger holes, but they were not mapped and are not shown on plates 1 or 2. The Peorian loess covers most of the east half of Yuma County south of the North Fork of the Republican River. Pleistocene to Recent deposits include alluvium along the rivers and a belt of dune sand traversing the county from southwest to northeast. The relation between the mapped units is shown by the fence diagram (pl. 2).

A generalized section of the geologic formations exposed in Yuma County is given in table 1. A more detailed discussion of the geologic formations and their water-bearing properties is given on pages 41–52.

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TABLE 1.—*Generalized section of the geologic formations*

System	Series	Geologic unit	Thickness (feet)	Physical character	Water supply
Quaternary	Recent and Pleistocene	Alluvium	0– 75±	Unconsolidated gravel, sand, silt, and clay, both intermixed and as alternating layers.	Yields adequate quantities of water for stock and domestic supplies. Alluvium in the valley of the North Fork of the Republican River yields a small quantity for irrigation; in the Arikaree River valley it yields moderate quantities for irrigation. In the valley of the South Fork of the Republican River alluvium yields moderate to large quantities for irrigation.
		Dune sand	0– 100±	Tan unconsolidated very fine to coarse quartz sand; wind deposited.	Generally lies above the water table and, hence, yields no water to wells. May yield amounts adequate for stock or domestic purposes where saturated. Dunes are important catchment areas for recharge from precipitation, owing to the relatively high permeability of the sand.
		—Unconformity—			
	Pleistocene	Peorian loess	0– 120±	Yellowish-gray silt and clay containing scattered sand grains and calcareous concretions; wind deposited.	Lies above the water table and, hence, yields no water to wells. Most precipitation runs off. Many intermittent lakes form on the surface.
		—Unconformity—			
		Sappa(?) formation	0– 10±	Light-gray fossiliferous sand and silty marl overlain by thin soil zone.	Generally lies above the water table and, hence, yields no water to wells.
		Grand Island(?) formation	0– 30±	Loosely consolidated calcareous reddish-brown to light-gray sand and gravel; stream deposited.	Do.
		—Unconformity—			
Tertiary	Pliocene	Ogallala formation	0– 460	Gravel, sand, silt, and clay containing beds of limy sandstone, opaline quartzite, and volcanic ash; "algal" limestone at top; stream deposited.	The principal aquifer in the county. Yields adequate quantities of water for stock and domestic supplies throughout most of area of its occurrence. In many places yields moderate to large quantities for irrigation.
		—Unconformity—			
Cretaceous	Upper Cretaceous	Pierre shale	1,300–2,500	Gray to black marine shale containing gypsum, bentonite, and calcareous concretions; weathered zone of yellow clay commonly present at top.	Not known to yield water to wells in the county.

GEOLOGIC HISTORY

Yuma County is underlain by deposits of limestone, shale, sandstone, sand, gravel, and clay ranging in thickness from 5,500 to about 6,800 feet. The studies of well cuttings and outcrops by many geologists have revealed much of the geologic history of the area. The following discussion of the geologic history of the area is taken largely from McLaughlin (1954), Cardwell and Jenkins (1963), and the writer's own observations.

Paleozoic era.—The area that now includes eastern Colorado was being eroded at the beginning of the Paleozoic era. Material formed during this time is sometimes encountered in deep oil-test holes in the form of fragments of red granite, called granite wash. Before the end of the Cambrian period the area was invaded by a widespread sea which deposited first a thin bed of sand (the Reagan sandstone) and then a thick sequence of limestone and dolomite (the Arbuckle limestone) during the last part of the Cambrian and during part of the Ordovician period. No rocks of Silurian or Devonian age have been found in Yuma County and probably none were ever deposited there. During the early part of Carboniferous time the seas again invaded the area, and more than 2,000 feet of marine limestone, shale, and sandstone were deposited during Carboniferous and early Permian time. The seas withdrew from the area before the end of the Permian period, and late Permian deposits consist mainly of nonmarine red beds, including some gypsum and salt.

Mesozoic era.—The period of erosion and nondeposition which started near the end of Permian time lasted well into the Mesozoic era. The earliest Mesozoic deposits in Yuma County are the variegated shale, sandstone, and limestones of the Upper Jurassic Morrison formation. Bones and tracks of dinosaurs, which have been found in outcrops of the Morrison formation elsewhere, are among the evidence pointing to deposition of the sediments on land. Another period of nondeposition was followed by the invasion of Late Cretaceous seas in which were laid down the thick sequence of sandstone, limestone, and shale that includes the Dakota, Graneros, Greenhorn, Carlile, Niobrara, and Pierre formations. This was the last marine invasion of the North American interior. Farther west in Colorado, the retreating seas laid down the Upper Cretaceous Fox Hills and Laramie formations. No trace of these formations has been found in Yuma County. If they were deposited, subsequent erosion has removed all traces of them. It is more likely that they were never deposited, and that this area was a highland during the withdrawal of the Cretaceous sea.

Cenozoic era.—The Cenozoic era was marked in this area by erosion, and by deposition of continental deposits derived largely from the erosion of the rising Rocky Mountains. The area was probably being eroded during most of Tertiary time until the middle of the Pliocene epoch.

During Pliocene time the Rocky Mountains were uplifted again, increasing the gradients of the streams flowing from them. The streams, heavily laden with rock débris, were unable to carry their load very far, and deposited it along their channels. As these channels were filled, the streams began to wander back and forth across the countryside, depositing their loads wherever they went. This sequence of gravel, sand, silt, and clay is known as the Ogallala formation. Subsequently, this formation was eroded away from areas near the mountains, leaving no connection in Colorado between the Ogallala and its source area.

The early part of the Quaternary period was largely one of erosion. Although no glaciers extended into Yuma County, their presence elsewhere affected the deposition in this area. The Grand Island(?) formation consists of gravel and sand laid down by streams formed by the melting of continental glaciers. The Sappa(?) formation and the Peorian loess were deposited by winds blowing during the dry interglacial stages.

Toward the end of the Pleistocene epoch and afterwards, northwesterly winds blew in sand, which now forms dunes covering much of the county. Meanwhile, the present drainage was developing and the streams were depositing alluvium along their channels.

OCCURRENCE OF GROUND WATER

PRINCIPLES

The following discussion of the occurrence of ground water is adapted in part from Meinzer (1923a, p. 2–102), and the reader is referred to his report for a more detailed discussion of the subject.

The rocks that form the outer crust of the earth generally contain many open spaces, called voids or interstices. These open spaces are the receptacles that hold the water which is found below the surface of the land and is recovered in part through wells and springs. The capacity of a rock to hold water is determined by the volume occupied by voids or open spaces, but its capacity to yield water is determined by the size, distribution, interconnection, and number of voids. The term "permeability" is used to describe the ability of a rock to transmit fluids. Permeability is measured by the rate at which the rock will transmit water through a given cross-sectional area under a given difference of head per unit of distance (in the Geological Survey, gallons per day per square foot, under unit hydraulic gradient and at 60° F.) Rocks that will not transmit water are said to be impermeable. Some deposits, such as dense silt or clay, may have a high percentage of void space but, because of the small size of the voids, transmit water very slowly. Other deposits, such as well-sorted gravel, contain large openings that are freely interconnected and transmit water readily. Any body of rock that contains and readily transmits water is called an aquifer.

Part of the water in any deposit is not free to drain into wells because it is held against the force of gravity by molecular attraction—that is, by the cohesion of the molecules of the water itself and by their adhesion to the walls of the pores. The ratio of the volume of water that a rock will yield by gravity, after being saturated, to its own volume is known as the specific yield of the rock.

Below a zone, which in Yuma County ranges in depth from zero to about 250 feet below the land surface, the permeable rocks are saturated with water under hydrostatic pressure. These saturated rocks form what is known as the zone of saturation, the upper surface of which is called the water table. Wells dug or drilled into the zone of saturation will become filled with ground water to the level of the water table.

The rocks that lie above the zone of saturation are said to be in the zone of aeration. The zone of aeration contains varying amounts of water whose movement is controlled chiefly by gravitational and capillary forces. The capillary forces in a given material vary, increasing with a decrease in moisture content. In fine-grained material, the capillary forces may be many times greater than the gravitational forces. The resultant of these two forces determines the direction of movement. When the capillary forces are greater than the gravitational forces, the water may move in any direction as determined by temperature and moisture gradients.

All the rocks penetrated by water wells in Yuma County are sedimentary, but they include several types that differ greatly in character and in their ability to store and transmit water. The principal water-bearing rocks in Yuma County are sand and gravel.

Water in sand and gravel.—Fresh ground water occurs in the deposits of stream-laid sand, gravel, silt, and clay in the alluvium and the Ogallala formation, and locally in the dune sand and the Grand Island(?) formation which underlie Yuma County. Some of the beds consist of well-sorted sand and gravel having a moderately uniform texture and a relatively high specific yield and permeability. The well-sorted coarse material yields adequate quantities of water to the many domestic and stock wells in Yuma County. Where the deposits of saturated sand and gravel are thick, properly constructed wells will yield large quantities of water.

In some parts of the county the deposits of sand and gravel are thin or are poorly sorted and contain silt and clay which tend to fill the pore spaces and reduce the permeability. Wells in this type of material generally yield only small to moderate quantities of water for domestic and stock use.

Where the Ogallala and alluvium are in contact they form a single hydrologic unit. Water moves freely from one formation to the other, the direction of movement depending on the hydraulic gradient.

Water in shale.—No wells in Yuma County are known to obtain water from shale. Shale is formed by the induration of clay or clayey mixtures and generally has a very low specific yield and permeability. In some places, however, shale may have sufficient open joints and bedding planes to permit moderately free movement of water. In other places the shale may contain enough sand to make it moderately permeable.

WATER TABLE

The water table in Yuma County marks the upper limit of water available to wells. In some places lenses of clay or tightly cemented sand and gravel confine the zone of saturation. Water levels in wells in these areas rise above the bottom of the confining layer, to about the same altitude as the water in the surrounding unconfined area.

Plate 3 shows the configuration of the water table as of 1958–59. It is a subdued replica of the land surface. The water table slopes generally eastward to northeastward, ranging in altitude from about 4,340 feet at the west edge of the county to 3,360 feet along the North Fork of the Republican River where it crosses the east edge of the county. The slope across the county averages about 20 feet per mile, ranging from about 5 feet per mile in the northern part of the county to about 100 feet per mile in the eastern part near the rivers.

The water-table map indicates the direction of movement of ground water, which is from areas of recharge to areas of discharge. The general slope toward the east and northeast indicates that the flow. which is normal to the contours, is in that direction. Upstream flexures of the contours indicate that ground water discharges from the aquifer to the streams. The discharge is evidenced by springs and seeps along the major streams in the eastern part of the county. The discharge of wells has not been great enough to affect the movement of ground water noticeably. Figure 9*C* illustrates the depression formed in the water table where ground water from an aquifer discharges to a stream. A mound is formed on the water table where a stream discharges to the aquifer (fig. 9*B*). Figure 9*A* shows that the position of the stream channel with respect to the water table determines whether the stream gains or loses water. Most of the perennial streams in Yuma County are gaining streams. Some of the ephemeral streams lose water, forming temporary mounds on the water table which are too small to be shown on plate 3.

The configuration of the water table reflects changes in the bedrock surface and variations in saturated thickness and permeability of the water-bearing deposits. A higher bedrock surface or a decrease in thickness or permeability restricts the flow, and the contours must be more closely spaced (the slope must be steeper) for the same quantity of water to move.

The depth to water in Yuma County is related to the topography. The depth to water commonly is less in low-lying areas. The depth-to-water map (pl. 4) shows that the water level is less than 50 feet below the land surface along the streams that drain the county and in most of the area overlain by sand dunes in the northeast corner of the county. The depth to water is greatest in an area in the northwestern part of the county, where it is about 250 feet.

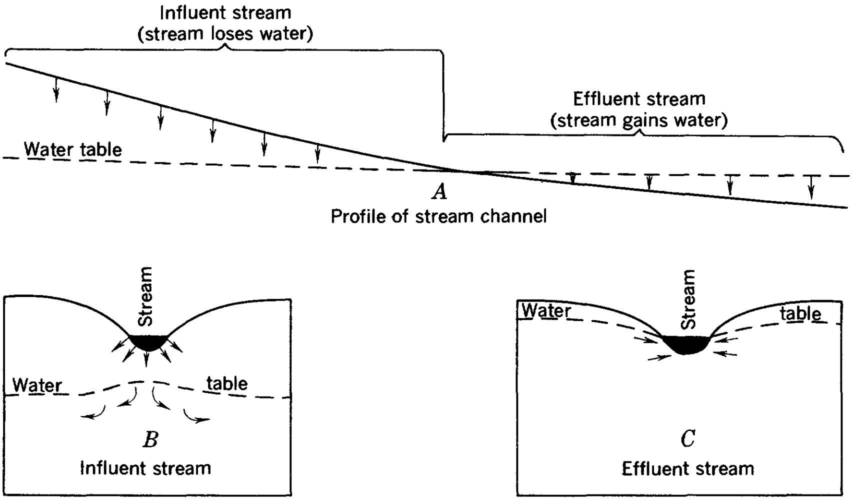

FIGURE 9.—Diagrammatic sections showing the relation between a stream and the water table. *A*, Longitudinal section showing how a stream loses and gains water; *B*, Transverse section across influent, or losing, part of the stream; *C*, Transverse section across effluent, or gaining, part of the stream.

HYDRAULIC PROPERTIES OF WATER-BEARING MATERIALS

Aquifer tests were made at 25 wells in Yuma County; 20 wells tap only the Ogallala formation, 4 tap both the alluvium and the Ogallala, and 1 taps only the alluvium. Four samples of material from the Ogallala were tested in the hydrologic laboratory of the U.S. Geological Survey at Denver. The purpose of the tests was to determine the ability of the aquifers to transmit and store water.

"Transmissibility" is the term used to describe the ability of an aquifer to transmit water. The coefficient of transmissibility is expressed as the number of gallons per day that would flow through a vertical section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile, at the prevailing temperature. It is the product of the field coefficient of permeability (gallons per day per square foot, measured at the prevailing water temperature) and the thickness of the aquifer, in feet.

"Coefficient of storage" is the term used to describe the ability of the aquifer to yield water from storage. It is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under unconfined (water-table) conditions, which exist in most places in Yuma County, it is virtually equal to the specific yield (p. 17).

The data from the tests were analyzed by nonequilibrium methods described by Wenzel (1942, p. 75–117).

The tests indicated that the coefficient of transmissibility of the Ogallala ranged from 3,700 to 300,000 and averaged 110,000 gpd (gallons per day) per ft (table 2). The single test of the alluvium indicated a coefficient of transmissibility of 15,000 gpd per ft. Tests of wells tapping both aquifers showed coefficients of transmissibility ranging from 65,000 to 120,000 and averaging 95,000 gpd per ft.

The wide range in test results may be due in part to erroneous interpretation of test data. Tests of short duration in unconfined aquifers, such as the ones made in Yuma County, may be considerably in error. The values of transmissibility and permeability represent the maximum expectable. Longer tests might show substantially lower values.

Storage coefficients were computed for only three tests; they were 0.005, 0.01, and 0.12 and are not thought to be representative of the long-term yield of the Ogallala. The short tests made in Yuma County may indicate values that are too low, owing to incomplete dewatering of the aquifer. According to G. H. Chase (written communication, 1960), the long-term storage coefficient of the aquifer in

TABLE 2.—*Summary of the results of aquifer tests*

[Aquifer: O, Ogallala formation; A, alluvium]

Well	Owner	Principal aquifer	Depth of well (feet)	Depth to bedrock (feet)	Depth to water below measuring point (feet)	Saturated thickness (feet)		Duration of pumping (hours)	Average pumping rate (gpm)	Drawdown (feet)	Specific capacity (gpm per foot of drawdown)	Coefficient of transmissibility (gpd per foot)	Average coefficient of permeability (gpd per square foot)		Water temperature (°F)	Date
						Total	Sand and gravel						Entire aquifer	Sand and gravel		
B1-44-10bbb	Roy Donovan	A	56.0	55	16.8	38	31	10	200	34	6	15,000	400	480	55	Sept. 6, 1957
B1-45-27bbb	Harry Fonte	O	260	250	87.1	162	143	10	1,050	10	105	220,000	1,400	1;600	58	Sept. 10, 1957
B1-47-4cad	Melvin Pletcher	O	314	311	101.9	209	134	3	1,440	17	85	230,000	1,100	1,700	59	Sept. 20, 1957
B2-42-27bbc	Jack Carson	O	140	140	31.7	107	107	5	480	36	13	30,000	280	280	57	Sept. 3, 1957
B2-48-34bca	Francis Rogers	O	421	--------	180.6	239	-------	4	895	17	53	110,000	460	--------	59	Oct. 8, 1957
B3-43-33cda	H. E. Jackson	O	118	--------	27.0	91	-------	4	300	23	13	30,000	330	--------	58	Aug. 30, 1957
B3-46-5bca	Paul Brophy	O	314	--------	133.8	179	-------	24	1,060	21	50	120,000	670	--------	59	Sept. 10, 1957
B4-47-26aba	L. A. Hoskins	O	300	295	185.0	110	85	14	440	24	18	27,000	250	320	56	Aug. 1, 1953
B4-47-32cbb	Perry Blach	O	292	289	171.0	118	80	30	1,260	12	105	300,000	2,600	3,800	59	Aug. 14, 1958
B5-43-24abb	E. H. Kinnie	O	260	--------	21.2	236	194	33	1,800	27	67	250,000	1,000	1,300	58	Aug. 27, 1957
C1-44-10acc	Albert Welp	O	318	--------	158.1	159	-------	29	650	42	15	35,000	220	--------	60	Sept. 11, 1957
C1-44-27bbb	Henry Wiltfang	O	263	257	114.0	142	59	2	1,310	28	47	100,000	730	1,800	59	Aug. 23, 1957
C1-45-35bad	Herbert Dickson	O	197	197	54.4	143	-------	13	865	21	41	80,000	560	--------	58	Aug. 29, 1957
C3-42-31ccc	Carl Busby	O	236	--------	173.6	62	-------	25	350	43	8	20,000	320	--------	60	Sept. 12, 1957
C4-42-3bbb	W. E. Klie	O	280	270	206.2	64	50	7	265	60	4.4	3,700	60	70	59	Sept. 10, 1957
C4-43-26cbb	Ray Wiley	O	275	269	186.9	81	55	10	1,100	70	16	40,000	490	730	60	Sept. 16, 1957
C4-44-31cbd	John Clark, Jr.	O	300	298	187.2	111	40	31	540	14	39	95,000	850	2,400	58	Oct. 2, 1957
C4-44-35bbb	Harold Helling	O	295	--------	196.6	97	-------	10	750	48	16	40,000	410	--------	59	Sept. 18, 1957
C4-48-20bac	Jack Cecil	A, O	26.8	--------	16.0	10	-------	2	400	5	80	120,000	8,000	--------	57	July 27, 1956
C4-48-35dab	Glen Blank	O	260	260	98.2	162	105	10	1,160	14	83	250,000	1,600	2,400	57	Oct. 3, 1957
C5-42-4cda	Ernest Wiley	A, O	53	52	13.5	37	32	10	420	17	25	65,000	1,700	2,000	55	Sept. 17, 1957
C5-44-22dca	J. C. Lengal	A, O	74	64	20.9	42	42	2	470	10	47	----------	--------	--------	57	Sept. 18, 1957
C5-44-30bcb	Ralph Kleweno	A, O	85.6	85	26.0	59	40	20	775	20	39	100,000	1,700	2,500	58	July 25, 1956
C5-47-14dcb	Elmer O. Boone	O	240	235	97.9	137	70	10	1,275	14	91	200,000	1,400	2,800	58	Oct. 4, 1957
C5-47-20bab	W. Heinrichs	O	281	281	114.4	167	-------	26	870	29	30	60,000	360	--------	58	Sept. 24, 1957

Kit Carson County is about 0.15. The laboratory tests of four samples showed an average specific yield of 0.28.

Permeability values computed from the tests seem to have no geographic pattern. This fact emphasizes the heterogeneous and unpredictable nature of the unconsolidated aquifers.

Average field coefficients of permeability were computed two ways. The coefficients of transmissibility were divided by the thickness of saturated deposits for the first permeability column and by the saturated thickness of only the most permeable materials for the second permeability column (table 2). The field permeability of the aquifers averaged 1,100 gpd per sq ft for 24 tests; the permeabilities of the sand and gravel deposits averaged 1,600 gpd per sq ft. By comparison, the four samples checked in the laboratory averaged 315 gpd per sq ft.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations reflect changes in ground-water storage. Water levels measured in 58 wells scattered through Yuma County showed no appreciable countywide trends during the 2 years of record. Figures 10–12 compare hydrographs of representative wells with the precipitation record at the three measuring stations in the county. Most of the wells fluctuated less than 1 foot during the 2-year period. In general, those that fluctuated more than 1 foot are in areas where the depth of water is less than 50 feet. The shallow water levels seem to be more responsive to climatic changes than deep water levels, as shown by fluctuations in well B3–42–4ccc in figure 11.

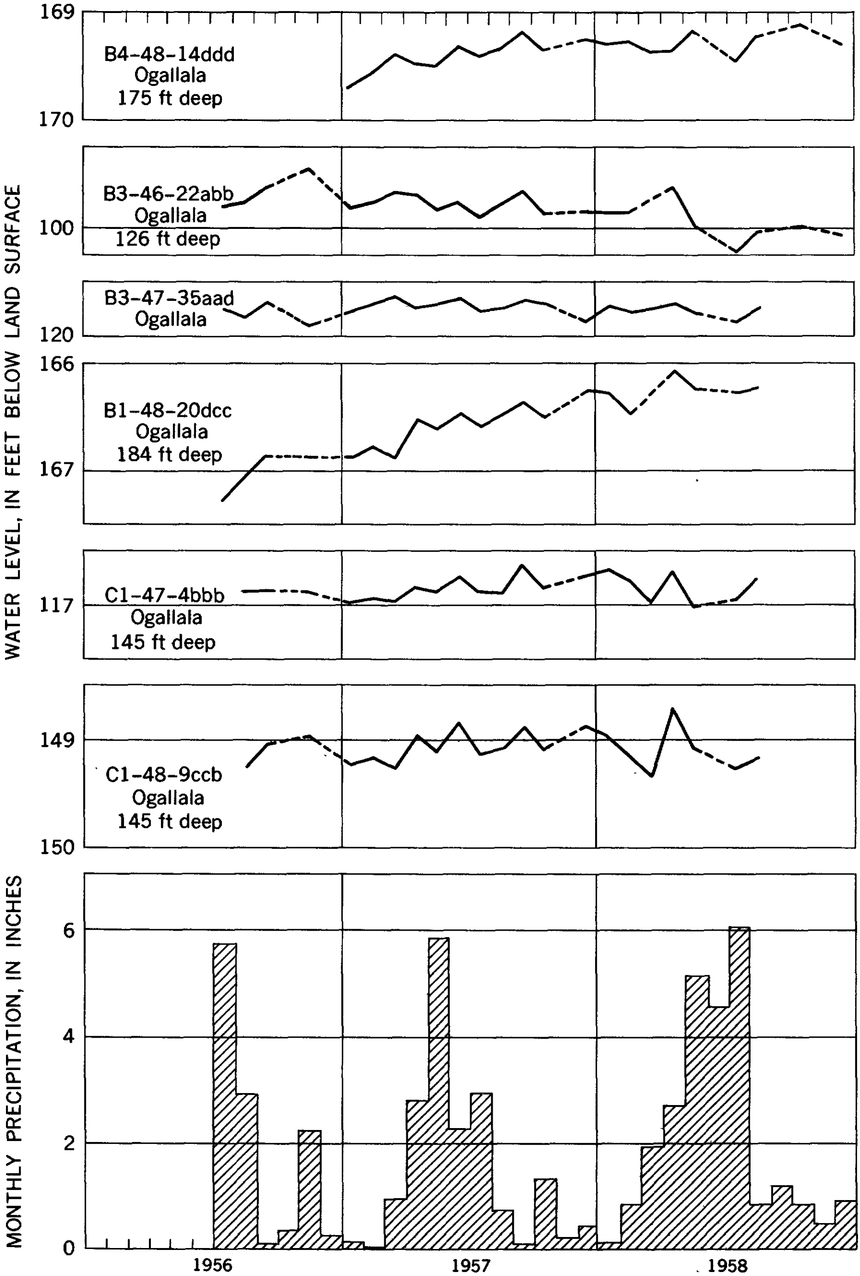

FIGURE 10.—Fluctuations of water levels in six wells in the Yuma area, and monthly precipitation at Yuma. Dashed line indicates no measurement.

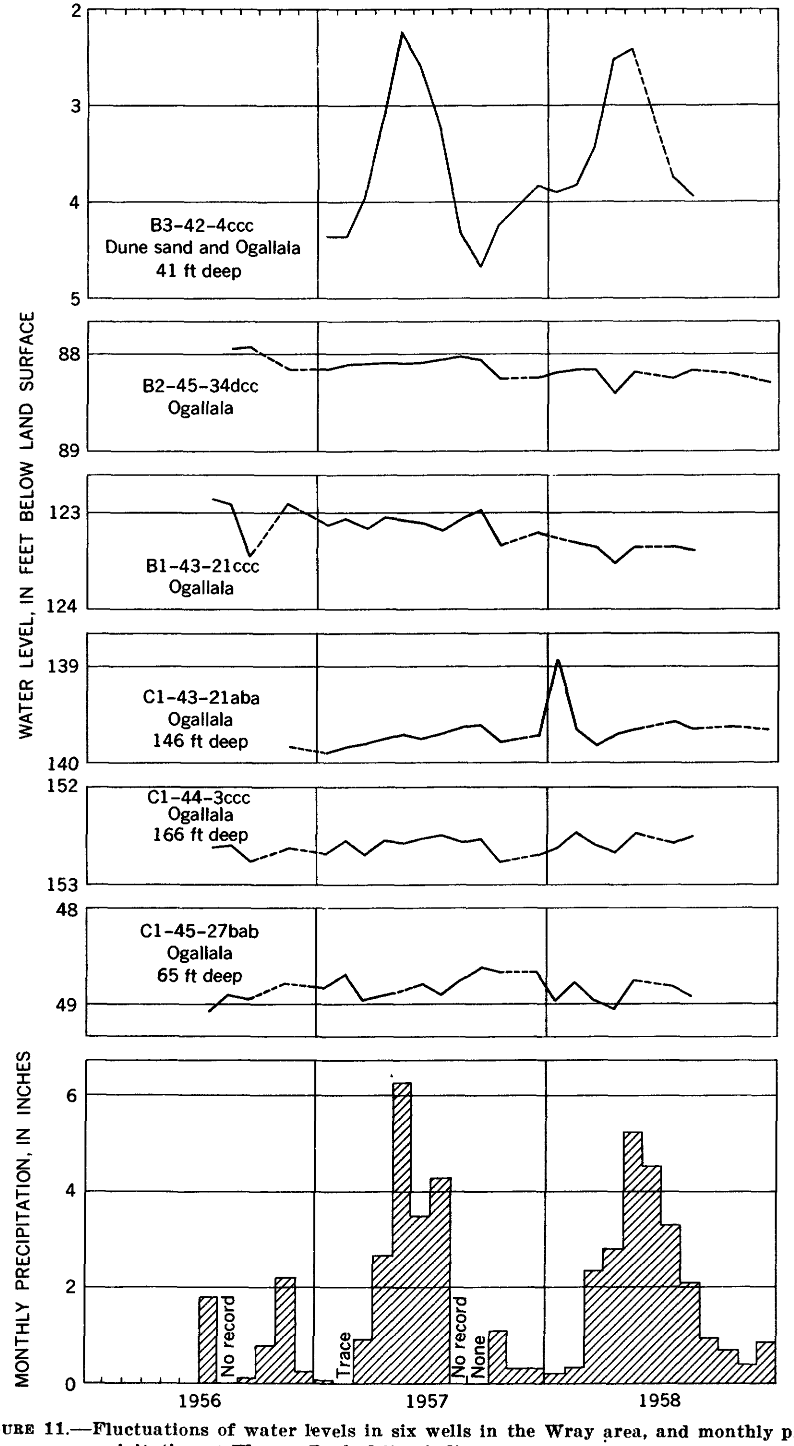

FIGURE 11.—Fluctuations of water levels in six wells in the Wray area, and monthly precipitation at Wray. Dashed line indicates no measurement.

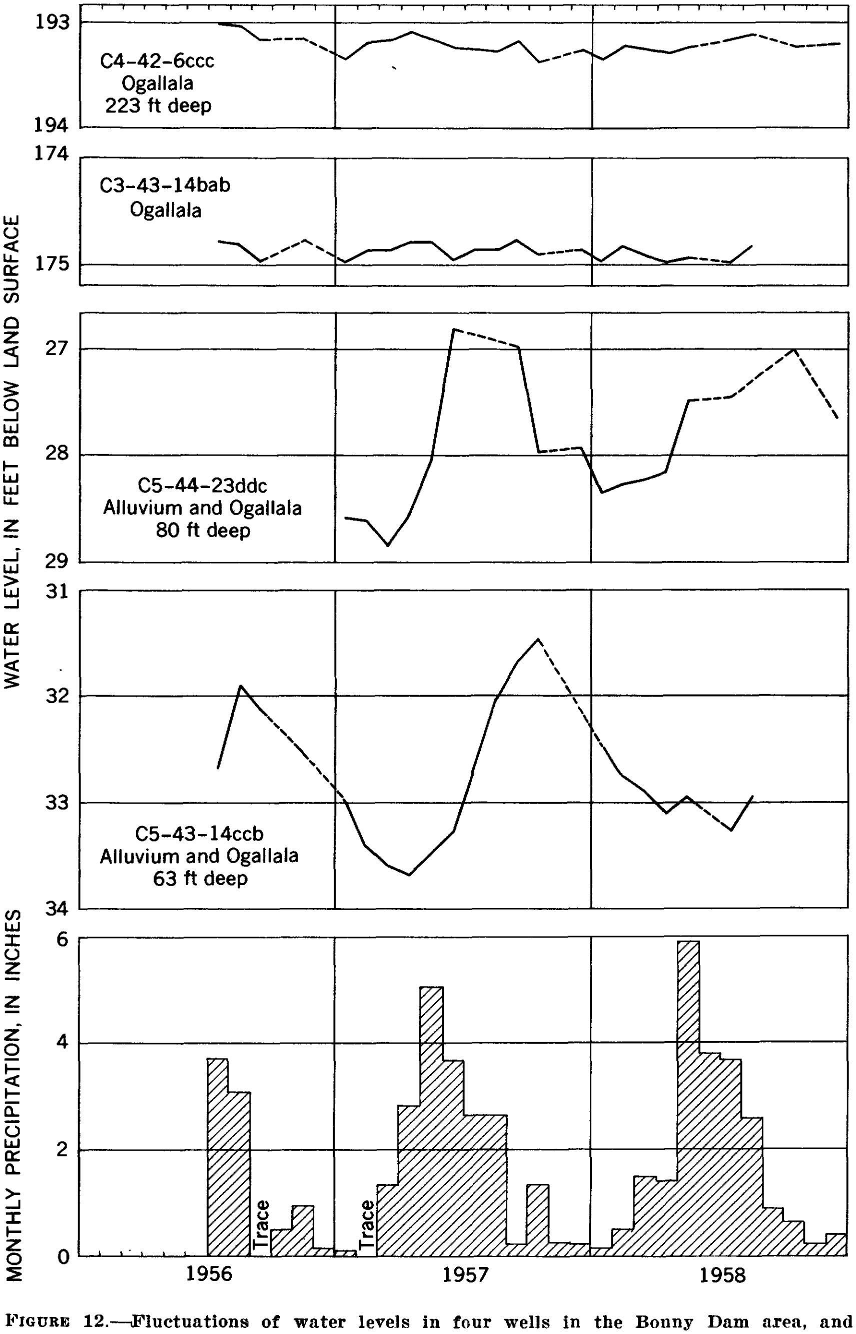

FIGURE 12.—Fluctuations of water levels in four wells in the Bonny Dam area, and monthly precipitation at Bonny Dam. Dashed line indicates no measurement.

RECHARGE OF GROUND WATER

The aquifers in Yuma County are recharged mainly by local precipitation and subsurface inflow from the west.

Recharge from precipitation.—Only a small part of the average annual precipitation (about 17 inches in Yuma County) reaches the ground-water reservoirs. Much of the precipitation is consumed by evaporation and transpiration, part leaves the area by direct runoff at the surface, and the remainder percolates to the water table.

The quantity of water lost by evapotranspiration depends upon the temperature, humidity, vegetative covering, depth to the water level below the land surface, and the length of time the processes of evapotranspiration have access to the moisture. Most of Yuma County is characterized by relatively flat uplands containing many shallow sinkholes and undrained depressions, and by areas of dune sand having little or no surface drainage. A large part of the precipitation in the upland areas is held in the undrained areas until it evaporates or moves downward to the water table. The water may be held in the sinkholes and undrained depressions of the uplands for long periods until most of it disappears by evaporation. In some sinkholes and depressions, however, the water disappears at a rate greater than can reasonably be accounted for by evaporation, suggesting that much of the water is moving downward to the water table. The water that accumulates as small temporary lakes in the poorly drained dune-sand areas generally disappears rapidly into the relatively permeable sandy soil. Part of the precipitation in Yuma County is transpired by plants, particularly during May through August when precipitation generally is greatest and plant growth most abundant. The downward-moving water is partly intercepted by plants which, during the growing season, may deplete the soil moisture as rapidly as it can be replenished by precipitation. At the end of the growing season the soil often is bone dry. Water that enters the soil during the fall and winter when evapotranspiration rates are low tends first to replenish the soil moisture, and then to move downward to the water table. From the first killing frost in the fall to the last killing frost in the spring, a considerable amount of water moves downward through the soil to the water table. The high rates of evaporation and transpiration during the growing season probably permit very little recharge except where the water table is near the land surface.

Because of the poorly developed drainage in the extensive upland areas in Yuma County, only a small part of the rainfall runs off directly. The drainage is well developed in the canyon areas in the southeastern and east-central parts of the county, but these make up only a small part of the total area of the county.

Recharge from streams.—Important areas of recharge to the ground-water reservoirs are channels of intermittent streams that lose water during periods of flow. Most of the small streams in the upland areas are intermittent because their channels lie above the water table. During periods of flow, much of the water may percolate downward through the sandy streambed and eventually reach the water table.

It was not practical during this investigation to estimate the amount of recharge to the ground-water reservoirs of Yuma County. The amount of water added to the reservoirs probably is large because of the large area of the county, but probably is only a small part of the total precipitation. The loss of water from some of the intermittent streams and the relatively rapid disappearance of water in some of the undrained depressions give some indications of the amount of recharge. Cardwell and Jenkins (1963) estimated that recharge from precipitation amounts to 0.9 inch per year in the Frenchman Creek drainage basin. Yuma County probably receives a similar amount.

Recharge from subsurface inflow.—Another significant source of recharge to the ground-water reservoirs of Yuma County is subsurface inflow from adjacent counties. Precipitation recharging the Ogallala formation west of Yuma County joins the water moving eastward as underflow. As can be seen from plate 3, most of the subsurface inflow comes from Washington County to the west, but a small amount comes from Kit Carson County. On the basis of an assumed average field permeability of 1,200 gpd per sq ft, an average saturated thickness of 100 feet along the Washington County line, and a hydraulic gradient of 20 feet to the mile, the subsurface inflow is estimated to be about 150,000,000 gpd (168,000 acre-ft per year). The inflow from Kit Carson County is estimated to be about 22,000,000 gpd (25,000 acre-ft per year) through an average saturated thickness of 50 feet.

Recharge from irrigation.—Although most of the water used for irrigation is lost through transpiration and evaporation, enough of it percolates back to the water table to constitute an important, though small, source of recharge. This is especially true in areas where the soil is very sandy.

DISCHARGE OF GROUND WATER

Ground water is discharged from the zone of saturation in Yuma County by evaporation, transpiration, and surface and subsurface outflow. Water is discharged within the county through seeps, springs, and wells, but the water either is evaporated and transpired or joins the surface or subsurface outflow from the county.

Discharge by transpiration and evaporation.—The roots of plants withdraw water from the aquifer both directly and indirectly. Phreatophytes, plants whose roots extend to or below the water table, transpire water taken directly from the aquifer. Other plants are supplied with moisture from the zone of aeration, which is replenished in some places by water withdrawn from the aquifer by capillarity. The roots of ordinary grasses and field crops extend downward only a few inches to a few feet; however, alfalfa and certain types of desert plants may send their roots to depths of several tens of feet to reach water.

Ground water in Yuma County is discharged by evaporation and transpiration only in areas of shallow water, such as the flood plains of the Arikaree and Republican Rivers and their tributaries, and in the sandhills in the northeastern part of the county. Alfalfa and cottonwood trees are the principal plant users of ground water in Yuma County. The major losses of ground water by evaporation occur along the channels of some of the streams where the water table is at or near the level of the stream channel. Other losses occur where the losses in soil moisture by evaporation are replenished by capillary movement from the aquifer. They are small, however, owing to the great depth to water throughout most of the county.

Discharge from springs and seeps.—Springs and seeps account for an appreciable but unmeasured part of the total discharge of ground water in Yuma County. They are found mainly in the central and southeastern parts of the county where they feed the flow of Chief Creek, both forks of the Republican River, Black Wolf Creek, and, in places, the Arikaree River. Records of the U.S. Geological Survey for a gaging station on North Fork Republican River near Wray show an average flow of 22.7 cfs (cubic feet per second) during October 1951 to September 1957. Nearly all this water came from seeps and springs. Water seeps from many low areas in the sandhills during wet years but flows only short distances before it evaporates or infiltrates the soil.

Two types of springs are found in Yuma County: those that form where topographic depressions intersect the water table and those that issue above the exposed contact of a permeable material overlying a relatively impermeable material. Depression springs are found mainly in the sandhills, and issuing from the Ogallala formation along the headwaters of Chief Creek and the North Fork of the Republican River. Contact springs issue from the Ogallala formation in the eastern part of the county where streams have cut deeply, exposing the underlying Pierre shale. A few contact springs issue above contacts within the Ogallala between beds having a great difference in permeability.

Discharge by wells.—A large part of the water discharged from the aquifers in Yuma County comes from wells. Most of the wells in the county are domestic or stock wells whose maximum yields are only a few gallons per minute. Their yields are small because little water is available or because they have not been drilled and equipped to produce larger quantities of water. The irrigation and municipal wells are drilled and equipped for large production and may discharge more than 2,000 gpm each by pumping (table 4).

The discharge from large-diameter municipal and irrigation wells has increased considerably since the investigation was begun and probably will continue to increase. In 1956 about 5,000 acre-feet of ground water was pumped for irrigation; by 1958 irrigation use increased to about 8,000 acre-feet.

Discharge by subsurface outflow.—Ground water moves out of the county by subsurface outflow to the east. The water-table contour map (pl. 3) shows that the water in the aquifers moves generally eastward and leaves principally across the east line of the county, but also that part moves across the north line. Subsurface outflow is estimated to be about 155,000,000 gpd (175,000 acre-ft per year).

WELL CONSTRUCTION AND PUMPING EQUIPMENT

Dug wells.—Dug wells are excavated with hand tools or power machinery and generally range from 2 to 6 feet in diameter. During the early period of settlement in Yuma County drilling machinery was scarce and most of the wells were dug, some to considerable depths. In recent years, however, most wells in the county have been drilled, and only a few dug wells remain. As a well generally cannot be dug more than a few feet below the water table, many of the dug wells go dry during extended droughts. Dug wells cannot be sealed as easily as other types of wells and generally are more susceptible to surface contamination. At least two of the dug wells in the county were later deepened by drilling.

Drilled wells.—Most of the wells in Yuma County are drilled wells excavated by means of percussion (cable-tool), rotary, or reverse-rotary drills. The drilled wells generally are cased with wrought-iron or galvanized-steel casing ranging in diameter from 3 to 6 inches in most domestic and stock wells, to 24 inches in some large-capacity irrigation wells. The casing generally is perforated opposite the water-bearing materials, or from the water table to the bottom of the well.

The size of the perforations is an important factor in the construction of a water well in unconsolidated material, especially a large-capacity well such as is used for irrigation or municipal supplies. The capacity and even the life of the well may be determined by the perforations. Fine material may filter through perforations that are too coarse and fill the well. On the other hand, if the perforations are too small, they may become clogged, thus impeding the entrance of water.

Wells in unconsolidated sediments may be equipped with well screens or with torch-cut perforations. It is common practice to select a slot size that will pass the finer grained 30 to 60 percent of the water-bearing material. Retention of the coarser particles around the screen forms a natural gravel pack which greatly increases the efficiency of the well.

Most of the large-capacity wells in Yuma County are artificially gravel packed. Such wells generally are effective in obtaining large supplies of water from relatively fine grained unconsolidated deposits, and they are used widely for irrigation and municipal supply. In construction of a well of this type, a hole 24 to 60 inches in diameter is first drilled and then is cased temporarily with iron or steel pipe. A well screen or perforated casing of smaller diameter than the hole is then lowered into place and centered in the larger pipe opposite the water-bearing beds. Unperforated casing extends from the screen to the surface. The annular space between the inner and outer casing is filled with sorted gravel, preferably of a grain size just a little larger than the openings in the screen or perforated casing, also larger than the grains of the water-bearing material. In most wells of this type a medium- or coarse-grained gravel is used, but in very fine-grained deposits a fine-grained gravel or coarse-grained sand may be used. The outer casing is then withdrawn part way to uncover the screen and allow the gravel packing to come in contact with the water-bearing material.

Maximum yields can be obtained by drilling the well through all the most productive water-bearing materials, by using proper screen or perforated casing, and by properly developing the well. Increasing the depth will have a greater effect on increasing the yield of a well than will increasing the diameter, provided that additional water-bearing materials are penetrated.

Methods of lift.—Most of the stock and domestic wells in Yuma County are equipped with cylinder-type lift or force pumps. The cylinders in the two types of pumps are similar. A lift pump generally discharges water only at the pump head, whereas a force pump can force water above the pump head—generally to an elevated tank.

Most of these pumps are operated by windmills, but a few are worked by hand or are run by gasoline or electric motors.

The large-diameter irrigation and municipal supply wells are equipped with deep-well turbine pumps consisting of a series of connected turbines, called bowls or stages which are placed below the water level in the well and are connected to a vertical shaft extending to the surface. The turbine pumps may be belt-driven or may be geared directly to the power source.

UTILIZATION OF WATER

Specific data on more than 600 wells in Yuma County were obtained during this investigation (Weist, 1960). Of these wells, 14 are used for public supplies, 355 for domestic and stock supplies, and 101 for irrigation supplies. The remainder were not in use at the time of the well inventory. Most of the unused wells formerly had been stock and domestic wells. The inventory included all the irrigation and municipal wells but only a representative sampling of the domestic and stock wells.

DOMESTIC AND STOCK SUPPLIES

All the homes in Yuma County, except those served by the municipal supply system at Wray, Yuma, and Eckley, obtain their water from domestic wells. Springs are the source of a few stock supplies. The water from a few springs is impounded so that it can be better utilized. Most of the domestic and stock wells are small-diameter drilled wells equipped with lift or force pumps operated by windmills or by small engines. The water is generally of good quality but is moderately hard to hard.

PUBLIC SUPPLIES

The towns of Wray, Yuma, and Eckley have municipal water supplies, all derived from wells. An analysis of a sample of water from each of the municipal systems is included in table 3.

Wray.—Wray (population 2,198) is supplied by seven municipal wells. The five oldest wells are on the slope north of the North Fork of the Republican River in the NW¼ sec. 6, T. 1 N., R. 43 W. They were drilled into the basal part of the Ogallala formation to a depth of about 75 feet. The reported yields range from 90 to 250 gpm; however, the old wells are used only in emergencies.

The two main supply wells are in the NW¼ sec. 36, T. 2 N., R. 44 W., where they penetrate 180 feet of the Ogallala formation. They yield between 500 and 700 gpm, and are generally used alternately.

The water is pumped from the wells to an underground concrete reservoir in the cliff south of the town. The reservoir has a capacity of 300,000 gallons and provides a pressure in the mains ranging from 40 to 90 psi (pounds per square inch). The average consumption is 300,000 gpd; the water is untreated.

Yuma.—The town of Yuma (population 1,908) is supplied by four municipal wells. The oldest well was dug in 1920, and later was deepened by drilling to about 300 feet. The other three wells were all drilled, two in the 1940's and one in 1955. All four wells are 300 feet or more in depth and draw their water from the Ogallala formation. Their reported yields range from 250 to 650 gpm. An elevated tank has a capacity of 120,000 gallons. The water is consumed at an average rate of 750,000 gpd and is treated with chlorine.

Eckley.—Eckley (population 295) is served by a single well which pumps into an elevated tank having a capacity of 50,000 gallons. The well was dug and drilled about 300 feet through the Ogallala formation. The average daily consumption of the water, which is untreated, is 20,000 gallons.

Other.—Two other wells inventoried in Yuma County can be classified as public-supply wells. Both have 5-inch casings and are equipped with hand pumps.

The well at Wauneta Community (B4–44–26abb) was drilled during 1955 into the Ogallala formation to a depth of 53 feet. The depth to the static water level was about 40 feet in June 1957, and the reported yield was 3 gpm.

The other public-supply well (C2–43–21adc) was drilled in 1954 to provide water for the Beecher Island Memorial Association picnic ground. It was drilled to 25.8 feet through the alluvium along the Arikaree River.

IRRIGATION SUPPLIES

The oldest existing irrigation well in Yuma County (C5–42–31ada) was drilled in 1936. It yields a reported 350 gpm from a 6-inch-diameter hole. The well taps about 84 feet of the Ogallala formation. Two more wells were put down the next year. One (C5–47–15cdb), which was dug part way and finished by drilling, yields about 400 gpm.

Well irrigation developed slowly until 1953, when there were 37 irrigation wells in the county. In 1954, 12 wells were drilled, and between the first of 1954 and the middle of 1958, 64 wells were drilled, only 2 of which were drilled in 1958.

Most of the irrigation wells are 12 to 16 inches in diameter, gravel packed, and equipped with deep-well turbine pumps. Yields range from about 50 gpm to more than 2,000 gpm, and the pumping lifts are as much as 250 feet.

POSSIBILITIES OF ADDITIONAL DEVELOPMENT OF LARGE SUPPLIES OF WATER FROM WELLS

Moderate to large additional supplies of water can be developed throughout much of Yuma County, without affecting the flow of streams in the area. However, because the potential rate of replenishment is small in comparison to the potential rate of development, the aquifer could be overdeveloped locally and the supply depleted. If developers are aware of the many factors affecting development, they may plan accordingly.

Extensive development of ground water in the High Plains areas in other States provides a basis for understanding the problems that may be faced by developers in Yuma County. Development of ground water generally becomes intensive in those areas overlain by irrigable land, underlain by thick saturated deposits, and having a shallow depth to water. Most of the area overlying the high-yielding part of the aquifers in the county is irrigable. Plate 5 shows where the deposits are the thickest and plate 4 shows the areas of shallowest water. Other areas where thick saturated deposits occur but in which the land is unirrigable, such as sand-dune areas, could be tapped for industrial or municipal supplies.

The rate of development generally depends on economic conditions. Development of ground water for irrigation commonly is accelerated after a period of poor crop yields resulting from extended drought. Other factors that may accelerate the development of irrigation include improved market conditions, government subsidies, and proved increases in profits shown by neighboring farms or experiment stations.

Areas favorable for developing moderate to large supplies of ground water for irrigation include all the area shown on plate 6 as being underlain by saturated deposits more than 50 feet thick; however variations in water-bearing properties from place to place may exclude part of this area from successful exploitation. Also, some areas having a saturated thickness of less than 50 feet may yield moderate supplies of ground water. The variations are unpredictable from present data except in a few places where exploratory holes have been unsuccessful; thus, planning for extensive development should include a test-drilling program to show the nature and extent of water-bearing materials.

Continuing ground-water studies should accompany extensive development of ground water so that predictions of aquifer depletion can be made. Proper management should include periodic measurements of water levels and areal estimates of withdrawal.

Ogallala formation.—The Ogallala is the most extensive aquifer in the county. It is exposed in the northwestern and southwestern parts of the county and along the bluffs above the major streams. The Ogallala also underlies all other formations shown on plate 1 except the Pierre shale and the alluvium in the eastern part of the valley of the North Fork of the Republican River and the Arikaree River valley.

The yields from irrigation wells tapping the Ogallala commonly range from 400 to 2,000 gpm, depending on the thickness and permeability of materials encountered and on well construction.

Some of the thickest and most permeable sections of the Ogallala are found where erosion has cut channels in the Pierre shale prior to deposition of the Ogallala. The bedrock contour map (pl. 7) indicates that the channels follow an eastward course across the county. Channels other than those indicated on the map probably exist but data were insufficient to delineate them.

Alluvium.—Alluvial deposits capable of yielding large quantities of water are found only in the valleys of the major streams in the county. Where the Ogallala underlies the alluvium, the two deposits form a single aquifer.

The existing irrigation wells in alluvial deposits commonly yield between 50 and 1,000 gpm. Yields from shallow water-bearing deposits may be increased by installing batteries of wells or infiltration galleries.

The best possibilities for obtaining large-capacity wells are found along the buried stream channels. Subsurface exploration is necessary to determine the location and extent of the channels because they are not readily identifiable from the surface.

Summary.—From the preceding discussion and examination of the maps (pls. 1, 5–7), it is evident that additional large-capacity wells can be developed in most areas in Yuma County. The prospects for development are unfavorable where deeply incised canyons have drained the Ogallala, and where the water-bearing materials are thin and the Pierre shale is at or near the surface.

QUALITY OF WATER

The chemical character of water from the Ogallala formation and the alluvium in Yuma County is indicated by the analyses of water from 27 representative wells (table 3).

The samples where analyzed in the laboratory of the U.S. Geological Survey at Denver, Colo. The analyses show the dissolved mineral content of the water but do not show its sanitary properties.

TABLE 3.—*Analyses of water from typical wells in Yuma County*

[Analyzed by U.S. Geol. Survey; results in parts per million except as indicated. Geologic source: O, Ogallala formation, A, alluvium]

Well	Depth (feet)	Geologic source	Date of collection	Temperature (° F)	pH	Specific conductance (micromhos at 25° C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (sum)	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate
B1-44-10bbb	56	A	Aug. 22, 1957	55	7.7	649			66	19.0	43.0	14.0	325	71.0	8.0	1.6	0.4		383	243	0
B1-45-27bbb	260	O	Sept. 4, 1957	58	7.8	314			32	13.0	12.0	8.0	181	11.0	3.0	1.2	2.6		172	133	0
B2-42-27bbc	140	O	Aug. 3, 1957	57	7.6	354			43	8.8	13.0	9.6	199	9.7	4.5	.8	8.0		195	144	0
B2-44-36bbb2	180	O	Jan. 12, 1957	58	7.6	337	68	0.03	35	11.0	17.0	8.2	186	13.0	6.0	.9	5.6		256	133	0
B2-46-26bcc	317	O	Aug. 22, 1957	60	7.7	328	60	.04	40	9.7	9.1	8.2	183	7.8	4.5	1.0	7.3		238	140	0
B2-47-17dda	420	O	do	59	7.7	338			38	9.7	15.0	8.2	182	16.0	5.5	.9	5.4		188	135	0
B2-48-22bad	312	O	Jan. 12, 1957	56	7.6	341	62	.02	37	10.0	17.0	8.2	182	16.0	6.0	.9	6.9		253	133	0
B2-48-28abd	316	O	Aug. 22, 1957	60	7.8	340			37	11.0	15.0	8.2	182	15.0	5.5	.9	4.7		186	138	0
B3-43-33cda	118	O	do	57	7.6	322			45	7.8	7.6	7.8	188	7.2	2.5	.7	5.8		176	144	0
B3-46-7aa	378	O	do	60	7.8	348			34	12.0	17.0	9.4	182	15.0	5.0	1.0	6.9		189	134	0
B4-44-14bcb	60	O	Sept. 26, 1957	56	7.7	413			61	8.8	6.3	9.6	224	8.4	6.0	.3	20.0		230	188	5
B4-47-32cbb	292	O	Sept. 4, 1957	59	7.8	308			32	11.0	14.0	8.0	167	13.0	4.0	1.0	5.9		171	125	0
B5-43-24abb	260	O	Aug. 22, 1957	57	7.8	362			42	14.0	9.1	8.6	176	33.0	3.5	.7	6.4		204	162	18
B5-47-22bdb	368	O	Sept. 4, 1957	59	7.9	328			29	9.7	22.0	7.2	166	16.0	6.5	1.3	6.1		180	112	0
B5-48-34dcd	357	O	do	58	7.9	297			31	7.3	17.0	6.8	156	13.0	5.0	1.1	5.0		163	107	0
C1-42-15aaa	78	A	Aug. 7, 1958	52	7.5	635			62	20.0	40.0	13.0	274	93.0	9.0	1.4	.0	0.12	373	236	12
C1-44-27bbb	263	O	Aug. 22, 1957	58	7.7	368			37	15.0	16.0	9.0	210	11.0	4.5	1.5	5.8		203	154	0
C2-43-22adb	57	A	Oct. 1, 1956	55	7.4	627			66	18.0	49		336	47.0	10.5	1.8	.0		358	238	0
C2-45-10bba	135	O	Sept. 26, 1957	58	7.5	384			38	16.0	17.0	9.2	213	15.0	8.0	1.2	6.9		216	161	0
C2-48-21bab	167	O	Oct. 9, 1957	56	7.8	350			38	13.0	13.0	7.0	193	13.0	4.0	.9	11.0		195	148	0
C3-42-31ccc	236	O	Sept. 23, 1957	60	7.8	348			32	11.0	22.0	6.2	184	16.0	4.5	1.2	9.0		192	125	0
C4-44-27bbc	329	O	Sept. 6, 1957	58	7.8	305			31	10.0	16.0	4.6	166	10.0	5.5	.9	5.5		166	118	0
C4-44-31cbd	300	O	Oct. 2, 1957	59	7.9	297			34	8.8	13.0	4.6	164	11.0	2.5	.8	5.5		161	121	0
C4-48-20bac	27	A, O	Aug. 12, 1958	57	7.5	514			53	14.0	33.0	6.8	243	30.0	10.0	1.0	23.0	.1	290	190	0
C5-43-14acc	101	A, O	do	56	7.6	391			45	11.0	14.0	5.6	198	17.0	4.0	1.0	11.0	.22	206	158	0
C5-44-30bcb	86	A, O	do	58	7.7	330			37	11.0	14.0	5.4	181	11.0	3.0	1.1	6.9	.1	178	138	0
C5-47-20bab	281	O	Sept. 24, 1957	58	7.8	295			35	6.8	17.0	4.0	164	11.0	4.0	.6	6.6		166	115	0

The dissolved mineral constituents are reported in parts per million (ppm). A part per million is a unit weight of a constituent in 1 million unit weights of water. Equivalents per million are not given in this report, although the expression of analyses in equivalents per million is preferred for some uses of the data. An equivalent per million is a unit chemical combining weight of a constituent in 1 million unit weights of water and is calculated by multiplying the concentration, in parts per million, by the reciprocal of the chemical combining weight of the constituent. For convenience in making this conversion the reciprocals of the chemical combining weights of the most commonly reported constituents are given in the following list:

Constituent	*Factor*	*Constituent*	*Factor*
Iron (Fe^{+2})	0.0358	Carbonate (CO_3^{-2})	0.0333
Iron (Fe^{+3})	.0537	Bicarbonate (HCO_3^-)	.0164
Calcium (Ca^{+2})	.0499	Sulfate (SO_4^{-2})	.0208
Magnesium (Mg^{+2})	.0822	Chloride (Cl^-)	.0282
Sodium (Na^+)	.0435	Fluoride (F^-)	.0526
Potassium (K^+)	.0256	Nitrate (NO_3^-)	.0161

Results given in parts per million can be converted to grains per U.S. gallon by dividing by 17.12. A calculated quantity of sodium and potassium is given in some analyses and is the quantity of sodium needed in addition to the calcium and magnesium to balance the anions.

The total hardness, as calcium carbonate ($CaCO_3$), is calculated from the equivalents of calcium and magnesium. The hardness caused by calcium and magnesium (and other ions if significant) equivalent to the bicarbonate and carbonate is called carbonate hardness. The hardness in excess of this quantity is called noncarbonate hardness. Carbonate hardness is not listed in table 3, as it can be found by subtracting noncarbonate hardness from total hardness.

CHEMICAL CONSTITUENTS IN RELATION TO USE OF WATER

The analyses of water from wells in Yuma County suggest that all the water is suitable for most uses. The hardness and silica content of some samples indicate that these are the only characteristics that may make some of the water unsuitable for some uses.

Dissolved solids.—The residue left after a sample of natural water has evaporated consists of mineral matter with which may be included some organic material and some water of crystallization. Water containing less than 500 ppm of dissolved solids generally is satisfactory for domestic use, except for the difficulties resulting from its hardness, iron content, and, in some areas, excessive corrosiveness. Water having more than 1,000 ppm generally is not satisfactory, for it is likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in other respects.

The dissolved solids contained in water samples collected in Yuma County ranged from 161 to 383 ppm and averaged 218 ppm. Therefore, water from the principal aquifers throughout Yuma County would seem suitable for most uses so far as dissolved-solids content is concerned.

Hardness.—The hardness of water, the property that generally receives the most attention, is most commonly recognized by its effects when soap is used with the water in washing. Calcium and magnesium cause nearly all the hardness of ordinary water. These constituents are also the active agents in the formation of most of the scale in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness, the table of analyses shows the noncarbonate hardness. Carbonate hardness, which can be determined by subtracting the noncarbonate hardness from the total hardness, is that caused by calcium and magnesium bicarbonate and can be removed almost completely by boiling. Carbonate hardness also can be reduced by a cheaper softening process than that needed for the reduction of noncarbonate hardness. Most of the water in Yuma County can be softened by this most economical method. This type of hardness is sometimes called temporary hardness. Noncarbonate hardness commonly is caused by sulfate or chloride of calcium and magnesium; it cannot be removed by boiling and has been called permanent hardness. With reference to use with soap there is no difference between the carbonate and noncarbonate hardness. In general, the noncarbonate hardness forms harder scale in pipes and boilers.

Water having a hardness of less than about 60 ppm generally is rated as soft, and its treatment for the removal of hardness generally is not necessary. Hardness between 60 and 120 ppm does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap, and its removal by a softening process is profitable for laundries and for some other industries. Hardness of more than 120 ppm can be noticed by anyone, and if the hardness is more than about 200 ppm it is common practice in some areas to soften water for household use or to install cisterns to collect rainwater.

Samples of water collected in Yuma County ranged in hardness from 107 to 243 ppm and averaged 151 ppm. Only 9 samples had a hardness greater than 150 ppm. The hardest water (more than 200 ppm) is that from the alluvium along the North Fork of the Republican River and along the Arikaree River.

Iron.—Next to hardness, iron is the constituent of natural water that generally receives the most attention. The quantity of iron in ground water may differ greatly from place to place, even though the water is derived from the same formation. If water contains much more than 0.3 ppm, the excess may precipitate as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste to water and to stain cooking utensils, may be removed from most water by simple aeration and filtration, but water from a few areas may require additional treatment.

The amount of iron was determined in only 3 of the 27 samples collected in Yuma County. In all 3 it was less than 0.1 ppm.

Fluoride.—Although fluoride is not so common in fairly large quantities as other constituents of natural water, it is desirable to know the amount of fluoride present in water that is likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing excessive concentrations of fluoride during the formation of the permanent teeth. This condition becomes more noticeable as the quantity of fluoride in water increases above 1.5 ppm. Recent reports indicate, however, that the incidence of tooth decay is decreased or prevented by quantities of fluoride that are not sufficient to cause permanent disfigurement from mottled enamel. (California State Water Pollution Control Board, 1952, p. 257.)

The concentration of fluoride in the samples of water collected in Yuma County ranged from 0.3 to 1.8 ppm and averaged 1.0 ppm. Only 2 samples contained fluoride in excess of 1.5 ppm. No evidence was found that fluoride is a problem in the county.

Nitrate.—The concentration of nitrate in drinking water has caused increased attention since the discovery that nitrate-rich water may cause methemoglobinemia, or cyanosis, in infants when the water is used in the preparation of babies' formulas. Some nitrate can be dissolved from nitrate-bearing deposits, but it is believed that large concentrations of nitrate generally are derived from surficial sources. Nitrate salts are very soluble and may be dissolved readily from soils having high concentrations of nitrate (sometimes derived from fertilizer) or from nitrogeneous materials in privies, cesspools, and barnyards; hence, high concentrations of nitrate may indicate that the water contains harmful bacteria also. Large amounts of nitrate are more commonly found in water from dug wells and springs, which generally are more poorly sealed from surface contamination, than from the deeper drilled wells.

Ninety parts per million of nitrate (as NO_3) in water is considered by some authorities as dangerous to infants, but a concentration of 45 ppm is considered dangerous by others (Comly, 1945).

None of the samples of water collected in Yuma County contained more than 23 ppm of nitrate, and only 4 samples contained more than 10 ppm.

Silica.—Silica in water generally does not affect the use of water except for some industrial purposes. Silica is particularly undesirable in water for boilers and steam turbines because it forms deposits in the tubes and on blades. At pressures under 150 psi a concentration of 40 ppm is permissible; at 150–250 psi, 20 ppm; at 250–400 psi, 5 ppm; and over 400 psi, 1 ppm. A limit of 10 ppm in water is recommended for ice making, and limits range from 20 to 100 ppm for pulp and paper making. Brewing requires water having a silica content less than 50 ppm. (California State Water Pollution Control Board, 1952, p. 353.)

The amount of silica in ground water in Yuma County was determined only for the samples obtained from the three municipal supplies. The concentrations ranged from 60 to 68 ppm. This is too high for most of the uses mentioned above. Future studies should include additional sampling for determination of silica.

Water for irrigation.—The suitability of water for irrigation depends mainly on the quantity of soluble salts and the relative amount of sodium in the water. But the suitability of water from a particular area also depends on many other factors such as the crops to be irrigated, the type of soil, and disposal of excess mineral content. Discussions of these factors are included in reports by the California State Water Pollution Control Board (1952, p. 147–153), Hem (1959, p. 242–250), and Wilcox (1955). The first two reports include extensive bibliographies on this subject.

The sodium (alkalinity) hazard is an expression of the rate at which sodium in the water is exchanged for calcium and other cations in the soil. As the amount of sodium in the soil increases, the soil tends to form a hard crust and may become nearly impermeable to water. All water analyzed for this report had a low sodium hazard.

No rigid limits of salinity (dissolved solids) hazard can be set because so many variable factors control the effect the water may have on a crop or a soil. Under average conditions in an arid climate, water containing as much as 2,150 ppm is suitable for most plants except sensitive ones. The most concentrated sample contained only 383 ppm of dissolved solids. The electrical conductivity of water is another measure of the salinity hazard. The specific conductance of the samples analyzed for this report ranged from 295 to 649 micromhos, suggesting that all the water has a low to medium salinity hazard.

Although a small amount of boron is necessary for proper plant nutrition, many plants are intolerant of excessive amounts. The greatest concentration of boron found was 0.22 ppm. According to Hem (1959, p. 245), this is acceptable for even the most sensitive crops.

Other mineral constituents of irrigation water, which may be harmful to crops when present in excessive amounts, include chlorides and bicarbonates. Because so many factors can affect the reaction of crops and soils to irrigation water, it is difficult to predict on the basis of water analyses alone what may take place. However, probably all the water sampled during this investigation is suitable for irrigation. Furthermore, water quality has not been recognized as a problem in Yuma County by local irrigators and agricultural scientists.

SANITARY CONSIDERATIONS

The analyses of water given in table 3 show the amounts of dissolved mineral matter in the water but do not indicate the sanitary quality. The water in a well may contain mineral matter that imparts an objectionable taste or odor and yet be free from harmful bacteria and entirely safe for drinking. On the other hand, the water in a well may be clear and pleasant to the taste and yet contain harmful bacteria.

Most of the people of Yuma County depend upon water supplied from wells, and every precaution should be taken to protect this water supply from pollution. A well should not be constructed near possible sources of pollution, such as barnyards, privies, and cesspools, and every well should be tightly sealed to a level below that of the water table. Dug wells are more likely to be contaminated from surface sources than drilled wells, chiefly because dug wells generally are not effectively cased or sealed at the surface. Drilled wells generally are well protected by casing, but many are poorly sealed at the top. Springs generally are more likely to be contaminated than wells and should be improved properly before being used as domestic supplies. Also, the water should be tested to make sure that it is not contaminated at the source in such a way that it cannot be made safe by chlorination or other treatment.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

PIERRE SHALE

The oldest formation exposed in Yuma County is the Pierre shale of Late Cretaceous age. It underlies the entire county and crops out along both sides of the Arikaree River in the eastern part of the county and in scattered areas along the south side of the North Fork of the Republican River (pl. 1). In some places where the Pierre shale is shown on the map as cropping out it is overlain by a thin mantle of slope wash.

The Pierre shale generally consists of dark-gray to black calcareous fissile shale laid down by Late Cretaceous seas which covered much of Colorado and extended over most of the central Great Plains. It contains many beds of bentonite and layers of limestone concretions, and in some places contains thick beds of sandstone. Thin layers of selenite (gypsum) are common. In many places a weathered zone of dark-yellow plastic clay as much as 30 feet thick rests on unaltered shale.

The thickness of the Pierre shale in Yuma County, as shown by logs of oil-test holes, ranges from about 2,500 feet in the western part of the county to about 1,300 feet near the Kansas state line.

Elias, in his report on the geology of Wallace County, Kans. (1931), described the Pierre shale in great detail and subdivided it into several members. He designated that part of the formation exposed in the Beecher Island area of Yuma County as the Beecher Island shale member. On the basis of ammonites of the *Discoscaphites* group, which were collected in this region, he dated this member as the uppermost part of the Pierre shale, and stated that it may represent a transition zone between the Pierre shale and the Fox Hills sandstone (Elias, 1931, p. 49).

The Beecher Island shale member of Elias is characterized by light-gray shale which has a distinct greenish tint in many outcrops. Many thin beds of limestone and streaks of limonite occur throughout the section (fig. 13). Thin streaks of white and brown bentonite occur in the lower part. The greatest thickness of the Beecher Island shale member is 100 feet. The member rests on a thick section of nearly featureless black shale, which in places weathers blue.

Local structure in the Pierre shale is difficult to map, owing to weathering, slumping, and the lack of key beds. Mather and others (1928, p. 106) report the presence of a "broad structural arch with

FIGURE 13.—Beecher Island shale member of the Pierre shale (Elias, 1931) capped by hard mortar bed of the Ogallala formation (C2–43–28).

low dips, alined in an easterly direction" in the Beecher Island area. They name this minor flexure the Black Wolf anticline. This is the only known structure in Yuma County.

Water supply.—The Pierre shale is not considered an important aquifer, and no wells are known to obtain water from it in Yuma County. However, fractured or sandy zones may be present and might yield small amounts of water of poor quality. The shale serves as a nearly impervious floor below the water-bearing materials and prevents the downward percolation of the water. The configuration of the surface of the shale is shown by contours on plate 7.

TERTIARY SYSTEM

PLIOCENE SERIES

OGALLALA FORMATION

The Pliocene Ogallala formation underlies all of Yuma County except for a few areas in the eastern part where streams have eroded it away. It ranges in thickness from a few feet to about 460 feet and lies unconformably on the Pierre shale. The formation consists of a series of relatively flat-lying beds of sand, gravel, clay, limestone, and sandstone which vary greatly in character both vertically and horizontally. Because of this variation it is difficult to correlate exposures for more than a few miles. Fossil seeds, volcanic-ash beds, and the so-called algal limestone at the top of the formation are the most reliable means of correlation.

The test drilling showed wide differences in the lithology of the formation throughout the county. Test hole 18 (B1–43–36ddd) penetrated 66 feet of the Ogallala formation, 49 feet of which is fine-grained calcareous very pale-orange to pinkish-gray mortar beds. The rest of the section consists of sandy calcareous light-greenish-gray clay and a thin bed of limestone. Six miles west of this locality, test hole 17 (B1–44–36ddd) penetrated 234 feet of the Ogallala formation, including 58 feet of mortar beds, 112 feet of calcareous clay, and 64 feet of fine gravel and coarse sand. Another test hole (No. 28, C4–48–31ccc) was drilled through 149 feet of the Ogallala formation, which included 97 feet of fine gravel and coarse sand interbedded with sandy calcareous clay; there were no mortar beds. Sixty feet of loose medium gravel and coarse sand was found near the base of 322 feet of the Ogallala in test hole 9 (B2–45–5bbb). (See Weist, 1960, for logs of the test holes.)

The dominant feature of the Ogallala formation in outcrops is the presence of highly resistant beds (fig. 14). These mortar beds are well-cemented sand and gravel and are white to pink except where darkened by lichens. The crossbedding of many of the strata (fig. 15) suggests that they were deposited by streams.

The top of the Ogallala formation where exposed in Yuma County is commonly marked by the "algal" limestone (fig. 16), which is a

FIGURE 14.—Typical exposure of the Ogallala formation along the North Fork of the Republican River (B1–43–7).

FIGURE 15.—Thin mortar beds of the Ogallala formation showing crossbedding. Roadcut north of Beecher Island (C2–43–15ccc).

FIGURE 16.—"Algal" limestone of the Ogallala formation exposed in a roadcut (B5–48–9bbb).

massive limy bed as much as 3 feet thick containing scattered sand grains. The bed is characterized by pinkish whorls and concentric crusts which Elias (1931, p. 136–141) identified as algal structures formed in quiet lakes. Swineford and others (1958, p. 98–115) have presented evidence that these structures are pisolites and are not of algal origin. The writer has not attempted to resolve this conflict but uses the term "algal" to designate this bed. The algal limestone is not readily identifiable in the subsurface. It was recognized in only two tests holes, No. 1 (B5–44–5bbb) and No. 20 (C1–44–5bbb). Following is a measured section describing typical beds of the Ogallala formation:

Section of the Ogallala formation in B1–44–16aa

	Thickness (feet)
Peorian loess:	
Silt, brown, cemented; contains caliche; forms cat-step terraces	40.0+
Unconformity.	
Ogallala formation:	
Limestone, light-gray, hard, rubbly, ledge-forming; contains opal; becomes sandier downward; exhibits algal structure	2.6
Silt, clayey, brown, soft, slope-forming	13.6
Sandstone, fine to coarse, light-gray, very hard, calcareous	14.6
Clay, silty, light-tan to gray, soft, slope-forming; contains hard streaks	8.9
Sandstone, fine to coarse, light-gray, hard, ledge-forming; contains calcareous concretions	7.5
Clay, silty, light-tan to pale-yellow, slightly cemented, slope-forming	5.2
Sandstone, fine to very fine, light-gray to tan, hard, ledge-forming	1.6
Clay, silty, light-tan, slightly cemented, slope-forming	6.8
Sandstone, medium to coarse, light-gray to tan, hard, calcareous	1.4
Clay, yellowish-tan, slightly cemented, slope-forming	4.4
Siltstone, tan, hard, ledge-forming; thickness irregular	.4
Clay, yellowish-tan, slightly cemented, slope-forming	17.4
Volcanic ash, light-gray, very hard	2.5
Volcanic ash, white, weathers gray; contains calcareous pipings	6.0
Sand, fine, yellowish-tan, slightly cemented	2.8+

Clay beds at the base of the Ogallala in some parts of Yuma County are practically indistinguishable from beds in Wallace County, Kans., that Elias (1931, p. 153–158) named the Woodhouse clays. East of Beecher Island, in an area along the north bank of the Arikaree River and centering in the E½ sec. 1, T. 2 S., R. 43 W., is a series of outcrops of a calcareous bentonitic clay containing a thin ash bed near the middle of the section. The color of the clay ranges from olive gray at the base to pale yellowish brown at the top. The outcrop of this clay was traced about 2 miles. At both ends of the outcrop the clay appeared to interfinger with beds of sand and gravel that were typical of the Ogallala formation. Similar clay was penetrated also above the Pierre shale in test holes 12 (B5–47–1aaa) and 36 (C2–43–

1baa), and possibly in test hole 9 (B2–45–5bbb). A section measured at the locality shown in figure 17 follows:

Section of the Ogallala formation in C2–43–1

	Thickness (feet)
Ogallala formation:	
Sand, very fine to coarse, clayey, loosely cemented, grayish-orange; forms nearly vertical slope	5.0+
Clay, bentonitic, slightly calcareous, plastic, pale-yellowish-brown; forms steep slope	4.0
Clay, bentonitic, noncalcareous, platy, plastic, light-olive-gray with yellow streaks; contains some limonite; forms slope	1.8
Sandstone, very fine-grained, silty, calcareous, platy, very pale orange; forms ledge	.3
Clay, sandy, bentonitic, slightly calcareous, dark-yellowish-brown with limonite streaks; forms gentle slope	4.5
Clay, bentonitic, slightly calcareous, plastic, light-olive-gray with yellow streaks; forms steep slope	7.5
Ash, slightly calcareous, white with pinkish streaks; has yellow strip at top and bottom; contains scattered sand grains; forms slight ledge	1.0
Clay, sandy, bentonitic, calcareous, greenish-gray; contains lenses of green sand; forms slope	17.0
Unconformity.	
Pierre shale:	
Shale, bentonitic, calcareous, fissile, plastic, olive-gray with dark-yellowish-orange streaks; weathers gray blue; forms slope	20.0+

FIGURE 17.—Woodhouse clays of the Ogallala formation (Elias, 1931). White ash bed near the base of the exposure (C2–43–1).

Water supply.—The Ogallala formation is the most important source of ground water in Yuma County, supplying all the wells in the uplands except a few domestic and stock wells. Water flowing from springs in the Ogallala formation forms the perennial flow of the North Fork of the Republican River, and adds to the flow of the South Fork of the Republican River and the Arikaree River. The yields of wells range from a few gallons per minute from small domestic and stock wells to more than 2,000 gpm from two irrigation wells. Wells tapping thick sections of coarse sand and gravel below the water table generally yield large supplies of water. Fine-grained or cemented materials generally yield smaller amounts of water. The map showing the saturated thickness of the Ogallala formation (pl. 6) indicates that a large amount of water is available from the Ogallala formation throughout much of Yuma County.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

GRAND ISLAND(?) FORMATION

The Grand Island(?) formation in Yuma County consists of irregular lenticular deposits of reddish-brown fine to coarse sand and fine to medium gravel, and is as much as 30 feet thick. The deposits lie disconformably on the Ogallala formation. They are loosely to moderately cemented and are crossbedded in most localities. The rounded grains are iron stained and consist principally of quartz, feldspar, and granite. In some places the formation contains bands and lenses of black-stained material. The deposits are calcareous and contain pipes and stringers of calcium carbonate near the top. They were laid down near the end of the Kansan stage of glaciation by streams flowing from the mountains and tablelands. Hill and Tompkin (1953, p. 24) have correlated these deposits with the Grand Island formation of Kansan age in Nebraska.

There are no known natural exposures of the Grand Island(?) formation in Yuma County; hence the formation is not shown on the geologic map (pl. 1). Gravel pits north of Wray and near Eckley have exposed as much as 24 feet of this formation. Several auger holes bored by the U.S. Soil Conservation Service have penetrated several feet of cemented sand and gravel of the Grand Island(?); the unit was recognized also in several test holes drilled during this study.

Water supply.—The Grand Island(?) formation lies above the water table in most of Yuma County. It is moderately permeable, and thus permits natural recharge to the underlying Ogallala formation.

SAPPA(?) FORMATION

In many places in Yuma County, the Sappa(?) formation overlies the Grand Island(?) formation conformably (fig. 18). It consists

FIGURE 18.—Sappa(?) formation resting on Grand Island(?) formation in a gravel pit (B3–44–10daa). Point of pick at contact.

of calcareous sand and clayey, silty marl containing fossils of mollusks, diatoms, and ostracods. The unit in most places is less than 10 feet thick. The color ranges from light gray to olive gray. The unit can be identified on the basis of lithology and the presence of ostracode remains (Hill and Tompkin, 1953, p. 25).

Because the Sappa(?) formation is thin and discontinuous, it was not differentiated from overlying dune sand and loess on plates 1 and 2.

Water supply.—The Sappa(?) formation is not known to yield water to wells in Yuma County. It may tend to confine water under pressure in the Grand Island(?) formation where that unit is saturated.

PEORIAN LOESS

The Peorian loess unconformably overlies the Ogallala formation in the upland areas south of the North Fork of the Republican River and east of Kirk. The thickness of this wind-deposited yellowish-gray calcareous silt ranges from 124 feet in test hole 17 (B1–44–36ddd) to a featheredge in the area near Kirk. Thin deposits of loess probably cover areas other than those shown on plate 1, but the deposits are too thin to be significant. In some areas slope wash has been mapped as loess because the loess is predominant.

Loess in Yuma County is a clayey calcareous yellowish-gray silt which locally is fossiliferous. It is composed principally of quartz grains, but it contains streaks of caliche and small root holes lined or filled with calcium carbonate. In some places the loess contains small amounts of coarse sand indicative of periods of high wind. It often forms steep slopes which exhibit columnar structure (fig. 19). Cat-step terraces develop in many places on grass-covered slopes. According to Brice (1958, p. 69–85) these miniature terraces are formed by sheet wash undercutting sod-capped scarps.

Water supply.—The Peorian loess is relatively impermeable and yields no water to wells. On the flat uplands, precipitation collects in intermittent lakes which may contain water most of the summer. The lakes are potential sources of water for artificial recharge. The loess forms a very rich soil, and much of the irrigated acreage in the county is underlain by it.

FIGURE 19.—Peorian loess in a roadcut north of Beecher Island (C1–43–33ad).

PLEISTOCENE AND RECENT SERIES

DUNE SAND

Plate 1 shows that about one-third of Yuma County is covered by a belt of sand dunes stretching from the north bank of the Arikaree River in the western half of the county to the northeast corner of the county. All the county north of Wray and east of Eckley is covered by dunes.

The dunes are formed by loose well-sorted fine to coarse grains of quartz and feldspar. Deposits range in thickness from 0 to about 100 feet. The sandhills, which are as much as 170 feet high, form northwestward-trending ridges as much as 10 miles long. Most of the sandhills are stabilized by grass, but in some places blowouts have formed and the sand is moving.

Many comparatively level areas are scattered through the sand-dune area (fig. 20). The level areas are underlain by sandy silt and clay and form good farmland. These interdune areas are probably old dunes, although in some places the underlying geologic units are exposed.

Water supply.—The dune sand in most of Yuma County is above the water table. Where it is saturated, it yields small amounts of water to stock and domestic wells. Because the sand is highly permeable and the area has no surface drainage, the area is important for natural recharge of ground water.

FIGURE 20.—Typical sand-dune topography northeast of Eckley (B2-45-13).

ALLUVIUM

Alluvium derived locally from the Ogallala formation and Pleistocene deposits lies along the valleys and underlies the flood plains of the major stream valleys and some of the smaller creeks. The alluvium in the larger valleys generally consists of moderately well- to well-sorted sand and gravel containing some silt and clay. The alluvium of the smaller valleys generally consists of finer grained materials. The greatest thickness of the alluvial deposits in the main valleys commonly is about 50 feet, whereas that in the smaller valleys probably is less than 20 feet. The greatest thickness of alluvium reported was 78 feet penetrated in well C2–43–14aca drilled in the valley of the Arikaree River.

Water supply.—The alluvium of the three major stream valleys constitutes the other major aquifer in Yuma County. Nearly everywhere the alluvium will yield adequate supplies of water for stock and domestic use and in many places it will yield enough for irrigation.

The prospects for development are least favorable in the alluvium in the valley of the North Fork of the Republican River. At the time of the study, only two irrigation wells had been drilled; neither yielded more than 200 gpm. An aquifer test on one of the wells (B1–44–10bbb) indicated a transmissibility of 15,000 gpd per ft and a permeability of 400 gpd per sq ft. The test holes drilled in this valley did not penetrate any thick deposits of gravel, the material penetrated being mostly sand and clay. However, surficial evidence suggests that the valley east of Wray may be underlain by buried channels containing thicker deposits of gravel which would yield moderate to large quantities of water.

The alluvium along the Arikaree River seems to be much more favorable than that along the North Fork of the Republican River for the development of large-capacity wells. Yields from wells drilled in this area commonly range from 100 to 1,000 gpm. A laboratory test of a sample of loose gravel obtained from test hole 27 (C3–46–31ddd) had a coefficient of permeability of 920 gpd per sq ft. An aquifer test made on a well near the west edge of the county (C4–48–20bac) showed a coefficient of permeability of 8,000 gpd per sq ft and a coefficient of transmissibility of 120,000 gpd per ft (table 2). The test was very short, and the calculated values are probably somewhat high. However, the test does indicate favorable conditions for the development of large-capacity wells. In the western half of the county the alluvium overlies the lower part of the Ogallala formation. To obtain maximum yields, wells should completely penetrate both formations.

The alluvium along the South Fork of the Republican River also is favorable for the development of large-capacity irrigation wells. In places it overlies the lower part of the Ogallala formation. Yields of 1,000 gpm have been reported for wells that tap both formations. A 20-hour aquifer test of well C5–44–30bcb, which was pumped at an average rate of 775 gpm, indicated a coefficient of transmissibility of 100,000 gpd per ft and a coefficient of permeability of 1,700 gpd per sq ft (table 2).

Care should be taken in prospecting for water in stream valleys, particularly if moderate to large quantities of water are being sought. Large yields generally are obtainable only where wells tap buried channels which contain the thickest and most permeable water-bearing materials. The buried channels lie beneath the flood plain and between the valley walls and generally have a much straighter course than the present meandering streams. The position of the buried channel, however, is in no way related to the position of the present channel, and the width and extent of the channel can be determined only by subsurface exploratory methods which include test drilling and geophysical surveys. Prospecting along a line extending across the valley generally is more successful than that done along a line parallel to the valley, for test holes drilled parallel to the valley might parallel the buried channel and miss it.

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