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Ground-Water Resources in Cleveland and Oklahoma Counties, Oklahoma

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U. S. Geological Survey

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P. R. Wood and L. C. Burton

ABSTRACT

Cleveland and Oklahoma Counties, in central Oklahoma, have a combined area of 1,252 square miles and a range in altitude of from 870 to 1,400 feet above sea level. The annual precipitation is about 33 inches at Norman and about 32 inches at Oklahoma City. In 1960 the two counties had a population of 487,000, of which 95 percent lived in the Norman and Oklahoma City urban areas and 5 percent lived in small towns and rural areas. General farming and livestock breeding are the predominant types of agriculture. Industry is widely diversified and is expanding rapidly.

Rocks exposed at the surface are Permian and Quaternary in age. The Permian rocks include the Wellington Formation, Garber Sandstone, Hennessey Shale, Duncan Sandstone, and Chickasha Formation. The Quaternary rocks include terrace deposits at one or more levels along the valleys of the principal streams, alluvium, and dune sand.

The terrace deposits and alluvium supply ground water for domestic and stock use at many places in the two counties. The alluvial deposits along the North Canadian River at Oklahoma City are capable of yielding 200 or more gallons of water per minute to properly developed wells. The Chickasha Formation, Duncan Sandstone, and Hennessey Shale yield small quantities of hard water to wells. In places, water from wells 100 or more feet deep is too highly mineralized for most uses.

The principal sources of ground water used for municipal and industrial purposes are the Garber Sandstone and the Wellington Formation. The two formations were deposited under similar conditions, and both consist of lenticular beds of sandstone alternating with shale. Beds may vary greatly in thickness within short lateral distances.

At variable depths below the land surface the Garber and Wellington contain water too highly mineralized for most uses. Hence, the depth to which wells may be drilled in search of potable water supplies is largely determined by the depth at which salt water is encountered. In southeastern Cleveland County salt water occurs about 100 feet below land surface. In eastern Cleveland and Oklahoma Counties salt water occurs at depths ranging from 200 to 660 feet below land surface. In the Oklahoma City, Lake Hefner, and Edmond areas salt water is 700 to 800 feet below land surface; in the Midwest City area, more than 1,000 feet; at Norman, 700 feet; and at Noble, 400 feet.

The depths of municipal, institutional, or industrial wells perforated or screened in the Garber and Wellington range from 300 to about 1,000 feet. Yields range from 50 to 450 gallons per minute and average 240. Pumping drawdowns range from 50 to 430 feet and average 200 feet. Coefficients of transmissibility, determined from pumping tests, ranged from 3,000 to 7,000 gallons per day per foot and averaged 5,000. The coefficient of storage averaged 2.0×10^{-4}. Specific capacities range from 0.6 to 3 gallons per minute per foot of drawdown, and average 1.3.

Throughout most of the area water levels in the Garber and Wellington have changed little since the 1940's, but they have declined substantially in the Norman and Midwest City areas. Water levels fluctuate in response to seasonal pumping and differences in replenishment in dry and wet seasons.

Recharge is estimated to be about 5 percent of the precipitation, or 90 acre-feet per square mile for the outcrop area. Annual recharge averages about 72,000 acre-feet.

Ground-water withdrawals from the Garber and Wellington for all purposes through 1959 are estimated to have been 280,000 acre-feet. Ground-water withdrawals for municipal, institutional, and industrial use during 1963 are estimated to have been 25,000 acre-feet.

Water from the Garber and Wellington is suitable for drinking, but locally is high in sulfate, chloride, or other mineral constituents. At most places it is suitable for irrigation, but locally it has an excessive amount of sodium.

The Garber and Wellington Formations in the two counties are estimated to contain 50 million acre-feet of fresh water, of which about 34 million is available for development. Thus additional supplies are available through development, but wells should be properly spaced to minimize interference between wells.

INTRODUCTION

Review of Investigations

An investigation of the ground-water resources in Cleveland and Oklahoma Counties was begun by the Federal and State geological surveys in the early 1940's to provide water data for defense installations. In Cleveland County, work done by and at the request of the U. S. Navy involved test drilling and aquifer testing to determine the availability of ground water in the Ten-Mile Flat area, and geologic and hydrologic studies to determine the availability of ground water in the Garber Sandstone at naval installations near Norman. In Oklahoma County, work done at the request of the U. S. Army involved geologic and hydrologic studies needed to evaluate ground-water conditions in the Garber Sandstone and Wellington Formation in the Oklahoma City area, and to determine the availability of ground water in those formations at the municipal airport (now Will Rogers World Airport), at the Oklahoma City

Air Depot, and at the Oklahoma City Aircraft Assembly Plant (now Tinker Air Force Base).

A memorandum report by Jacobsen and Reed describing ground-water conditions in the Oklahoma City area was prepared and placed in the open file in typewritten form in 1944. In view of the continued interest in the ground-water resources of the area, and at the request of the Oklahoma Geological Survey, the report was rewritten and published as Oklahoma Geological Survey Mineral Report 20 (Jacobsen and Reed, 1949).

Owing to the rapid industrial growth and associated population expansion in the Oklahoma City metropolitan area after World War II, various planning and economic groups became concerned as to the availability of water for further development. Accordingly, it was decided to use the previously collected data on ground water in the Garber Sandstone and Wellington Formation as the basis for a report on the two-county area. This investigation was undertaken as a cooperative project between the U. S. Geological Survey and the Oklahoma Geological Survey. A systematic well inventory was started in 1952 by personnel of the U. S. Geological Survey. During the period 1954-1958, L. C. Burton, hydraulic engineer, U. S. Geological Survey, collected, compiled, and tabulated records of wells, ground-water levels, water quality, and ground-water pumpage; made several aquifer tests to determine the hydrologic properties of deposits tapped by wells; compiled a reconnaissance geologic map of the two counties; and prepared a manuscript report which covered the geology and some phases of the ground-water resources of the area. Work on the project was suspended during the 1958-1964 period.

In April 1964 the present project chief, P. R. Wood, was assigned to synthesize the previously collected data, to collect additional data necessary for the evaluation of current development, and to prepare this report.

The purpose of this investigation was to describe the occurrence of ground water in the Garber Sandstone and Wellington Formation, to determine its present state of development, and to estimate as nearly as possible the potential for additional ground-water development in the two counties.

Although much information was obtained on ground water in the Quaternary deposits, the deposits are described only briefly in this report.

From its beginning, this project has been a cooperative one between the U. S. Geological Survey and the Oklahoma Geological Survey. In its beginning, the project was under the general supervision of A. N. Sayre, formerly chief of the Branch of Ground Water, U. S. Geological Survey, and R. H. Dott, formerly director of the Oklahoma Geological Survey. It was completed under O. M. Hackett, chief of the Branch of Ground Water, and C. C. Branson, director of the Oklahoma Geological Survey. The report was prepared under the immediate supervision of A. R. Leonard, district geologist of the U. S. Geological Survey in charge of ground-water investigations in Oklahoma.

The geology of Cleveland and Oklahoma Counties has been described by Gould (1905), Aurin, Officer, and Gould (1926), Anderson (1927), Travis (1930), and Miser (1954). The stratigraphy, structure, and problems encountered during development of the Oklahoma City oil field were discussed by McGee and Clawson (1932).

Reports describing the occurrence of ground water in all or parts of Cleveland and Oklahoma Counties include those of Gould (1905), Phillips, Alvord, and Billingsley (1913), Schwennesen (1915), McGee and Clawson (1932), Jacobsen and Reed (1949), and Dennis (1954).

Brief descriptions of the geography and physiography of the area are included in comprehensive reports by Snider (1917) and Fenneman (1923). In 1957, the Oklahoma Geological Survey issued a small-scale physiographic map of the State which showed two physiographic units in the two-county area (Curtis and Ham, 1957).

The soils of Oklahoma County were described by McLandon and Jones (1907), and the soils of Cleveland County were mapped and described by Buchannan and others (1954).

Acknowledgments

The collection of hydrologic data for this report and the success of the investigation were made possible mostly by the cooperation of public agencies, private companies, and individuals. City officials, water superintendents, and engineers in charge of water departments in the cities and towns in Cleveland and Oklahoma Counties furnished information on wells and supplied pumpage data. The Oklahoma Water Resources Board furnished information on many industrial wells.

The U. S. Bureau of Reclamation made available hydrologic information compiled during feasibility and engineering studies for the Lake Thunderbird reservoir on Little River. The U. S. Army Corps of Engineers and the U. S. Navy furnished information on wells drilled at military installations in the early 1940's. The University of Oklahoma supplied well data, chemical analyses, and pumpage data for wells operated on university property.

Special thanks are due the officials of the cities of Edmond, Nichols Hills, Midwest City, and Norman; The University of Oklahoma, Norman; Central State Griffin Memorial Hospital; and Tinker Air Force Base for allowing the U. S. Geological Survey to make aquifer tests in their wells.

Acknowledgment also is due the many residents, owners, well drillers, consulting engineers, and company officials who furnished well data and other hydrologic information used in this report.

Well-Numbering System

Wells and test holes are referred to in this report by numbers and letters which indicate their locations within legal rectangular subdivisions of the public lands, referenced to the Indian base line and meridian. For example, in the number 11N-3W-8cbb, which was assigned to a well in the southwestern part of Oklahoma City, the first two segments of the number designate the township (11N)

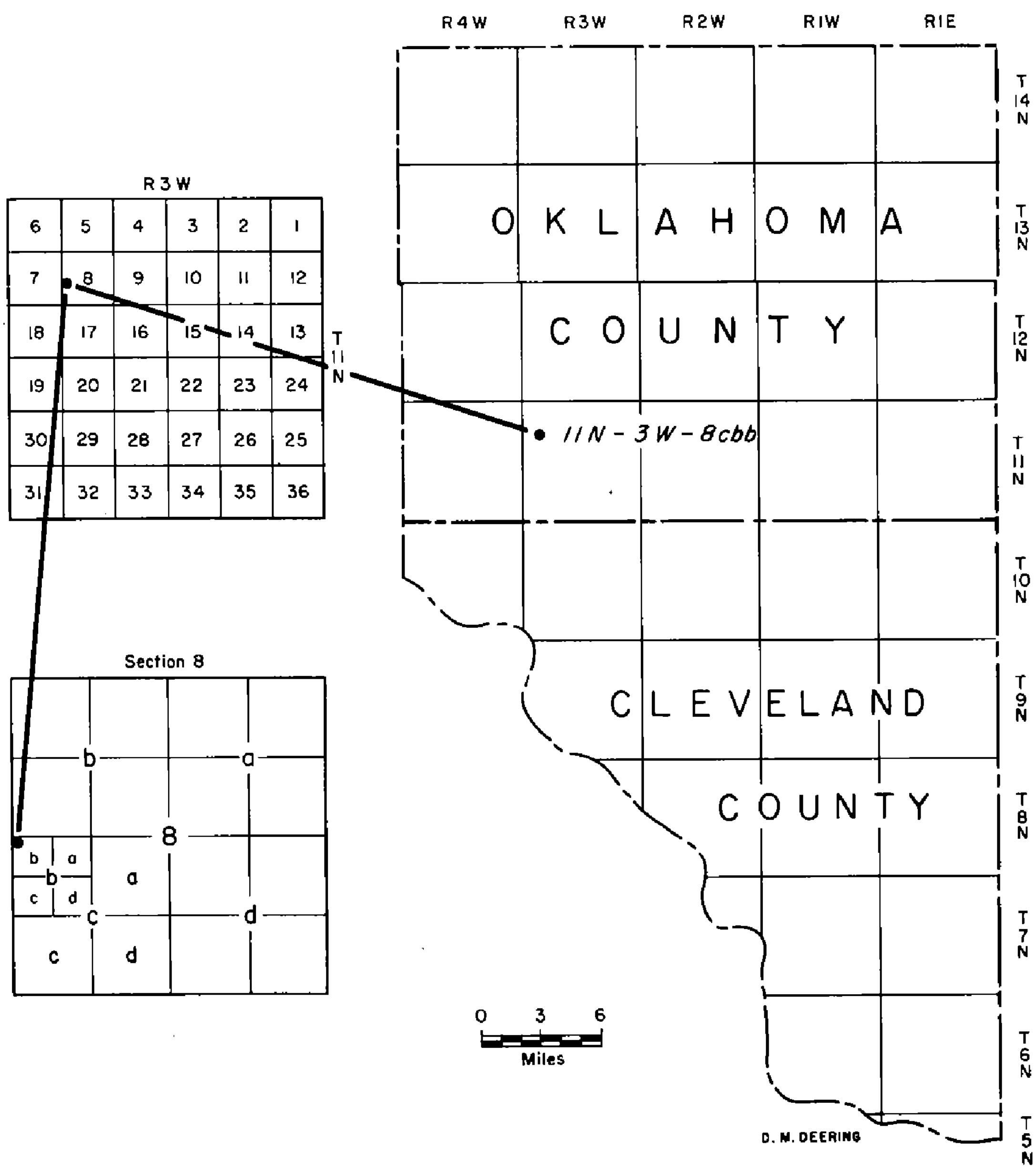

Figure 1. Sketch showing U. S. Geological Survey well-numbering system in Oklahoma.

and the range (3W); the third segment gives the section number (8), followed by three lower-case letters. The first letter (c) is the quarter section (160-acre tract): a—northeast quarter, b—northwest quarter, c—southwest quarter, d—southeast quarter, as illustrated in figure 1. The second letter (b) is the quarter-quarter section (40-acre tract), and the third (b) the quarter-quarter-quarter section (10-acre tract). In cases where more than one well has been inventoried within a 10-acre tract, the wells are numbered serially by the addition of an arabic numeral at the end. Thus, well 11N-3W-8cbb1 is the first well to be listed in NW¼ NW¼ SW¼ sec. 8, T. 11 N., R. 3 W.

GEOGRAPHY

Location, Population, and Economy

Cleveland and Oklahoma Counties are in the central part of the State (fig. 2). Oklahoma City, the capital of the State and the county seat of Oklahoma County, is on a bend of the North Canadian River, almost at the geographical center of Oklahoma. Norman, the county seat of Cleveland County and the site of The University of Oklahoma, is near the Canadian River, about 20 miles south of downtown Oklahoma City.

Of the 77 counties in Oklahoma, Oklahoma County ranks 53rd in area (705 square miles) and is first in population, having 439,500 inhabitants in 1960. About 97 percent (425,500) of these live in the Oklahoma City urban area, which covers about 40 percent of the county. Less than 3 percent (14,000) live in small towns and rural areas. Cleveland County, which covers 547 square miles, ranks 70th in area and 7th in population, having 47,600 inhabitants in 1960. About 70 percent (33,400) live in Norman, 7 percent (3,500) live in the Oklahoma City urban area (which extends into the northern part of Cleveland County), and 23 percent (10,700) live in small towns and rural areas.

The economy of Cleveland and Oklahoma Counties is influenced to a large degree by government institutions and installations. Oklahoma City, the State capital, is the site of many State offices having a large number of employees. Most State offices are concentrated in the complex of office buildings near the State Capitol, but some agencies are scattered around the city, the largest being The University of Oklahoma Hospital and Medical School. In addition, several Federal installations are located in Oklahoma City. Tinker Air Force Base, in the southeastern part of Oklahoma County is the largest single employer in the State. Other large Federal installations are the Federal Aviation Agency Aeronautical Center at Will Rogers World Airport and the Veterans Administration Hospital at the University of Oklahoma Hospital.

The principal employer in Edmond is Central State College. Many of the people in Edmond not employed by the college work in industries, institutions, or installations in Oklahoma City. The economies of other towns and cities in Oklahoma County are inextricably interwoven with that of Oklahoma City.

The economy of Norman is dominated by the State institutions located there, the largest of which is The University of Oklahoma. Central State Griffin Memorial Hospital and the Oklahoma Cerebral Palsy Center also employ a large number of people. Many of the

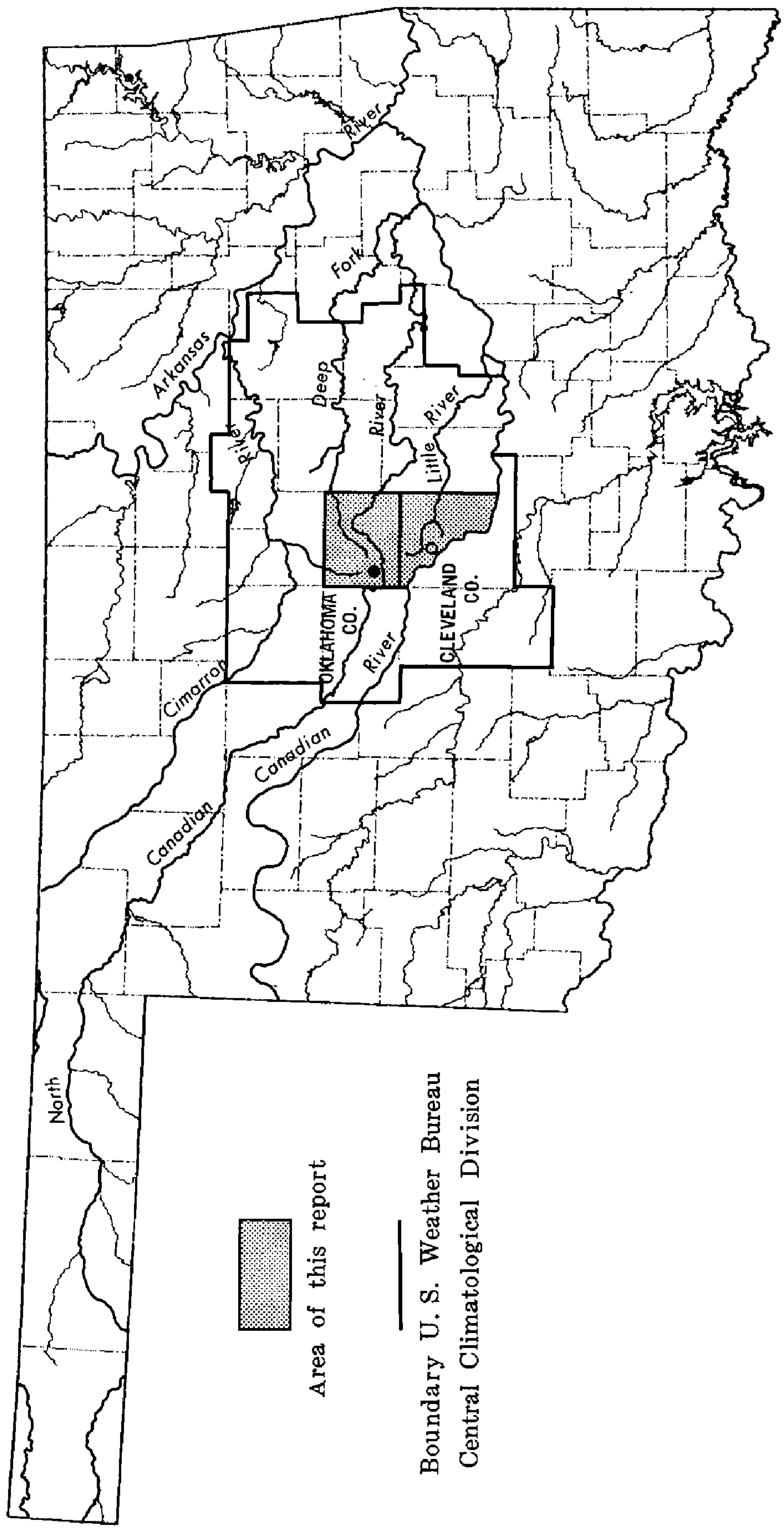

Figure 2. Index map of Oklahoma showing the location of Cleveland and Oklahoma Counties and the boundaries of the U. S. Weather Bureau Central Climatological Division.

people living in Norman, Moore, and smaller towns in Cleveland County work in Oklahoma City.

Before World War II, the major industries were those associated with the production, processing, and marketing of natural gas, petroleum and petroleum byproducts, meats and meat byproducts, and various foods for human or animal consumption. After World War II, industry diversified and expanded rapidly. New industries include firms specializing in steel construction and in the production of piston and jet aircraft, electronic components, stone and concrete products, electric and telephone equipment, plastics, clothing, printing and publishing, furniture, and many other products. Commercial and financial enterprises also expanded in number and variety.

The agricultural economy of Cleveland and Oklahoma Counties has been developed and maintained largely through the production and sale of small grains, sorghums, dairy and poultry products, livestock, and vegetables. In 1959 the gross value of farm products was estimated at 10 million dollars. In that same year, about 74 percent of the area (258,000 acres) in Cleveland County was covered by farms ranging in size from less than 10 to more than 900 acres, and averaging 230 acres. In Oklahoma County, 61 percent of the area (276,000 acres) consisted of farms ranging in size from fewer than 10 to more than 1,000 acres, and averaging 180 acres. Most of the land was dry farmed, but about 200 acres in Cleveland County and about 500 acres in Oklahoma County were irrigated. (Data from U. S. Census of Agriculture, 1959.)

CLIMATE

The climate of Oklahoma and Cleveland Counties is controlled by the interaction of tropical and polar air masses and is characterized by wide ranges in temperature and wide deviations from average precipitation. The average annual temperature is about 60°F, but the seasonal range is great (table 1). Precipitation from regional cyclonic storms and from local thunderstorms occurs throughout the year but is greatest during the spring and summer (table 1). At Norman, altitude 1,170 feet, the average precipitation for a 67-year period was 33.36 inches, and at Oklahoma City, altitude 1,250 feet, the average for 73 years was 31.76 inches.

The annual precipitation for the period of record and the cumulative departure from the average annual precipitation at the Oklahoma City station are shown graphically on figure 3. The graph of the annual precipitation illustrates how much the year-to-year precipitation deviates from the long-term average, and the cumulative departure curve shows precipitation trends during the 73-year period 1891-1963. Upward trends on the cumulative departure curve represent periods of greater than average precipitation and downward trends represent periods of below-average precipitation. The alter-

TABLE 1. — AVERAGE TEMPERATURE AND PRECIPITATION IN CENTRAL OKLAHOMA*

MONTH	AVERAGE TEMPERATURE (°F)	AVERAGE PRECIPITATION (INCHES)
January	38.8	1.43
February	43.0	1.58
March	49.3	2.08
April	61.1	3.44
May	69.0	5.44
June	72.8	4.46
July	81.0	3.07
August	82.1	2.69
September	69.5	3.35
October	63.9	2.93
November	49.7	1.81
December	41.3	1.53
Annual	60.1	33.81

* Source: U. S. Weather Bureau Climatological Data. Central Oklahoma is in the U. S. Weather Bureau's Central Division (fig. 2).

nating wet and dry periods at Oklahoma City correlate generally with similar periods at other precipitation stations in the Great Plains region (Thomas, 1962, fig. 11, p. 25) and suggest that prevailingly dry periods, ranging in length from 5 to 9 years, alternate with wet periods of 2 to 15 years' duration. Thus, the severe drought of 1933-1939 was followed by a generally wet period, 1940-1951, and the drought of 1952-1956 by above-average precipitation in 1957-1961.

PHYSICAL FEATURES

The land surface in Cleveland and Oklahoma Counties may be divided into three topographic units: sandstone hills, prairies, and wide alluvium-filled valleys of major streams. Each of these units reflects the geology of the underlying rocks and the erosional effects of wind and water.

Sandstone hills occupy the eastern half of the area. They are low, steep-sided hills formed by the differential erosion of lenticular beds of red sandstone and shale in the area underlain by the Garber Sandstone and Wellington Formation (pl. I). The sandstone hills are strongly dissected by intermittent streams that occupy broad, relatively flat-floored alluvial valleys. Local relief ranges from 50 to 200 feet. Hills underlain by sandstone are forested with small blackjack and post oaks and other deciduous trees. Hills underlain by shale are covered by grasses and commonly are barren, or nearly barren, of trees.

The soils of the sandstone hills are shallow to moderately deep, and are reddish brown. Because of the hilly terrain and shallow soils, surface drainage is rapid, runoff rates are relatively high, and the area is highly susceptible to both sheet and gully erosion.

The prairies in the western part of the area form a gently rolling grass-covered plain developed chiefly on the Hennessey Shale (pl. I). Local relief ranges from 20 to 150 feet and is greatest near major streams and in the east where the prairies merge with the sandstone hills. In most places, beds of sandstone occur near the base of the Hennessey. Where these beds have weathered to form rounded or flat-topped hills of low relief, the prairies merge with the sandstone hills, and the boundary between the two units cannot be easily distinguished.

In some places, especially near Lake Overholser on the North Canadian River and near the Canadian River in the northwest corner of Cleveland County, sand dunes stand out in relief on the prairie surface. The source of the sand probably was the flood plains or alluvial terraces of the rivers. The prevailing southerly winds have shifted the sand and shaped it into dunes. Most of the dunes are now more or less stabilized by vegetation, but near the rivers some are actively shifting and are barren of vegetation.

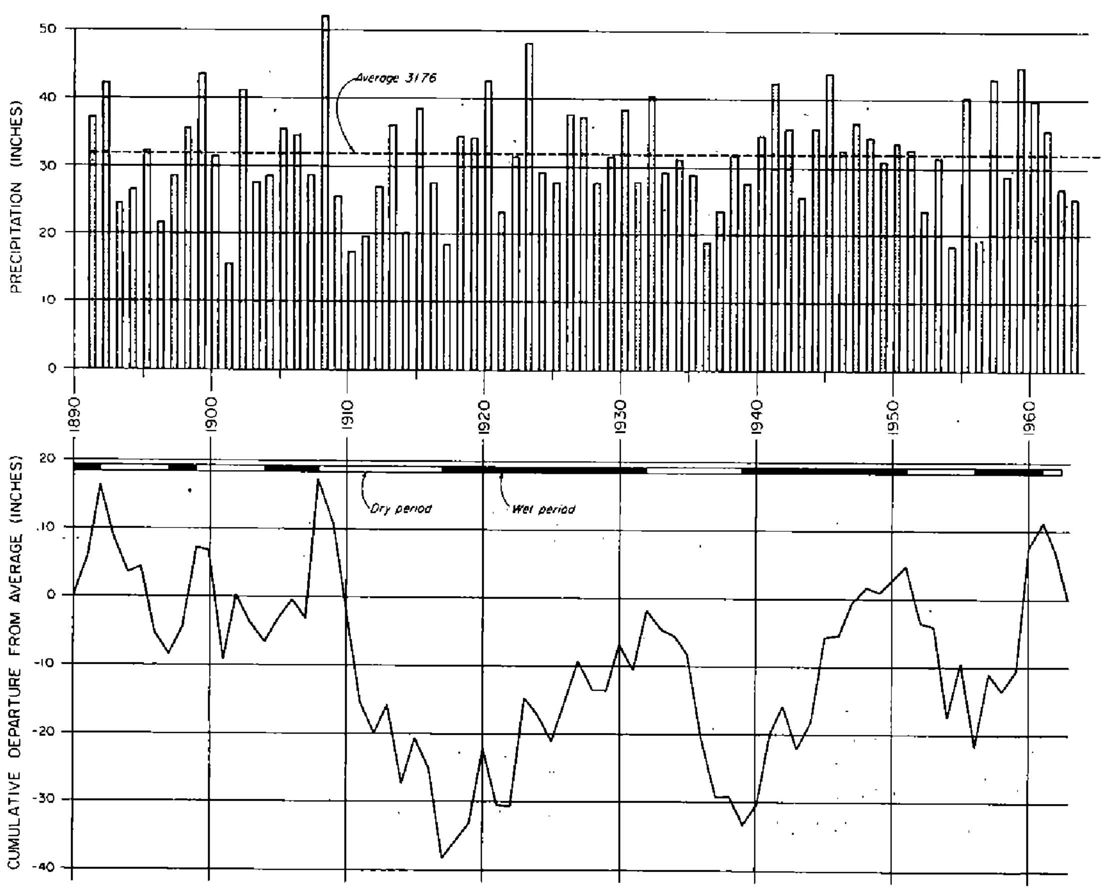

Figure 3. Graphs showing annual precipitation and cumulative departure from average at Oklahoma City (1891-1963).

The soils of the prairies are red to reddish brown, are moderately deep, and have been developed chiefly from slightly calcareous clay shale and sandy shale. Surface drainage is slow to rapid, depending upon local relief. Runoff rates are high, and most sloping surfaces are susceptible to sheet and gully erosion.

Wide, alluvium-filled valleys occur along the Canadian and North Canadian Rivers, which cross the area before joining the Arkansas River in eastern Oklahoma (fig. 2). Alluvial valleys also occur along Little River and its major tributaries in Cleveland County and along Deep Fork and its major tributaries in Oklahoma County. In many places, two or more terraces of varying lengths and widths occur along the principal streams, and terraces large enough to be of agricultural importance are extensively farmed.

The land-surface altitudes in Cleveland County range from 960 feet above sea level at the point where Little River leaves the county to 1,360 feet above sea level on the drainage divide between the Canadian and North Canadian Rivers in the northwest corner of the county. In Oklahoma County, land-surface altitudes range from 870 feet at the point where Deep Fork leaves the county to 1,400 feet on the drainage divide between the Canadian and North Canadian Rivers in the southwest corner of the county.

Cleveland County is drained by the Canadian and Little Rivers and their tributaries. Oklahoma County is drained chiefly by the North Canadian River and Deep Fork, a major tributary of the North Canadian. A small area in the northwest corner of the county drains northward to the Cimarron River by way of Bluff, Deer, Chisholm, and Cottonwood Creeks. The southwest corner of the county is drained by the Canadian River, and the south-central and southeastern parts of the county are drained by tributaries of Little River.

The principal streams flow in broad alluvial valleys, but throughout most of the year they are restricted to narrow channels that carry only small volumes of water. During dry periods they may have no surface flow.

The Canadian River forms the southern boundary of Cleveland County and in this reach has a gradient of about 4 feet per mile southeastward. Its average rate of flow past the gaging station near Purcell from October 1959 to June 1961 was about 1,300 cfs (cubic feet per second), or 940,000 acre-feet* per year.

The North Canadian River, which flows generally eastward across Oklahoma County, also has a gradient of about 4 feet per mile. Its average rate of flow past the State Highway 62 (NE 23rd St.) gaging station near Oklahoma City during the 11-year period of record, 1952-1963, was 136 cfs, or 98,460 acre-feet per year.

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* An acre-foot is a volume defined by an area of 1 acre (43,560 sq ft) and a thickness of 1 foot; it is equal to 325,828 gallons.

Little River, which drains about half of Cleveland County, has a gradient of about 12 feet per mile southeastward. Its average rate of flow past the gaging station east of Norman during the 11-year period of record, 1952-1963, was 63.2 cfs, or 45,700 acre-feet per year. Since this report was completed in 1964, the U. S. Bureau of Reclamation has constructed an earth-fill dam across Little River, just downstream from the mouth of Hog Creek, to form Lake Thunderbird reservoir. The reservoir supplies water to Norman, Del City, and Midwest City for municipal and industrial uses. It has a storage capacity of 195,000 acre-feet at the top of the flood-control pool. Of this amount, 75,000 acre-feet is allocated to flood control, 85,000 acre-feet to municipal and industrial water supply, and 35,000 acre-feet for minimum pool capacity and sediment accumulation (data from U. S. Bureau of Reclamation). The area covered by the reservoir is underlain by the Garber Sandstone, and leakage from the reservoir may provide recharge for deep wells tapping the Garber west of the reservoir near Norman.

Lake Hefner, part of the municipal water-supply system of Oklahoma City, was formed by building an earth-fill dam across Bluff Creek in secs. 26, 27, T. 13 N., R. 4 W., about 8 miles northwest of midtown Oklahoma City. The lake, which is underlain by the Hennessey Shale, covers about 2,600 acres and has a capacity of about 75,000 acre-feet.

Stanley Draper Lake, also a part of the municipal water-supply system of Oklahoma City, was formed by building an earth-fill dam across East Elm Creek in secs. 23, 24, T. 10 N., R. 2 W., about 7 miles east of Moore. The lake, which serves as a storage reservoir for water pumped to Oklahoma City from Lake Atoka in the southeastern part of the State, covers about 7,200 acres and has a capacity of 100,000 acre-feet. The area covered by the lake is underlain by the Garber Sandstone, and water lost by subsurface leakage may serve as a source of recharge to deep wells in the area near Moore.

GEOLOGY

The rocks exposed in Cleveland and Oklahoma Counties include consolidated sedimentary rocks (redbeds) of Permian age, and unconsolidated terrace deposits and alluvium of Quaternary age. Their lithologic character and water-bearing properties are summarized in table 2. Gravel, clay, and gravelly clay deposits older than those beneath the terraces cap some of the higher hills in the eastern part of the area. At some places, deposits ranging from 1 to 10 feet in thickness have been quarried for use in surfacing roads. These deposits are thin, cover limited areas in widely separated places, and are not a source of ground water. Hence, although of academic interest to the geologist and geomorphologist, the gravel deposits were not mapped and will not be discussed further in this report. Pennsylvanian and older rocks occur beneath the Permian rocks, and some of the older rocks contain petroleum and natural gas of considerable economic importance. However, all those rocks contain water too salty for domestic, municipal, and most industrial uses, and for this reason they are not discussed in this report.

Permian Rocks

The oldest rocks exposed in Cleveland and Oklahoma Counties are siltstones, sandstones, and shales of Permian age. The Permian rocks generally are called redbeds because they are predominantly red, although other colors, such as orange, maroon, purple, white, gray, and greenish gray, may be seen in exposures.

In ascending order, the Permian rocks exposed in Cleveland and Oklahoma Counties are: Wellington Formation, Garber Sandstone, Hennessey Shale, Duncan Sandstone, and Chickasha Formation. Miser (1954) mapped the Garber and Wellington as separate units north of the North Canadian River, but as a combined unit south of the river. Because of their lithologic similarity, the two formations constitute a single aquifer system. The upper sandy part of the Hennessey Shale has been called the Cedar Hills Sandstone Member in Canadian County and northwestward (Mogg, Schoff, and Reed, 1960; Miser, 1954; Fay, 1962; Ham, 1962; Bado and Jordan, 1962). The Cedar Hills Sandstone Member has not been recognized south of the North Canadian River. The Chickasha Formation and Duncan Sandstone were mapped separately in southeastern Canadian County by Armstrong (1958). Because of their small areal extent and unimportance as aquifers, these formations have been mapped as a single unit in this report.

The rocks of Permian age form roughly parallel outcrop patterns in the two counties (pl. I; Miser, 1954). In Oklahoma County the strike of the rocks is nearly northward, but in Cleveland County it is north-northwestward. The exposed bedrock formations become progressively younger toward the west, and their regional dip is 30 to 35 feet per mile westward and southwestward toward the trough of a large asymmetrical syncline commonly referred to as the Anadarko basin.

Although the regional structure is that of a gently westward-dipping homocline, local irregularities reflect important structures in deeply buried rocks. With respect to ground water, the more important of these irregularities are local flexures in the Garber Sandstone and Wellington Formation in the Oklahoma City and Midwest City areas. The flexures are related to and reflect the location of the structural high beneath the Oklahoma City oil field and the structural trough in the Midwest City area (Travis, 1930).

GARBER SANDSTONE AND WELLINGTON FORMATION

The Garber Sandstone and Wellington Formation crop out across the eastern two-thirds of Cleveland and Oklahoma Counties in a northward-trending belt 6 to 20 miles wide. The area of outcrop is characterized by rolling, steep-sided hills that are forested with scrub oak and other small, slow-growing deciduous trees.

The Wellington Formation is the oldest of the Permian rocks exposed in Cleveland and Oklahoma Counties. Its base is not exposed in either of the counties, and the Garber Sandstone conformably overlies or grades into it. Because of the absence of fossils and key beds and the similarities of lithology, the Garber Sandstone and Wellington Formation are not readily distinguishable in the area. The two formations have similar water-bearing characteristics and therefore have been mapped as a single unit (pl. I).

The contact of the Garber Sandstone with the overlying Hennessey has been described as "apparently conformable" (Anderson, 1927, p. 9; Travis 1930, p. 11). Generally, the contact is relatively easy to recognize because it is marked by the boundary between forested hills of the Garber and the nearly smooth, grass-covered prairies developed on the Hennessey. However, close examination suggests that the contact is gradational, at least locally. In road cuts in the northern part of Oklahoma County, sandstone layers having a lithology similar to the Garber can be observed to grade laterally into shale resembling the Hennessey. Thus, in places there may be a zone 20 or 30 feet thick in which the two formations interfinger.

The Garber and Wellington consist of lenticular beds of massive-appearing, cross-bedded sandstone irregularly interbedded with shale which is in part sandy to silty. The sandstone layers are fine to very-fine grained and loosely cemented. According to C. L. Jacobsen (written communication, 1944), none of the sand in the Garber and Wellington is coarser than 0.350 mm (millimeter), and the average diameter of the grains is 0.155 mm. The sandstone is composed almost entirely of subangular to subrounded fragments of fine-grained quartz.

Cross-bedding in the sandstone is well developed and many layers that appear to be massive are actually formed by a large number of cross-bedded units, each only a few inches thick. The cross-bedded units are typically wedge shaped, the foreset inclinations vary greatly in direction, the laminations have little upward concavity, and the foresets are relatively short. Commonly, lenticular sandstone beds terminate laterally along cross-bedded laminations. In a single exposure the inclinations of the laminae may be in several directions, and commonly they are opposed.

The sandstone is poorly cemented and it crumbles easily. The most common cement is a fine red mud, although thin discontinuous beds and irregular masses of sand have been cemented with calcite, dolomite, and barite. Sand-barite rosettes (Ham and Merritt, 1944, p. 30), fragments of fossilized wood, and small concretions and concretionary masses, composed chiefly of calcite, dolomite, barite, or hematite, have been reported from many beds. Thin discontinuous beds, layers, and stringers of dolomitic conglomerate or dolomitic sandstone occur at the base of sandstone beds in many places. Thin layers of chert conglomerate occur at the base of sandstone beds in a few places in the eastern part of the outcrop area.

In general, the sandstone content of the Garber and Wellington is greatest in northeastern Cleveland and southeastern Oklahoma Counties. In that area about 75 percent of the exposed rock is sandstone. From that area northward and southward along the strike of the beds and westward downdip, the sandstone content becomes progressively less and the proportion of shale progressively greater. Near the Canadian River in southern Cleveland County, the Garber and Wellington are about 25 percent sandstone and 75 percent shale. As the massive beds of sandstone, which are exposed in the eastern part of the area, are traced downdip and along the strike, the greatest thicknesses of sandstone occur at progressively greater depths. Individual sandstone layers range in thickness from a few inches to 50 feet or more and vary greatly in thickness in short distances. The sandstone beds range in color from nearly white to pink, orange, deep red, or purple. In many places, beds that are red or reddish brown on weathered outcrops are white or light gray in fresh exposures.

Although some sandstone beds are relatively thick, beds 5 feet or less in thickness are more common. For instance, a well drilled in 1963 for the city of Norman near SE cor. sec. 15, T. 9 N., R. 2 W., penetrated 45 sandstone beds, having an aggregate thickness of 371 feet between depths of 100 and 700 feet. These beds ranged in thickness from 1 to 30 feet, but only 4 were 20 or more feet thick, 20 ranged from 5 to 20 feet, and 21 were 5 feet or less. Shale layers ranged from 1 to 40 feet in thickness, but only 3 were more than 10 feet and 36 were 5 feet or less.

According to Jacobsen (written communication, 1944), the thickness of the Garber is about 400 feet in central Cleveland County, about 350 feet in central Oklahoma County, and about 300 feet at the north boundary line of Oklahoma County. The Wellington is about 500 feet thick in the outcrop area but attains a thickness of 700 feet in the subsurface. Therefore, the two formations as a unit have a total thickness of 800 to 1,000 feet.

The shale beds of the Garber and Wellington are nonlaminated, white to deep red, and vary greatly in thickness in short distances. In the Wellington the shale is clayey and blocky and breaks with a conchoidal fracture. In the Garber the shale commonly is silty or sandy. As previously noted, the proportion of shale increases somewhat downdip toward the west. Near the west edge of Cleveland and Oklahoma Counties the Garber and Wellington are largely shale or shale and siltstone that contains little fresh water (fig. 4).

HENNESSEY SHALE

The Hennessey Shale covers the western one-third of Cleveland and Oklahoma Counties. Its area of outcrop is characterized by relatively flat, grass-covered prairies, largely barren of trees except along the valleys of intermittent streams.

The Hennessey consists dominantly of reddish-brown shale containing layers of siltstone and fine-grained sandstone. The shales are clayey to silty, and the siltstones contain large amounts of clay. In places along the outcrop well-indurated beds of siltstone or sandstone have weathered to form low shelflike ledges.

Beds of essentially homogeneous shale range from a few inches to 10 feet or more in thickness. Much of the shale is massive; where stratification is evident, it ranges from thinly laminated to medium bedded. The massive shales weather to form polygonal fragments and break with sharp-edged conchoidal fractures. The siltstone and sandstone beds occur in well-indurated layers ranging from a few inches to about 10 feet in thickness. Some beds of both shale and siltstone have an abundance of light-gray and gray-green spots. In outcrops, white, gray, or light-green bands occur discontinuously in beds of shale and siltstone. Lenticular beds of fine-grained sandstone, ranging from less than 1 to about 15 feet in thickness, occur near the base of the formation. In outcrop areas the thicker sandstone beds form low, steep-sided, tree-covered hills similar to the hills in the outcrop area of the Garber Sandstone.

The Hennessey Shale has a total thickness of 600 to 650 feet; however, at most places in Cleveland and Oklahoma Counties the upper part of the formation has been removed by erosion. Its thickness is believed to be about 200 feet at Norman, 40 to 100 feet in the Midwest City area east of the Oklahoma City anticline, 200 to 300 feet in the Oklahoma City area, and less than 400 feet northwest of Lake Hefner.

The Hennessey Shale as an aquifer.—Because of its lithology the Hennessey Shale is poorly permeable; however, it is an aquifer that furnishes small quantities of water to rural domestic and stock wells. About 90 percent of the wells are less than 80 feet deep, and most obtain their water supplies from a zone of weathered material above the relatively unaltered shale. Below the weathered zone, water is obtained from cavities left by the removal of soluble materials and from fractures.

The water from these wells is generally satisfactory in quality for domestic use but inadequate in quantity for a windmill or for a jet pump unless operated for brief periods in conjunction with a pressure tank. A few wells have been drilled to depths of 100 to 300 feet, and produce water largely from fractures or solution cavities that are recharged by downward seepage from the saturated zone in the weathered material. The water from the deep wells generally is highly mineralized and is used only for watering stock.

According to Dennis (1954, p. 14), the weathered zone in the Hennessey is an aquifer of local importance, although of small capacity and low permeability. Wells and holes tested by him showed transmissibilities ranging from 125 to about 2,500 gpd per foot. Several of the wells tested had specific capacities of the order of 1 to 2 gpm per foot of drawdown. During dry periods, however, the yields of all wells probably would decline as saturated material in the weathered zone became partly dewatered because of evaporation, transpiration, and pumping.

CHICKASHA FORMATION AND DUNCAN SANDSTONE

Beds of sandstone, siltstone, and shale exposed on the north side of the Canadian River in the northwest corner of Cleveland County and in the southwest corner of Oklahoma County have been referred to the Chickasha Formation and Duncan Sandstone (Armstrong, 1958). Because of their small areal extent and relative unimportance as aquifers, the Chickasha Formation and Duncan Sandstone have been mapped together for this report (pl. I). The Chickasha and Duncan, which conformably overlie the Hennessey Shale, are 150 to 200 feet thick and consist of sandstone, siltstone, siltstone conglomerate, and shale. Armstrong described the sandstone as massive, cross-bedded, fine to very fine grained, and soft to well cemented. Some of the siltstone layers are highly cross-bedded and resistant to erosion so that they make small ledges or cap low hills. All beds are lenticular and the sandstone grades laterally into siltstone or shale. The sandstone beds commonly are red orange or pink orange, but locally are brown. The shale layers generally are red.

The Chickasha and Duncan are poorly permeable and have little value as an aquifer in Cleveland and Oklahoma Counties. They are tapped by only a few small-capacity wells for domestic and stock use. In general, the water is suitable for human consumption but, in some places, contains too much dissolved gypsum or is otherwise too highly mineralized even for stock use.

Quaternary Deposits

The Quaternary deposits of Cleveland and Oklahoma Counties include terrace deposits at one or more levels in, or adjacent to, the valleys of the Canadian and North Canadian Rivers, alluvium in the valleys of the principal streams, and dune sand. The areal distribution of the deposits is shown on the geologic map (pl. I), and their lithologic character and general hydrologic properties are summarized in table 2.

The Quaternary deposits supply ground water for rural, domestic, and stock purposes at many places in the two counties, and they are the source of most of the ground water used to satisfy the water needs of several small towns and unincorporated communities in the valleys of the Canadian and North Canadian Rivers. However, except for two areas along the Canadian River near Norman and an area along the North Canadian River between Oklahoma City and Lake Overholser, they have not been studied in detail.

The terrace deposits and dune sand overlie the Permian rocks and, because of their relatively high permeability, facilitate the recharge of the underlying rocks. Because the Quaternary deposits are more permeable than the Permian redbeds, springs, seeps, or "wet-weather springs" occur where the contact between the two is exposed in low areas. The alluvium generally fills valleys cut 20 to 100 or more feet below the uplands. Because of this topographic relationship, the alluvium receives some seepage from sandy units or fractured zones in the bedrock. This seepage helps to maintain a high water table in the alluvium. Water in the alluvium is discharged principally by evaporation and transpiration, but some moves downstream in the alluvial deposits, and some seeps into the stream channels to maintain flow in dry seasons.

TERRACE DEPOSITS

Terrace deposits consist of materials laid down by ancient streams, which, since the time of deposition, have cut valleys to lower levels. In Cleveland and Oklahoma Counties, the streams that made the deposits were ancestors of the Canadian and North Canadian Rivers. The deposits consist mostly of lenticular beds of sand, silt, clay, and gravel, which vary greatly in thickness within short lateral distances. Where they have sufficient saturated thickness, the terrace deposits yield larger quantities of water of lower mineralization than that in the Permian rocks, and, on the whole, water of

TABLE 2—GEOLOGIC UNITS EXPOSED IN CLEVELAND AND OKLAHOMA COUNTIES

System	Series	Stratigraphic Unit	Thickness (Feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	Recent	Dune sand	0-20	Fine-to coarse-grained wind-blown sand. Consists chiefly of subrounded quartz grains. Forms a thin mantle or hummocky surface that obscures older rocks. Most extensive deposits on north side of North Canadian River near Lake Overholser.	Moderately to highly permeable, but mostly above the water table and saturated only locally. Where saturated, yields water readily to domestic or stock wells, but supply may not be permanent. Water most likely to occur in this unit where underlain by poorly permeable redbeds. Provides infiltration areas for recharge to underlying rocks.
	Pleistocene and Recent	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of streams.	Moderately permeable. Yields small to moderate quantities of water to wells in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil-field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil-field brines.
PERMIAN	Lower Permian	Chickasha Formation and Duncan Sandstone	200 ±	Beds of reddish-brown sandstone, siltstone, shale, and siltstone conglomerate. Individual beds of sandstone highly cross-bedded and well cemented, in western part of area between Canadian and North Canadian Rivers.	Poorly permeable. Tapped by only a few small-capacity wells for domestic or stock use. Water is hard and in places highly mineralized.
		Hennessey Shale	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limy shale. Forms relatively flat to gently rolling grass-covered prairies.	Poorly permeable. Yields meager quantities of very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500 ±	Deep-red to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded with and interfingered with red shale and siltstone.	Poorly to moderately permeable. Important source of ground water in Cleveland and Oklahoma Counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500 ±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone irregularly interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

better quality than that in the alluvium. Replenishment of ground water in the terrace deposits comes mainly from infiltration of precipitation that falls on the terrace surface.

The terrace deposit on the upland between Lake Overholser and Lake Hefner (pl. I), known locally as the Bethany terrace, is the source of the ground water pumped by the city of Bethany (Jacobsen and Reed, 1949). The deposit also supplies water to many shallow wells used for residential gardening in Bethany, Warr Acres, and adjoining parts of Oklahoma City.

Logs of test holes drilled for the Bethany and Oklahoma City Water Departments indicate that the terrace deposit has a maximum thickness of about 80 feet and that it is thickest over a buried stream channel that curves southward through the central part of sec. 6, SW¼ sec. 5, western part of sec. 8, and SE¼ sec. 7, T. 12 N., R. 4 W. (L. C. Burton, written communication, 1958). Elsewhere, the deposits of the Bethany terrace vary greatly in thickness over short lateral distances, according to the configuration of the buried bedrock surface (Hennessey Shale) and the amount of terrace material removed by erosion.

The depth to water generally is less than 30 feet below land surface. The yields of wells tapping the terrace deposits are not known, but it is likely that, where the saturated thickness is at least 5 feet, properly spaced wells would yield 5 to 10 gpm. Where the saturated thickness is more than 50 feet, properly spaced and developed wells should be capable of sustained yields of 100 to more than 200 gpm.

Other terrace deposits that occur in Oklahoma County, as shown on plate I, have not been studied by the U. S. Geological Survey and are not known to have been tested as a source of ground water for large-capacity wells; hence, their ground-water potential is not known.

Terrace deposits also were mapped along the upland bordering the Canadian River in Cleveland County. However, except for an area near Norman (Stacy, 1961), the deposits have not been studied by the U. S. Geological Survey and their ground-water potential is little known.

According to Stacy (1961), the terrace deposits in the vicinity of Norman contain considerable quantities of water of good quality at depths generally less than 50 feet below land surface. The logs of test holes indicate that the deposits range from 40 to 95 feet in thickness and that their saturated thickness averages 40 feet. At favorable sites, wells that are properly constructed and developed should be capable of producing as much as 200 gpm.

ALLUVIUM

The modern channels, flood plains, and low terraces along the Canadian, North Canadian, and Little Rivers and their major tributaries are covered with alluvium (pl. I). These deposits represent the present cycle of erosion and deposition, and the deposits are still being formed, eroded, and reworked. The flood plains generally are 5 to 10 feet lower than the surface of the adjacent low terraces, and the stream channels are cut as much as 3 or more feet into the flood plains.

Along the Canadian and North Canadian Rivers the alluvium is a band averaging about 2 miles in width, but at Ten-Mile Flat on the Canadian, about 5 miles northwest of Norman, and at Oklahoma City, on the North Canadian, it is more than 3 miles wide. The Canadian River has a sandy shifting channel 1,000 to 6,000 feet wide. Phreatophytes, such as marsh grass, cattails, and willow and cottonwood trees, are common along the channel and on the flood plain in many places.

The alluvium consists mostly of lenticular beds of sand, silt, and clay. It probably also contains some lenticular beds and stringers of gravel and gravelly sand in the lower part. The alluvium ranges in thickness from a few inches to about 90 feet. Thicknesses are greater only where the present stream alluvium is underlain by older alluvium that fills channels cut into the bedrock and commonly referred to as buried stream channels.

The alluvium in the North Canadian River valley in Canadian County has been studied intensively by Mogg, Schoff, and Reed (1960). They showed that these deposits are as much as 60 feet thick in places and contain permeable sand and gravel capable of yielding several hundred gallons of water per minute to wells. These deposits probably have similar properties in the western part of Oklahoma County, where they supply water to numerous industrial wells and to emergency-supply wells drilled by Oklahoma City (table 3).

At Ten-Mile Flat on the Canadian River the alluvium has a maximum thickness of about 70 feet. The alluvium is thickest over a buried stream channel that approximately parallels the eastern margin of the flat in secs. 4, 5, 9, 16, 21, 28, 33, T. 9 N., R. 3 W. Information obtained from the logs of 32 test holes drilled by the U. S. Navy and the logs of many geophysical shotholes furnished by the Carter Oil Company indicate that throughout much of its length the buried channel was 1,000 to 2,000 feet wide, that it was cut 25 or more feet below the bedrock surface in other parts of the flat, and that its base was 110 to 140 feet below the upland surface immediately to the east (Jacobsen and Reed, written communication, 1943).

The data collected by Jacobsen and Reed indicate that along the buried stream channel the alluvium may average 60 feet in thickness, and that in other parts of the flat it may range in thickness from 20 to about 40 feet.

The depth to water in 1943 was about 10 feet below land sur-

TABLE 3—YIELD CHARACTERISTICS OF WELLS TAPPING TERRACE DEPOSITS AND ALLUVIUM OF NORTH CANADIAN RIVER VALLEY IN THE OKLAHOMA CITY-LAKE OVERHOLSER AREA

Area	Number of Wells	Depth (feet)		Yield (gpm)		Drawdown (feet)		Specific Capacity (gpm/ft)	
		Range	Average	Range	Average	Range	Average	Range	Average
. 11 N., R. 4 W., secs. 1-6	27	40-60	49	50-248	214	6-22	11	6-40	21
. 12 N., R. 3 W., secs. 31, 32	7	38-45	40	162-408	283	10-20	15	8-29	19
. 12 N., R. 4 W., secs. 6, 7, 18, 31-36	20	41-90	61	138-525	261	5-27	14	8-53	21
Average			50		253		13		20

face in most of the area. Water levels probably vary little from year to year because there is little pumping.

A test well (9N-3W-21dcc), drilled to a depth of 65 feet by the U. S. Navy in 1943, yielded 130 gpm with a pumping drawdown of 28 feet during a 24-hour pumping test. Since that time, several irrigation wells have been drilled in the area. These wells are reported to range from 50 to about 70 feet in depth, and well yields reportedly range from less than 100 to more than 300 gpm.

The geology and hydrology of the alluvium in the North Canadian River valley between Lake Overholser and Oklahoma City were discussed by Jacobsen and Reed (1949). The yield characteristics of wells tapping the alluvium in this area are summarized in table 3. These deposits are capable of yielding large quantities of water for at least several months.

The ground-water potential of the alluvium in other parts of Cleveland and Oklahoma Counties is unknown, but it seems likely that water supplies sufficient for domestic and stock use could be found in areas where the alluvium has 5 or more feet of saturated thickness. Where large quantities of ground water are required, as for municipal, industrial, or irrigation purposes, a series of test holes should be drilled to determine the thickest and most permeable areas in the alluvium.

Ground water in the alluvium is variable in quality and, before it is used for human consumption, should be tested to determine its chemical and bacteriological properties. Wells near the Canadian River and wells near the North Canadian River below Oklahoma City may yield water that has been contaminated by sewage effluent, industrial wastes, or oil-field brines. Wells on the flood plains or low terraces some distance from the rivers probably would not yield water contaminated by sewage or industrial effluents being flushed down the rivers, unless pumped continuously for extended periods.

DUNE SAND

Dune sand covers the surface of the older rocks in many places, but, except for an area near Lake Overholser in Oklahoma County and an area near the Canadian River in the northwest corner of Cleveland County (pl. I), the sand is too thin or occurs in scattered dunes too small to be shown on the geologic map. In most places the dunes support sparse vegetation and appear to be stabilized. In some areas, however, sand is advancing upon older dunes, terrace deposits, and older rocks, and in these areas the size and shape of the dunes are being changed by the prevailing southerly winds.

The dune sand is above the zone of saturation and is not a source of ground-water supply. It is highly permeable, however, and facilitates ground-water recharge by readily absorbing and transmitting local precipitation and surface runoff downward to the ground-water body.

HYDROLOGY OF THE GARBER SANDSTONE AND WELLINGTON FORMATION

The Garber Sandstone and Wellington Formation constitute the most important source of ground water in Cleveland and Oklahoma Counties. The cities of Edmond, Nichols Hills, Del City, Midwest City, Moore, and Norman, and many small towns obtain all their water supplies from wells completed in one or both of the formations.* Tinker Air Force Base, a major service facility in the national-defense establishment, The University of Oklahoma, Central State Griffin Memorial Hospital, and many commercial and industrial firms also obtain their water supplies from wells tapping one or both formations. Oklahoma City and several commercial and industrial establishments in the city have wells in one or both formations. Since the 1951-1956 drought, the Oklahoma City wells and many of the commercial wells have been little used, but they are maintained on a standby basis.

The Garber and Wellington constitute a single aquifer, or water-bearing zone. The two formations were deposited under similar conditions, and both consist of lenticular beds of sandstone, siltstone, and shale that may vary greatly in thickness within short lateral distances. Wells drilled into the water-bearing zone may tap individual beds of sandstone as much as 50 feet thick and may penetrate as much as 200 to 300 feet of water-bearing sandstone. Other wells drilled nearby may tap only a few relatively thin beds of sandstone and may penetrate less than 100 feet of water-bearing material.

Thickness of the Fresh-Water Zone

Wells obtain fresh water from the Garber and Wellington at depths of 100 feet or less in the areas of outcrop and at maximum depths of about 1,000 feet in the structural depression in the Midwest City area. The maximum depth at which wells obtain potable water supplies is controlled by the depth at which salt water is encountered in these formations (fig. 4). The contact between the fresh water and salt water probably is not abrupt because an intermediate brackish-water zone has been found in some wells. Where such brackish water is encountered, the wells commonly are plugged back and completed in a higher water-bearing zone.

The approximate depths below land surface of the base of the fresh-water body in different parts of the area are as follows: near

* Since completion of this report, the Lake Thunderbird reservoir has been completed, and Norman now derives all public water supplies from this source, maintaining the old wells on a standby basis. Del City and Midwest City fulfill their needs from both the reservoir and wells.

Canadian River in southeastern Cleveland County, 100 feet; Noble, 400 feet; Norman, 700 feet; Moore, 850 feet; southwest corner Oklahoma County, 1,000 feet; Harrah, 300 feet; Choctaw, 640 feet; Midwest City, 1,000 feet; Oklahoma City-Lake Hefner area, 800 feet; Edmond, 700 feet; and Luther, 200 feet.

Figure 4 is a contour map of the base of the fresh-water body. The base was determined from electric logs of oil and gas wells, drillers' logs, and chemical analyses of water samples obtained from water wells. The bottom of the lowermost fresh-water sandstone at any location was assumed to be the base of the fresh-water section. However, if that sandstone grades laterally into shale, the next higher sandstone that would have been chosen as the base of the fresh-water body in an adjacent well may be several tens of feet higher.

In general, the base of the fresh-water body in the two counties has the shape of an elongate westward-tilted trough, trending slightly west of north and parallel to the regional strike of the geologic formations. In most places the base of the fresh-water body dips westward at rates ranging from 10 to 20 feet per mile. The steep rise, or gradient, which extends northward along the west side of the two counties from a point near Norman, probably represents the limit to which salt water has been flushed from individual sandstone beds in the Garber Sandstone and Wellington Formation. Although the contact between fresh and salt water is represented as a sharply defined one, there is probably a transition zone in which fresh water gradually grades into salt water.

The contours on the base of the fresh-water body reflect some structural features in the Garber and Wellington. Thus, the greatest depth of fresh water corresponds to the Midwest City depression and the shallower depth of fresh water southeast of Oklahoma City corresponds to the Oklahoma City anticline. However, the steep rise in the slope of the contact between the fresh water and the salt water at the west edge of the map is unrelated to rock structure and may reflect a change of facies from coarser to finer sediments.

Two cross sections (figs. 5, 6) illustrate the lensing and interfingering of sandstone, shale, and silty beds in short lateral distances and show the approximate base of the fresh-water body as determined from figure 4. Section A-A′ (fig. 5) is a small-scale electric-log section drawn from east to west across the Oklahoma City area, following roughly the direction of dip. The section shows the lenticular character of the individual beds and lithologic units that makes it difficult or impossible to correlate such units from well to well. However, the approximate base of the fresh-water body is indicated on the section.

Section B-B′ (fig. 6) is a detailed lithologic section based upon

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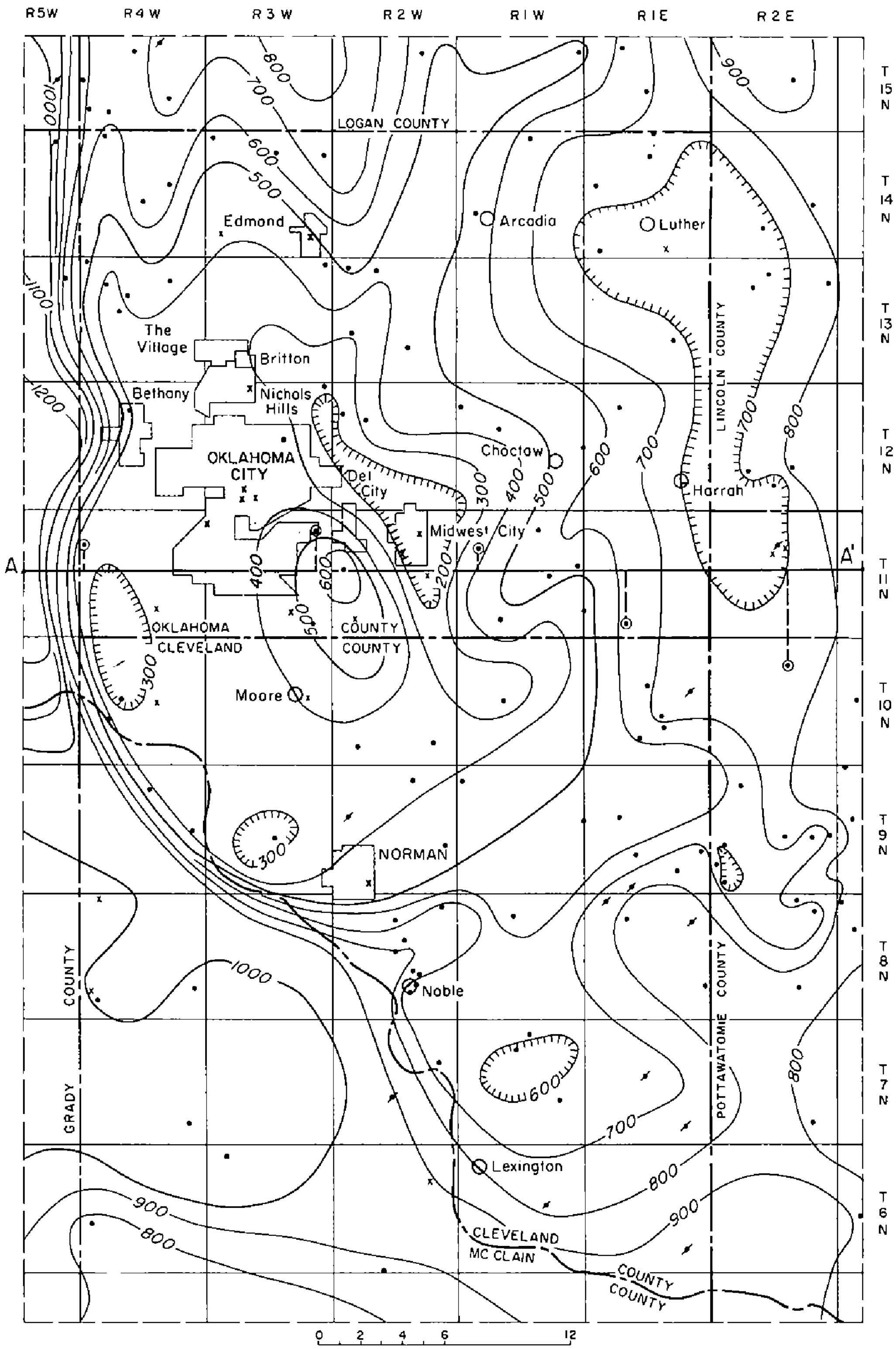
Figure 4. Map showing the base of fresh ground water in Cleveland and Oklahoma Counties. Cross section A-A′ is shown in figure 5.



700

Contour on base of fresh-water zone
(Interval: 100 feet; datum: mean sea level)

Positive control point
(Base of fresh water shown on electric log)

Negative control point
(Base of fresh water above interval shown on electric log)

Deep well producing fresh water

Well shown on electric-log section A-A'
(see fig.5)

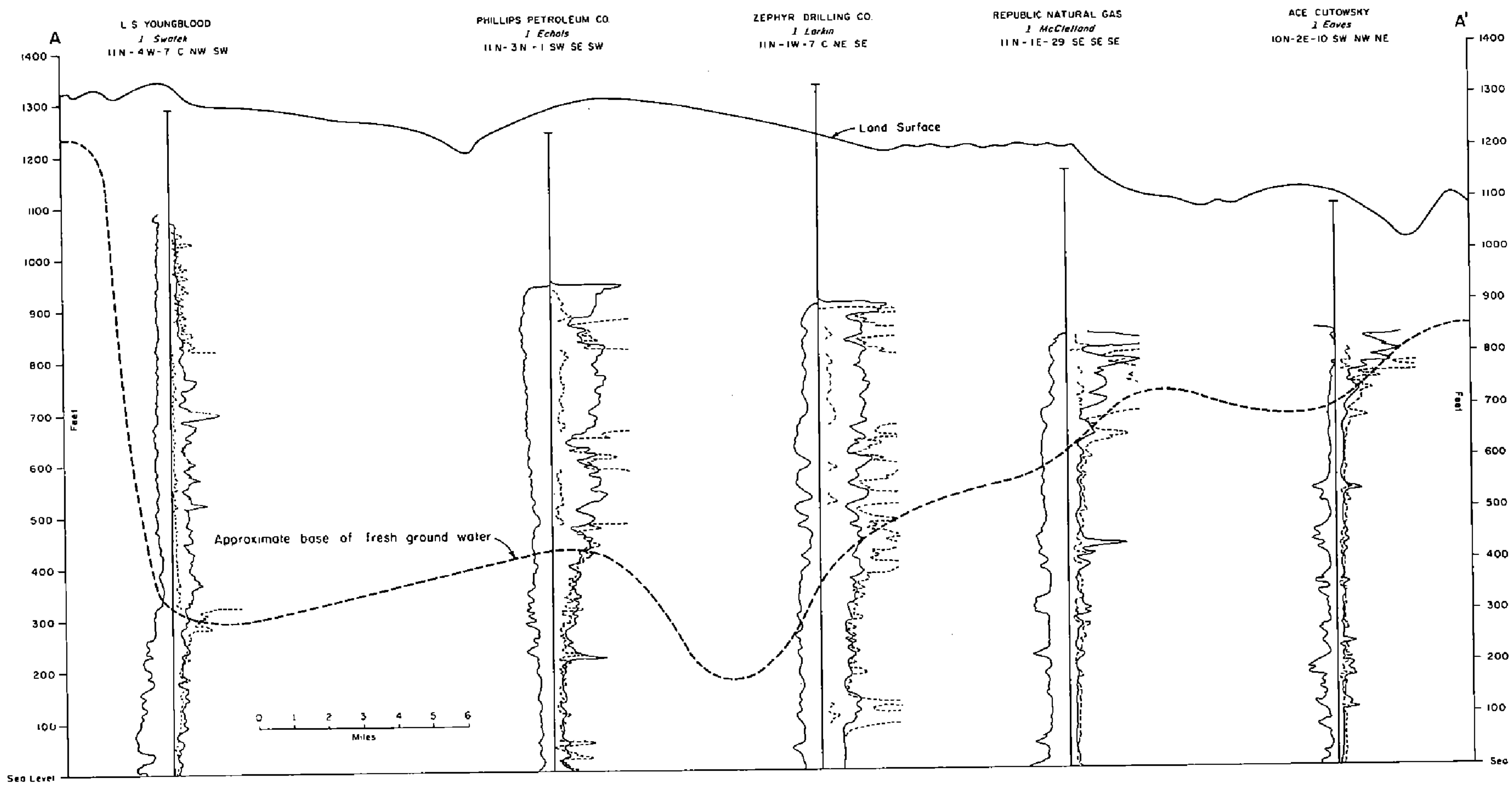


Figure 5. Electric-log cross section A-A' showing the approximate contact between fresh and salt water in Oklahoma County. The section is projected to a west-east line through the center of T. 11 N., as shown in figure 4, and not well-to-well, as shown on plate I.

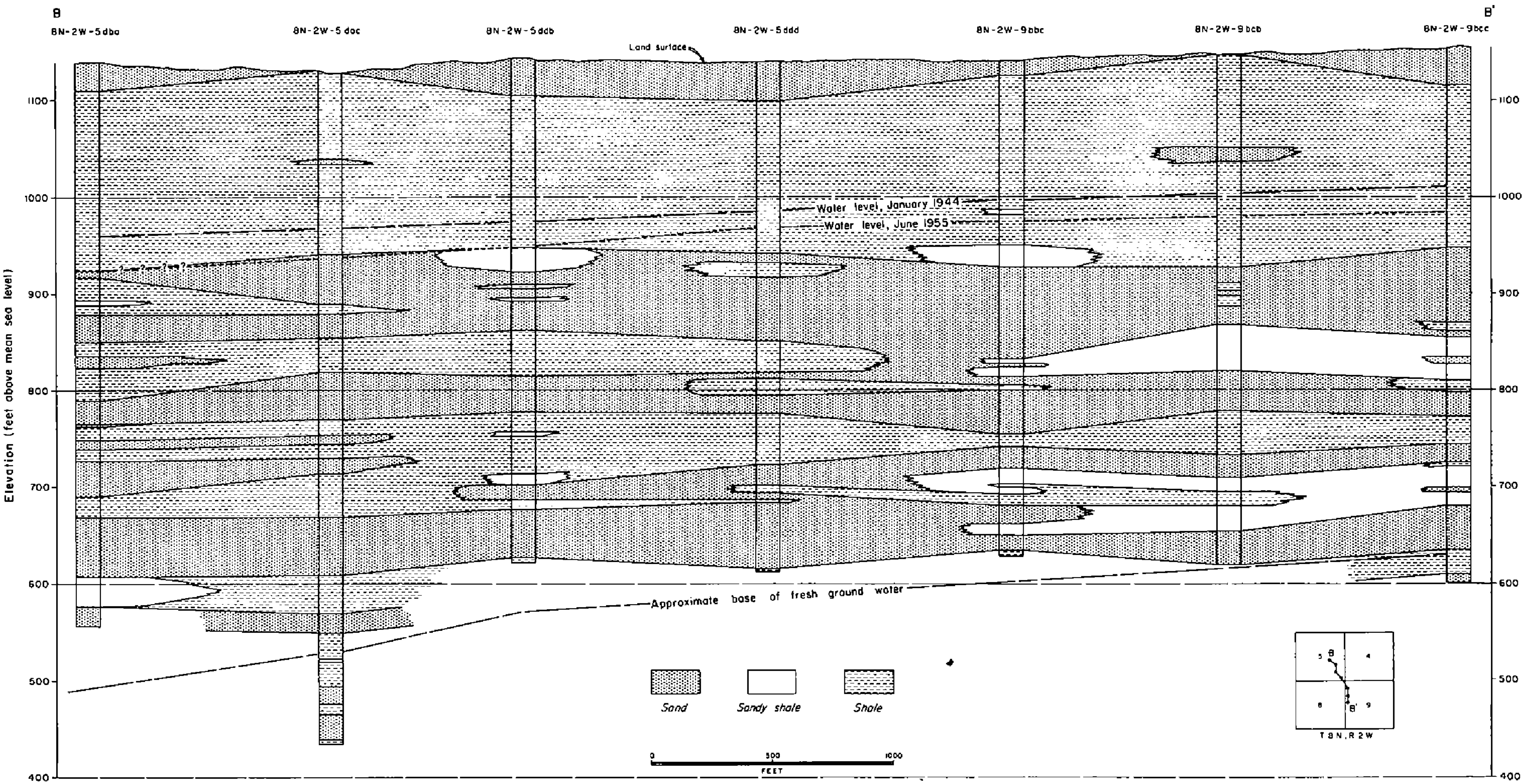


Figure 6. Well-log section B-B′ showing the lenticular character of the Garber Sandstone and Wellington Formation in the Norman area, Cleveland County.

logs of water wells spaced roughly 1,000 feet apart in an area just south of Norman (T. 8 N., R. 2 W.). The section illustrates how the various lithologic units in the Garber Sandstone and Wellington Formation interfinger and intertongue in short lateral distances. The section also shows wide differences in the amount of sandstone encountered in different wells, and indicates the approximate base of the fresh-water-bearing rocks in the Norman area.

Permeability, Transmissibility, and Storage Coefficients

The hydrologic properties that determine the quantity of water that an aquifer, or water-bearing zone, will yield to wells are principally the saturated thickness, permeability, and storage coefficient of the aquifer. The permeability and storage coefficient vary with differences in the size, shape, and extent of the openings in the rocks and with the degree to which the openings are interconnected.

The *permeability* of a water-bearing material is its capacity for transmitting water under pressure. In ground-water hydraulics, the permeability of an aquifer generally is expressed as a *coefficient of permeability,* which is the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot. The measure of permeability used in this report is called the *field coefficient of permeability* and is defined as the number of gallons of water per day that percolates, at the prevailing temperature of the water, through each mile of the aquifer (measured at right angles to the direction of flow), for each foot of thickness of the aquifer, and for each foot per mile of the hydraulic gradient. The *coefficient of transmissibility* may be expressed as the number of gallons of water a day, at the prevailing temperature, transmitted through each mile-wide strip by the entire saturated thickness of the aquifer under a hydraulic gradient of 1 foot per mile; hence, it is the product of the average coefficient of permeability and the saturated thickness of the aquifer.

The *coefficient of storage** of an aquifer is defined as the volume of water it 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 artesian conditions the coefficient of storage is a small value, generally 10^{-3} or 10^{-5}, representing water derived by compaction of fine-grained materials, and by expansion of the water itself, as the head declines. Under water-table conditions the storage coefficient includes this small amount plus the generally much larger amount represented by the water that drains by gravity out of the uppermost material as the water table declines. This larger amount, called the *specific yield,* is defined as the ratio of the volume of water

* The reader is referred to Ferris and others (1962, p. 74-78) for a detailed discussion of the storage-coefficient concept and its application to artesian and water-table aquifers in horizontal and inclined attitudes.

that a saturated aquifer will yield by gravity to the volume of the aquifer. It is, therefore, a measure of the quantity of water that a saturated aquifer will yield when drained by gravity. Not all water contained in the interstices of a material will be drained by gravity because some will be retained by capillary action. The volume of retained water, expressed as a ratio of the total volume of material, is called the *specific retention* of the material. The specific yield and specific retention are together equal to the *porosity*, which is the percentage of the total volume of openings or interstices in a material. Thus, if 100 cubic feet of a saturated material will yield 8 cubic feet and retain 13 cubic feet of water when drained by gravity, the specific yield is 0.08 (8%), the specific retention is 0.13 (13%), and the porosity (the sum of the two) is 0.21 (21%).

The main hydrologic properties of an aquifer may be determined by laboratory methods or by field methods. The laboratory method (Wenzel, 1942) involves a mechanical and mathematical analysis of specimens obtained from outcropping rocks, samples of drill cuttings, and relatively undisturbed sections of cores obtained by various means.

The field method (Ferris and others, 1962) involves a mathematical analysis of hydrologic data that reflects the rate of decline, or recovery, of the piezometric surface in the vicinity of a pumped well. The hydrologic data are collected during an aquifer test, or so-called pumping test, and the analysis is made by means of mathematical formulas based on equilibrium or nonequilibrium conditions.

In another method, developed by Theis and others (1954) and used by Thomasson, Olmsted, and LeRoux (1960, p. 207-223), the transmissibility of an aquifer is estimated by multiplying the average specific capacity of wells by 2,000.

In this report, the basic nonequilibrium formula (Theis, 1935, p. 519-524), or one of its variations (Cooper and Jacob, 1946, p. 526-534), was used to determine the aquifer constants. The field coefficients of permeability were determined by dividing the coefficients of transmissibility by the reported thickness of sand in the zone open to the wells tested.

During the period of fieldwork for this report, aquifer tests involving the use of two or more observation wells in addition to the pumped well were made at Norman, Midwest City, Nichols Hills, and Edmond. All the tests were made to determine the aquifer coefficients of the water-bearing zone in the Garber Sandstone and Wellington Formation. The results are summarized in table 4.

The coefficients of transmissibility determined by the tests, although locally representative, are not necessarily indicative of the values in all parts of the aquifer; the coefficients differ considerably with changes in lithology, effectiveness of casing perforations, and interference from unidentified wells pumped intermittently during the tests.

TABLE 4—RESULTS OF AQUIFER TESTS MADE IN THE GARBER SANDSTONE AND WELLINGTON FORMATION

Location	Coefficients: Permeability (gpd/ft²)	Coefficients: Transmissibility (gpd/ft)	Coefficients: Storage	Date	Remarks
University of Oklahoma (Main Campus)	36	3,000	2.0×10^{-4}	April 1964	Tests involved three wells (9N-2W-31SE¼) ranging in depth from 500 to 660 feet. Several tests made to measure rate of recovery in each of the wells and to determine rates of drawdown in observation wells. Pump discharge ranged from 75 to 123 gpm. Analysis by C. E. Jacob, U. S. Geological Survey, from data supplied by S. L. Schoff, U. S. Geological Survey, and W. W. Kraft, University of Oklahoma.
University of Oklahoma (North Base, formerly U. S. Naval Air Station)	20	4,000	2.0×10^{-4}	1943-1944	Tests involved eight wells (9N-2W-19 and 9N-3W-13) ranging in depth from 605 to 635 feet. Drawdown and recovery tests were made in one or more wells several times during the test. The number of pumping wells, rates of discharge, and duration of the pumping period varied during many of the tests. Tests and analysis by E. W. Reed and C. L. Jacobsen, U. S. Geological Survey.
University of Oklahoma (South Base, formerly U. S. Naval Air Technical Training Center)	28	5,000	3.0×10^{-4}	June 1955	Tests involved four wells (8N-2W-5) ranging in depth from 512 to 616 feet. Well 2 (8N-2W-5dbal) pumped continuously for 70.5 hours at 210 gpm. Rates of drawdown and recovery were measured in three observation wells. Data and analysis by L. C. Burton, U. S. Geological Survey.
Midwest City	..	5,000	3.0×10^{-4}	July 1944	Test involved two wells (1N-2W-10), each about 800 feet deep. Data obtained by analyzing the rate of recovery in a newly developed well 700 feet from the pumped well, which discharged 170 gpm. Hydrologic data collected by E. W. Reed, and C. L. Jacobsen; analysis by L. C. Burton.
Nichols Hills	..	4,000	1.0×10^{-4}	Jan. 1963	Tests made to determine if pumping from deep wells perforated in the lower part of the aquifer would cause water-level declines in nearby shallow wells ranging from 60 to 125 feet in depth (fig. 7). Data obtained by analyzing rates of drawdown and recovery in a newly developed well 1,270 feet from another newly developed well (12N-3W-2NE¼) discharging 184 gpm during a 70-hour test. Hydrologic data collected by the U. S. Geological Survey and others; analysis by P. R. Wood. Water levels in the shallow wells were not affected by pumping during the test.
Edmond	35	7,000	2.0×10^{-4}	Nov.-Dec. 1949	Tests involved three wells (14N-3W-26 and 35) ranging in depth from 405 to 465 feet. Several tests made to determine rates of drawdown and recovery in an observation well located 1,617 feet and 3,300 feet north, respectively, of two pumped wells, which discharged 255 and 275 gpm. Hydrologic data collected by E. W. Reed; analysis by L. C. Burton.

The storage coefficients shown in table 4 represent minimum values because the storage coefficient increases with time as additional water drains from that part of the aquifer within the cone of depression created by pumping. For example, Wenzel (1942, p. 135) stated that the specific yield (coefficient of storage) as determined from a 24-hour aquifer test on an irrigation well near Gothenburg, Nebraska, was only 16 percent of the specific yield determined in laboratory tests of the same material, where drainage was complete.

The range in coefficients obtained from the aquifer tests probably is due in large part to the lenticular character of the water-bearing beds and the manner in which water was forced to enter or leave the well bores. In all the tests the pumped well and the observation wells were perforated through only a small part of the aquifer; hence, water moving toward the pumped well had a vertical component of flow which deviated widely from radial flow assumed in derivation of the mathematical formulas. The wide differences in total thickness of water-bearing beds and wide departures from radial flow may cause large errors in the drawdown or recovery in the observation wells. Consequently, the computed aquifer coefficients given in table 4 should be considered correct only to a general order of magnitude.

An average drawdown curve that would be generally useful in planning the development of a well field cannot be prepared because the coefficients of transmissibility and storage differ from place to place. When large quantities of water are sought, preliminary test drilling and test pumping will provide the necessary facts upon which to base well specifications.

Yield, Drawdown, and Specific Capacity of Wells

The yield characteristics for wells tapping the water-bearing zone in the Garber Sandstone and Wellington Formation are summarized in table 5. The depths of wells and perforated intervals were obtained from examination of drillers' logs and geophysical logs and from reports by well owners and consulting engineers. The yield and drawdown figures are based on information supplied by drillers, tests performed by engineers, and measurements made by the U. S. Geological Survey and the Oklahoma Geological Survey.

Both formations contain lenticular beds of poorly cemented sandstone that are similar in grain size and permeability. However, owing to a wide variation in thickness of individual sandstone beds within short lateral distances, the water-bearing beds penetrated by wells do not have similar or uniform hydrologic properties throughout the area.

The yields of wells screened in the water-bearing zone in the Garber and Wellington provide a general index of the permeability of the rocks, but it should be recognized that the yields also depend on thickness of the water-bearing material screened, the efficiency of

TABLE 5—YIELD CHARACTERISTICS FOR WELLS TAPPING THE GARBER SANDSTONE AND WELLINGTON FORMATION

Well No.	Depth (feet)	Perforated Interval (feet)		Yield (gpm)	Drawdown (feet)	Duration of Test (hours)	Specific Capacity (gpm/ft)	Date of Test
		Top	Bottom					
9N-2W-15add	726	281	726	350	106	26	3.30	8-16-63
-15ddd	693	279	693	364	112	22	3.25	7-12-63
-20dcd	662	...	...	90	114	....	0.79	12- 3-45
-22add	638	246	638	357	136	25	2.62	8- 1-63
-28bdc	663	...	...	285	142	24	2.00	3- -60
-30aba	640	340	605	178	122	24	1.40	9- -39
9N-3W-2baa	698	290	651	170	185	....	0.91	10-20-53
do.	...	...	...	197	220	....	0.89	2- 8-54
-2dbl	729	300	632	170	155	....	1.09	10-21-53
do.	...	...	...	185	155	....	1.19	Spring-54
-2dca	682	291	648	180	130	....	1.38	Spring-54
-24cbb	620	365	618	45	58	6	0.77	....
10N-3W-10abb	842	268	828	405	178	24	2.28	2- -63
-14abb	701	340	684	375	170	36	2.00	5- -62
-15abb	798	389	793	395	130	20	3.00	2- -63
-15cab	740	310	724	320	160	24	2.00	6- -62
-26b	294	255	293	15	20	¼	0.75	1- -51
-35bdc	701	292	694	190	190	....	1.00	Spring-54
-35cac	692	300	685	195	107	....	1.82	12-17-53
11N-2W-5acc	730	265	710	220	120	....	1.80	- -61
-7dbc	743	278	740	220	115	....	1.90	- -61
-11cbb	800	593	761	242	271	24	0.89	11-17-43
-11bbcl	793	340	706	246	276	24	0.86	10-31-43
-15bbb	780	408	693	336	430	24	0.78	8- 1-41
-15bbc	741	428	741	340	430	24	0.79	12- 4-41
-22bbc	792	355	650	175	161	24	1.08	8- -43
-23daa	850	507	723	115	163	24	0.70	5- -43
11N-3W-3db	728	491	728	70	51	8	1.40	8- -37
-4cbdl	730	243	730	271	210	24	1.29	5- -55
-5aba	780	316	770	238	230	24	1.34	5- -55
-8bad	797	504	792	155	165	24	0.94	5- -55
-8cba	788	402	788	200	245	24	0.81	5- -55
-18aaal	792	254	788	253	123	24	2.06	4- -55
12N-1E-26ac	346	232	333	100	140	....	0.70	10- -55
12N-3W-2abd	745	436	718	184	183	36	1.00	1- -63
-8ca	808	...	...	310	245	1,424	1.26	Aug.-Oct., 1938 (for -8ca, -8cb, -8dc)
-8cb	801	...	...	240	245	1,256	0.98	
-8dc	840	110	838	475	250	1,392	1.90	
-9ddc	738	326	682	280	130	24	2.15	4- -55
-12bcd	797	365	766	235	245	24	0.95	2- -55
-13bbbl	778	394	788	268	225	24	1.19	2- -55
-13bcc	790	328	758	320	285	24	1.12	2- -55
-13cccl	760	...	...	308	295	24	1.04	1- -55
-16ccdl	753	307	749	307	240	24	1.27	3- -55
-17abc	785	376	770	318	160	24	1.98	3- -55
-24cca	168	...	...	20	30	¼	0.66	3- -50
-27dd	795	502	795	140	220	48	0.63	- -37
-32dcd	780	316	770	238	230	24	1.00	4- -55
12N-4W-11dca	770	470	764	241	155	24	1.55	4- -55
-13ccd	729	420	716	271	205	24	1.32	3- -55
-24bccl	760	480	759	233	275	24	0.84	3- -55
-24ddal	790	403	782	270	123	24	2.19	4- -55
-25ddbl	675	389	675	260	154	24	1.68	3- -55
13N-3W-28cac	796	416	790	240	130	24	1.84	7- -55
-29ddd	790	402	789	200	185	24	1.08	7- -55
-31ccc	805	498	706	242	175	24	1.38	7- -55
14N-3W-26c	743	490	740	275	285	8	0.96	12- -49

the well, and the drawdown. In Cleveland and Oklahoma Counties few, if any, of the wells are screened in all the water-bearing material penetrated. Therefore, most of the wells yield less than the maximum possible.

The yields and the pumping drawdowns of many deep wells drilled for municipal and industrial purposes were based on pumping tests of 24 to 48 hours' duration (table 5). These tests indicate that the yields of deep wells ranged from about 50 to about 450 gpm (gallons per minute) and averaged 240 gpm. Pumping drawdowns* ranged from about 50 to 430 feet and averaged 200 feet.

The yields and the pumping drawdowns of shallow wells in outcrop areas of the formations are little known. However, most of the shallow wells are used for domestic and stock purposes that require only about 5 to 10 gpm. Many of the shallow wells obtain most of their water from a zone of weathered material above the relatively unaltered bedrock. Wells of this type may fail, or "go dry," during extended dry periods, but, in most places, additional supplies of water can be obtained by deepening the well a few tens of feet and tapping a bed of saturated sandstone in the underlying rocks.

The specific capacity of a well is more diagnostic of an aquifer's capacity to yield water than is the yield without reference to the drawdown. However, the specific capacity is affected by the efficiency of the pumping equipment, the diameter of the well and its depth of penetration into the water-bearing zone, the effectiveness of the perforations to admit water, the extent and effectiveness of well development, and to some extent the duration of the pumping period used to determine the specific capacity. Consequently, the specific capacities reported in table 5, many of which are based upon reported static and pumping levels measured one or more days apart and which generally were determined for wells perforated in only a small part of the water-bearing section, give only a general measure of the aquifer's capacity to yield water.

High average specific capacities indicate an aquifer capable of transmitting relatively large amounts of water, and the converse is true for low average specific capacities. The specific capacities listed in table 5 range from 0.6 to 3.3 gallons per minute per foot of drawdown and average 1.3. The average specific capacities reported for the principal cities are: Norman, 1.0; Moore, 2.0; Midwest City (includes Tinker Air Force Base), 0.9; Del City, 1.8; Oklahoma City, 1.3; Nichols Hills, 1.0; and Edmond, 0.9. Except where a relatively large number of figures are available — as for Norman, Midwest City, and Oklahoma City — the average specific capacities may not be representative.

* Drawdown is the difference between the "static," or nonpumping, water level and the pumping water level in a well. For example, if the static level in a well is 205 feet below the measuring point and the pumping level is 386 feet, the drawdown is 181 feet.

Water-Level Fluctuations

Records of water-level fluctuations in wells reflect changes in the volume of water contained in the ground-water reservoir. In general, the ground-water surface rises when recharge (derived chiefly from precipitation) exceeds discharge and, conversely, the ground-water surface declines when the discharge (by natural or artificial means) exceeds recharge. Thus the fluctuations of water levels in wells are an index to the inflow and outflow of water from a ground-water reservoir, somewhat as the fluctuation of the water level in a surface reservoir indicates changes in the amount of water it contains. However, for the recharge or discharge of a given quantity of water, the ground-water surface fluctuates through a greater range than does the water level in a surface reservoir.

Water-level measurements made in areas where ground water is pumped extensively for municipal, industrial, or agricultural purposes provide an index of the extent of ground-water development. As pumpage from wells increases, the water levels in the area decline until they become adjusted to the increased use. If pumping exceeds recharge, the water levels continue to decline; thus ground-water levels reflect the relationship between the available water supply and its development.

Records of ground-water levels in wells tapping water-bearing deposits in Cleveland and Oklahoma Counties have been published in annual water-level reports for the years 1940-1955 (U. S. Geological Survey, 1944-1957). Water-level records for the years 1956-1962 (Hart, 1963; Wood and Moeller, 1964) have been published by the Oklahoma Water Resources Board.

Fluctuations of water levels in representative wells tapping the Garber Sandstone and Wellington Formation are illustrated by hydrographs of two wells in Cleveland County and three wells in Oklahoma County (pl. II). The graphs illustrate the type of fluctuations that result from pressure changes in deep, areally extensive artesian aquifers. The fluctuations in all the wells show seasonal trends as the artesian pressure responds to seasonal pumping. Because the wells are several miles from the recharge area, the fluctuations show no direct correlation with local precipitation.

The hydrograph of well 9N-1W-30dbb (pl. II, fig. B), east of Norman, illustrates seasonal fluctuations in an area some miles distant from pumping wells. The water level in this well rises during the winter and spring, reaches a peak in late spring or early summer, and declines steadily during summer when the ground-water withdrawals are largest. The hydrograph shows the steep water-level decline that resulted from ground-water withdrawals, in 1943, required to meet municipal and military demands in the Norman area during World War II. The water-level recovery recorded for the period 1945-1947 probably resulted from a decline in the quantities of water pumped to meet the demands of a reduced military establishment after the war. The hydrograph also shows that water levels declined about 9 feet in a 10-year period (1947-1956), probably as a result of pumping to meet municipal and industrial demands during the dry period 1950-1956. During the 5-year period 1957-1961, water levels showed no general rise or decline. The hydrograph of well 8N-2W-9bba (pl. II, fig. B) shows only minor seasonal fluctuations. The steep water-level decline recorded for the summer and winter of 1963 reflects the pumpage from wells drilled nearby to meet water demands during a period of deficient rainfall.

The hydrographs of three wells in Oklahoma County (pl. II, fig. A) illustrate a pattern of fluctuation that follows definite seasonal withdrawals of ground water for municipal and industrial uses. The exaggerated seasonal fluctuations, which are best shown by the graph for well 12N-3W-26bdb during the period 1943-1949, reflect pressure changes within the artesian aquifer in response to heavy pumping from nearby wells. The seasonal fluctuations shown by the hydrographs of wells 13N-3W-29bbd and 12N-3W-26bdb for the period 1958-1963 reflect less pumping from wells in the immediate vicinity of the observation wells. The graphs for these wells indicate that there has been little net change in the over-all pressure head of the artesian aquifer in the Oklahoma City area during the 21-year period of record (1943-1963). The graphs also show that during the 6-year period 1958-1963 water levels rose at the rate of about 2 feet per year.

The hydrographs for well 11N-2W-11bbc (pl. II, fig. A) shows that water levels in the Midwest City-Tinker Air Force Base area declined steadily from 1946 to 1956, remained about the same from 1956 to 1961, and declined slightly from 1961 to 1963. According to the hydrograph, water levels declined at a rate of about 6 feet per year between 1946 and 1951. During the 1952-1956 drought, water levels declined at a rate of about 14 feet per year. During the 1957-1961 wet period, the downward trend was checked, and water levels remained about the same. The change in the water-level trend reflects an adjustment of the pressure head within the artesian aquifer in response to recharge and possibly to a decrease in seasonal pumping.

Water levels in the Del City-Midwest City-Tinker Air Force Base area (T. 11 N., R. 2 W.) should be expected to recover as the cities rely increasingly on Lake Thunderbird as a source of water supply; at present both cities continue to derive part of their water supply from wells. Water levels should rise as the cones of depression level out, the rate and extent of the recovery being governed largely by the permeability of the water-bearing zone and the magnitude of the over-all reduction in pumpage.

Relation between fluctuations in deep and shallow water-bearing zones. — Lack of connection between sandstone lenses in the Garber

Sandstone and Wellington Formation is illustrated by the pumping test made in one of the Nichols Hills wells in January 1963. Nichols Hills well 20, 745 feet deep, was pumped for 3 days — January 7 to 10. During the period of pumping the water level in the pumped well declined from 167.92 feet to 351.70 feet (fig. 7). During the pumping period two other deep wells, one (Nichols Hills 19) about 0.5 mile northwest, the other (Nichols Hills 21) about 0.5 mile northeast of the pumped well, also declined as shown on figure 7. In contrast, water levels in three shallow wells fluctuated only slightly during the pumping-test period. In fact, water levels in two of them rose slightly during the early part of the test, apparently in response to changes in barometric pressure. The behavior of water levels in these wells during the test period suggests that there is no direct connection locally between the sands tapped by the shallow wells and those tapped by the deeper wells. This fact demonstrates that the lenticular nature of the sandstones in the Garber Sandstone and Wellington Formation persists into the subsurface. It is not possible to tell on a test of short duration whether or not some ground water may "leak" through shale beds that separate sandstone zones. Probably in the area where the Nichols Hills tests were made there is little connection between the deep zones and shallow zones. Water levels in the shallow zones are affected by changes in barometric pressure, by local precipitation, and by seepage of water from the shallow sands into Deep Fork and its tributaries, but not by pumpage from the deeper aquifers.

Recharge

Because of the complex geology and differences in hydrostatic head between the different sandstone layers, the rate of recharge to the aquifer in the Garber and Wellington cannot be determined directly from available data. However, a usable estimate of recharge can be made by comparing this aquifer with others of similar type where recharge computations have been made. The Permian Rush Springs Sandstone in the Caddo County area is lithologically similar to the sandstones of the Garber Sandstone and Wellington Formation and might be expected to have similar recharge capabilities. Tanaka and Davis (1963) estimated the recharge rate for the Rush Springs to be 10 percent of the annual precipitation. Because the transmissibility of the Garber is less than that of the Rush Springs and the soils and topography are somewhat less conducive to recharge, the recharge rate to the Garber probably is smaller—perhaps only about 5 percent of precipitation. Using an estimate of 5 percent of the annual precipitation, recharge to the aquifer in the Garber and Wellington in Cleveland and Oklahoma Counties would average about 1.7 inches annually, or approximately 90 acre-feet (30 million gallons) per square mile per year. Because only about half the geologic section composing the Garber and Wellington consists of sandstone,

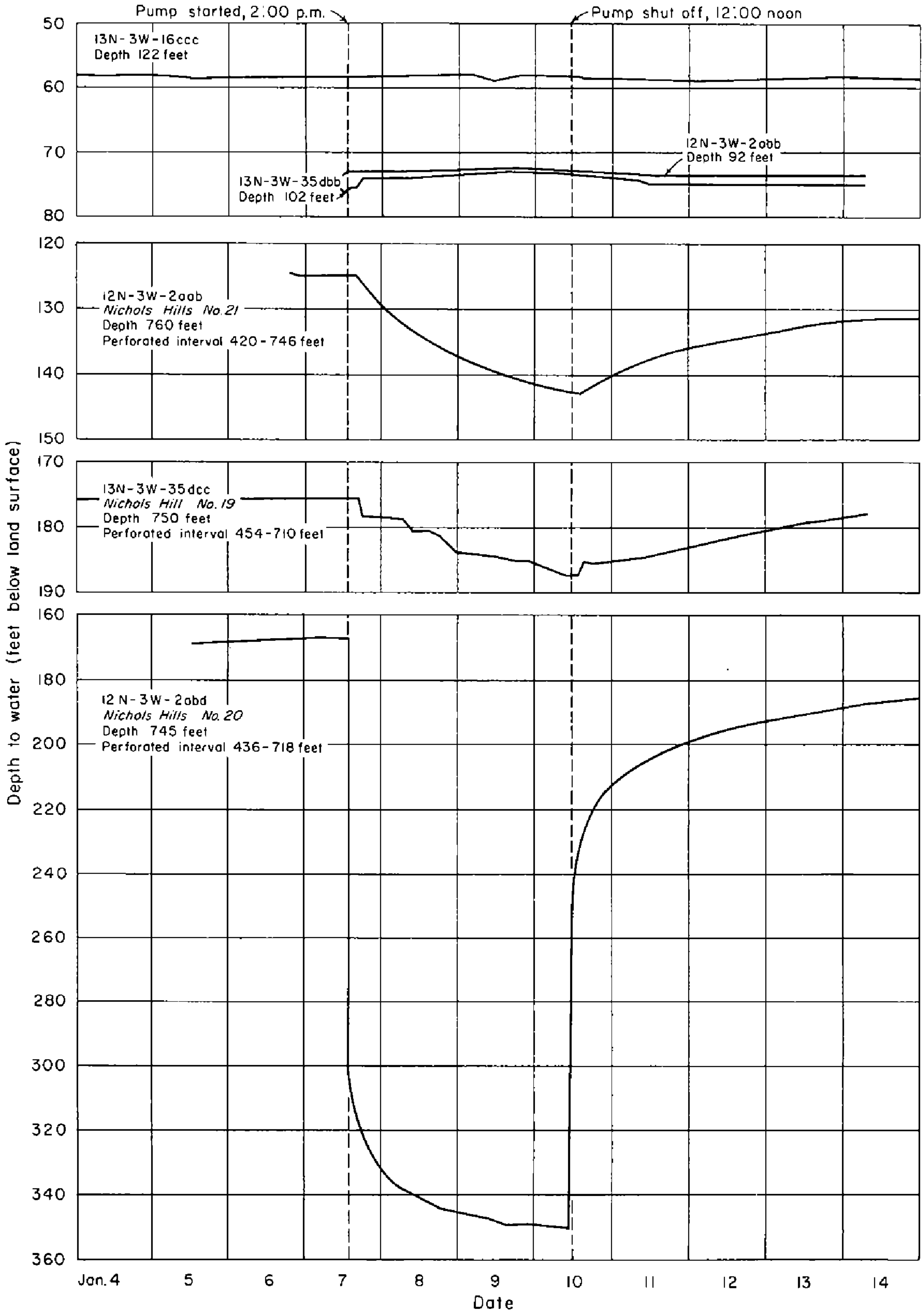


Figure 7. Hydrographs showing fluctuations of water levels in shallow and deep wells during aquifer test, January 4-14, 1963.

recharge over the entire outcrop area of these formations might average about half this amount, or approximately 15 million gallons per square mile per year. The outcrop area over which recharge might be effective averages approximately 15 miles in width from the top of the Garber Sandstone eastward. If the 15 million gallons per square mile is a reasonable figure for this outcrop area, the total recharge in a 3-mile-wide strip from the Moore well field eastward would be approximately 700 million gallons per year.

Because of the relatively low transmissibility of the aquifer and the low gradients from the outcrop area westward toward the main centers of pumping, it may not be possible for the aquifer to transmit water from the recharge areas toward the pumping centers at the estimated rate of recharge. If this is true, the effective recharge would be increased by the lowering of water levels in the main areas of pumping, thus increasing the gradient toward the pumping centers from the areas of recharge. Probably a considerable part of the potential recharge of the Garber and Wellington is "rejected" in the outcrop area because of the inability of the aquifer to transmit the water away from the outcrop area. Water-level data in the outcrop area are rather sketchy, but they suggest that water levels reflect the topography and that locally ground water moves toward adjacent streams from both sides rather than westward toward the centers of pumping. If this conjecture is true, then only part of the outcrop area would actually contribute recharge, under natural conditions, that would go to replace the water withdrawn in the main centers of pumping.

Data from water-level measurements indicate that water levels have changed little in the area north of the North Canadian River but have declined substantially in the vicinity of Norman and Midwest City. These declines are caused in part by the greater concentration of pumping near Norman and Midwest City, but may also indicate that recharge in the northern part of the project area is greater than in the southern part. This difference probably is due to two factors: (1) the greater width of the outcrop in the northern part of Oklahoma County, which would provide a larger recharge area, and (2) a somewhat thicker section of sandstone, which would allow both a greater amount of recharge and a greater movement of water from the recharge area.

A check on the estimate for rate of recharge can be made for the Del City-Midwest City-Tinker Air Force Base area. If the area contributing recharge water is 6 miles wide in a north-south direction and extends eastward for 15 miles, and if half the area is underlain by sandstone, then recharge could take place over a 45-square mile area. During the 5-year period 1957-1961, precipitation totaled about 192 inches, or 16 feet. If 5 percent of the precipitation for the period became recharge, the replenishment to the aquifer would have been 23,000 acre-feet. However, although more than 30,000 acre-feet of water was pumped, water levels rose slightly, indicating that pumpage was less than replenishment. Because the effective recharge area probably is less than that postulated above, it is concluded that recharge to the Garber Sandstone and Wellington Formation in southern Oklahoma County during 1957-1961 was greater than 5 percent of the precipitation.

Ground-Water Withdrawals

Ground-water withdrawals from the Garber Sandstone and Wellington Formation began before 1900. The quantity of ground water pumped for all purposes from 1900 through 1959 is estimated to be about 72,000 acre-feet in Cleveland County and 207,000 acre-feet in Oklahoma County (table 6a). The quantity of ground water pumped for municipal and industrial purposes at selected cities in

Table 6a. — Estimated Ground-Water Pumpage from the Garber Sandstone and Wellington Formation in Cleveland and Oklahoma Counties

Area	Period	Pumpage[1] (acre-feet)
Cleveland County		
Norman (includes municipal, industrial, and commercial pumpage in the city and adjoining urban areas)	1910-59	36,600
University of Oklahoma	1910-59	26,000
Central State Hospital	1940-59	6,000
Moore	1928-59	1,400
Noble	1930-59	1,300[2]
Other small towns, commercial or industrial establishments, and individuals	1930-59	700[2]
Total for Cleveland County through 1959		72,000
Oklahoma County		
Oklahoma City commercial and industrial establishments (includes use by oil industry 1938-1959)	1918-59	80,300
Oklahoma City oil-field development	1931-37	24,200
Oklahoma City municipal wells	1955-57	5,300
Midwest City	1942-59	16,700
Del City	1946-59	8,400
Tinker Air Force Base	1942-59	36,400
Nichols Hills	1936-59	13,500
Britton	1940-55	4,500
Edmond	1930-59	15,300[2]
Harrah	1954-59	400
Other small towns, commercial or industrial establishments, independent water companies, and individuals	1930-59	2,000[2]
Total for Oklahoma County through 1959		207,000

[1] Unpublished information furnished by C. H. Guernsey & Co., Consulting Engineers, Oklahoma City, unless otherwise indicated. Data rounded to nearest 100 acre-feet.
[2] Estimated by U. S. Geological Survey.

the area is shown in tables 6b and 6c. Figure 8 shows graphically how pumpage has increased since 1940. According to Gould (1905, p. 158, 166), at least 10 wells ranging in depth from 20 to 365 feet were drilled in Cleveland County between 1892 and 1903, and at least 10 wells ranging in depth from 34 to 168 feet were drilled in Oklahoma County between 1896 and 1903. Phillips, Alvord, and Billingsley (1913, p. 176-188) canvassed 34 municipal, industrial, and commercial wells, ranging from 6 to 10 inches in diameter and 120 to 256 feet in depth in the Oklahoma City area in 1912, and reported that many privately owned wells ranging from 60 to 150 feet in depth were pumped for domestic requirements. Their published data indicate that 27 of the 32 wells canvassed were more than 200 feet deep and that specific capacities ranged from 0.6 to 1.8 gpm per foot of drawdown and averaged 1.1 gpm per foot.

According to C. H. Guernsey & Co. (1959), the first well that obtained water from a depth greater than 600 feet below land surface was drilled in Oklahoma City about 1920, on property owned by the Missouri-Kansas-Texas Railroad. Since that time, several hundred deep wells have been drilled to supply water for municipal, industrial, and commercial purposes. The locations of many of the wells are shown on plate I, and information pertaining to individual wells is given in tables 5, 7, and 9.

During the development of the Oklahoma City oil field in the 1930's, many wells were drilled into the Garber Sandstone and Wellington Formation to supply water required for drilling oil wells. According to McGee and Clawson (1932, p. 1002), about 4,000 barrels per day (bpd), or 168,000 gpd, of water was required for the first 3,000 feet of each hole drilled; about 2,200 bpd (92,400 gpd) of water was needed to drill from a depth of 3,000 to a depth of 5,000 feet; and about 1,800 bpd (75,600 gpd) was needed to drill from a depth of 5,000 to a depth of 6,500 feet. McGee and Clawson reported that better developed wells, which tapped the Garber Sandstone and Wellington Formation in the Oklahoma City oil field, supplied as much as 8,000 bpd (336,000 gpd or about 230 gpm) of water for oil-field use.

The quantity of water pumped from wells during the development of the Oklahoma City oil field (1931-1937) has been estimated to be about 24,200 acre-feet (table 6a). The quantity of water pumped since 1937 is not known. Jacobsen and Reed (1949, p. 8) reported that the oil industry was using 1.5 mgd (million gallons per day) in 1943. If water use by the oil industry remained fairly constant, then about 40,000 acre-feet of water was pumped for use by the oil industry during the 26-year period 1938-1963.

The city of Nichols Hills drilled its first wells in 1936. Prior to that time Nichols Hills had obtained its water supplies from the Oklahoma City Water Department. The quantity of ground water

TABLE 6b. — ANNUAL PUMPAGE OF GROUND WATER FOR MUNICIPAL AND INDUSTRIAL SUPPLIES AT SEVERAL PLACES IN CLEVELAND AND OKLAHOMA COUNTIES, 1960-1963

(Data from records supplied by city managers and water superintendents)

	ANNUAL PUMPAGE (MILLION GALLONS)				
	1960	1961	1962	1963	TOTAL
Edmond	265.680	282.233	320.523	379.861	1,248.297
Nichols Hills	334.714	332.019	369.014	440.634	1,476.381
Midwest City	694.107	702.805	826.300	955.211	3,178.423
Tinker Air Force Base	1,042.367	1,151.362	1,342.610	1,428.258	4,964.597
Norman	709.959	733.203	859.063	1,018.909	3,321.134
Univ. of Oklahoma	316.925	330.325	363.175	366.825	1,377.250
Total	3,363.752	3,531.947	4,080.685	4,589.698	15,566.082

pumped annually since 1959 is shown in table 6b, and monthly pumpage for 1963 is shown in table 6c.

The town of Britton used ground water pumped from at least one well 160 feet deep in 1900 (Gould, 1905, p. 166). Pumping from wells greater than 600 feet deep started about 1940.

During the early 1940's, the U. S. Army built the Oklahoma City Air Depot and the Oklahoma City Aircraft Assembly Plant (now Tinker Air Force Base) in an undeveloped area southeast of Oklahoma City. Midwest City and Del City were formed during the same period to provide living facilities for families of military and civilian personnel employed in the area. Water used for municipal, industrial, and military purposes was obtained from the Garber Sandstone and Wellington Formation by pumping from wells ranging in

TABLE 6c. — MONTHLY PUMPAGE DURING 1963 AT SELECTED PLACES IN CLEVELAND AND OKLAHOMA COUNTIES

(Data from records supplied by city managers and water superintendents)

	PUMPAGE (MILLION GALLONS)				
MONTH	EDMOND	NICHOLS HILLS	MIDWEST CITY	TINKER AIR FORCE BASE	NORMAN
January	24.424	23.022	61.160	101.274	69.383
February	27.568	27.121	65.550	88.909	64.244
March	24.088	27.472	90.392	104.596	69.202
April	31.411	34.152	81.270	113.014	76.593
May	29.816	32.995	113.351	129.489	88.427
June	34.486	46.371	120.362	143.574	93.136
July	34.821	66.263	102.632	149.908	112.682
August	42.515	51.395	75.110	145.827	105.051
September	38.528	33.005	69.835	121.695	90.233
October	36.878	48.102	62.892	129.376	103.127
November	29.677	29.180	53.737	99.993	76.300
December	25.649	21.556	58.920	100.603	70.531
Total	379.861	440.634	955.211	1,428.258	1,018.909

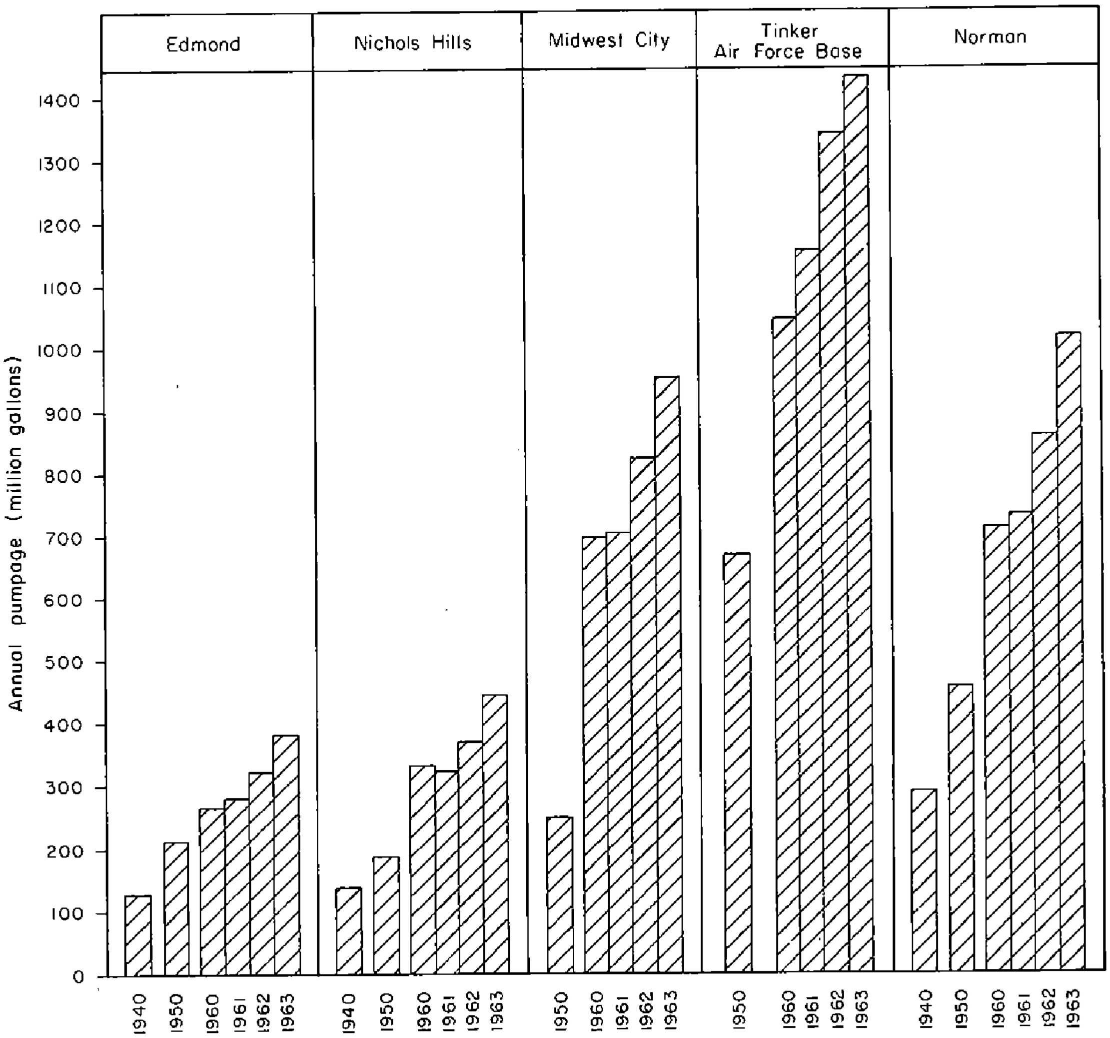


Figure 8. Graphs showing ground-water pumpage at selected places in Cleveland and Oklahoma Counties (1940-1963).

depth from 300 to about 1,000 feet. The total ground-water withdrawals to meet municipal and industrial demands in the Midwest City-Del City-Tinker Air Force Base area through 1959 were estimated to be 61,500 acre-feet (table 6a). The amount of ground water pumped annually since 1959 is shown in table 6b and the monthly pumpage during 1963 is shown in table 6c.

Because of a severe drought in the area from 1951 through 1956, the Oklahoma City Water Department drilled at least 25 deep wells to obtain water from the Garber Sandstone and Wellington Formation. Water pumped from these wells during the period 1955-1957 was estimated to be about 5,300 acre-feet (table 6a). Since the drought-breaking rains of 1957, the wells have not been used extensively, but they are maintained on a standby basis.

In Cleveland County, ground water for municipal and industrial use was pumped from wells 200 or more feet deep at Moore, Norman, Noble, and Lexington before 1900 (Gould, 1905, p. 158). The University of Oklahoma drilled a well to a depth of 282 feet in 1903. Most of the municipal and industrial wells drilled after 1935 at Moore and Norman have been 600 or more feet deep. The annual pumpage at Norman and The University of Oklahoma since 1960 is given in table 6b, and the monthly pumpage at Norman in 1963 is given in table 6c.

Current withdrawals.—In 1959, ground water was being pumped from the Garber Sandstone and Wellington Formation in the two-county area at the rate of about 16 mgd (million gallons per day), according to C. H. Guernsey & Co. (1959). About 9 mgd was for municipal and institutional use, and about 7 mgd was for commercial and industrial use, principally in the Oklahoma City area. By 1963, pumping for municipal and institutional use had increased to 15 mgd, but commercial and industrial pumping had increased only slightly, so that the total was about 22 mgd. Part of this increase was caused by the drought of 1963, which resulted in an increase of more than 1 mgd in pumping for municipal use between 1962 and 1963.

Pumping of ground water from the Garber Sandstone and Wellington Formation is not uniformly distributed over the area. About 12.3 mgd, more than half the total pumped, is concentrated in the Norman and Del City-Midwest City-Tinker Air Force Base areas. Most of the remainder is in Oklahoma County and is rather widely scattered.

Because municipal use of water is far from uniform during the year, annual rates of pumping are apt to be misleading. For instance, Midwest City's average use during 1963 was about 2.6 mgd, but use during June averaged more than 4 mgd (table 6c). During the peak day in 1963 more than 6 mgd was used and in 1964, 7 mgd. To supply needs during seasons of high water use a city must have the capacity to pump from 2.5 to 3 times the amount of water used on an average day.

CHEMICAL QUALITY OF THE WATER

Water Quality in Relation to Use

Chemical analyses of ground water in the water-bearing zone of the Garber and Wellington and in the Hennessey Shale are given in table 7. Six of the samples analyzed were from the Hennessey Shale and 131 from the Garber and Wellington.

The chemical character may limit the use of water for domestic, agricultural, and industrial purposes. Requirements vary greatly from one industry to another, and the requirements for some industries are more rigid than those for public supplies.

Domestic use.—Chemical-quality standards for water used for drinking and cooking on interstate carriers have been recommended by the U. S. Public Health Service (1962). These standards are commonly used to judge the suitability of all public water supplies. The standards are given as the maximum tolerable concentrations, in parts per million*, of various chemical constituents present in the water. Most individuals, however, can become adjusted to drinking water that contains most of the listed constituents in considerably higher concentrations than those specified in these standards. Some of the limits suggested by the Public Health Service are as follows: iron (Fe), 0.3 ppm (parts per million); sulfate (SO_4), 250 ppm; chloride (Cl), 250 ppm; nitrate (NO_3), 45 ppm; total dissolved solids, 500 ppm. The recommended limit for fluoride (F) in drinking water depends upon the annual average of the maximum daily air temperatures. In Cleveland and Oklahoma Counties it is 1.6 ppm.

Of the 55 samples (all from the Garber and Wellington) of which the content of iron was determined, only 1, from well 14N-2W-9cc, had an iron content above 0.1 ppm. Sulfate ranged from 3 to 1,450 ppm in water from the Garber and Wellington, but only 10 samples contained more than 250 ppm. However, the sulfate contents of 4 samples from the Hennessey were 729, 945, 1,602, and 3,600 ppm. The chloride content ranged from less than 1 to 458 ppm; 7 samples, all from the Garber and Wellington, contained more than 250 ppm.

Nitrate has little effect on the use of water for most purposes; however, large concentrations of nitrate in water used for infant feeding may cause methemoglobinemia, the so-called "blue-baby" disease. Four of the samples from the Garber and Wellington contained more than 45 ppm (table 7), the recommended limit for nitrate in drinking water.

Although fluoride is desirable in small amounts in drinking water because it reduces dental caries in children, in large amounts it causes mottled enamel. Water from 10 wells drilled in the Garber and Wellington contained more than 1.6 ppm.

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* A part per million is one unit weight of a constituent in 1 million unit weights of water.

Calcium and magnesium make water hard and are responsible for the scale formed in water heaters, steam radiators, pipes, valves, and other fixtures. Hard water increases soap consumption and causes deposits that accumulate in bathtubs, lavatories, and laundry equipment. Arbitrarily, water has been classified as follows with regard to hardness: 60 ppm or less, soft; 61-120 ppm, moderately hard; 121-180 ppm, hard; more than 180 ppm, very hard. Judged by these standards, water from the Garber Sandstone and Wellington Formation ranges from soft to very hard; water from the Hennessey Shale is moderately hard to very hard.

Dissolved solids, in water from the Garber and Wellington, ranged from 109 to 2,107 ppm; 28 samples contained more than 500 ppm and 9 had more than 1,000 ppm. Dissolved solids were determined for only 4 samples from the Hennessey; one of these samples contained 2,750 ppm; another, 5,900 ppm.

In general, water from the Garber and Wellington is suitable for drinking, but locally it may be hard, or high in sulfate, chloride, fluoride, nitrate, or dissolved solids. At some places, water from the Hennessey is suitable for drinking, but at others it is hard and high in sulfate and dissolved solids.

Irrigation.—The suitability of water for irrigation depends upon (1) the total concentration of soluble salts (salinity hazard), (2) the relative proportion of sodium to other cations (sodium or alkali hazard), (3) the concentration of boron or other elements that may be toxic, and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium and magnesium (U. S. Salinity Laboratory, 1954). Other criteria that affect the suitability of water for irrigation include the type and drainage characteristics of the soil, the amount of water applied, and the amount and distribution of precipitation.

The total concentration of soluble salts in irrigation water is commonly expressed in terms of specific conductance. Specific conductance is a measure of the ability of water to conduct an electric current and is expressed in micromhos per centimeter at 25°C. Nearly all irrigation water that has been used successfully has specific conductance of less than 2,250 micromhos. Water of higher specific conductance has been used occasionally, but crop production, except on very well-drained soil, has not been successful. Specific conductance exceeded 2,250 micromhos in 4 samples from the Garber and Wellington and in 2 samples from the Hennessey Shale.

When sodium is present in an irrigation water in concentrations higher than that of calcium and magnesium, it tends to replace the calcium and magnesium absorbed on soil colloids. Soil colloids then tend to disperse and restrict the movement of air and water through the soil, resulting in a soil of poor tilth and low permeability. When sodium in an irrigation water exceeds about 50 percent of the total

TABLE 7—CHEMICAL ANALYSES OF WATER FROM WELLS IN CLEVELAND AND OKLAHOMA COUNTIES*

(Chemical constituents in parts per million except as indicated)

Well No.	Depth of Well (Feet)	Geologic Source[1]	Date of Collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids[2]	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific Conductance (Micromhos at 25° C)	pH
CLEVELAND COUNTY																		
6N-1E																		
5ddb	442	Pgw	4-44	....	....	....	164		300	31	16	39	0.2	....	12	....	684	....
5ddc	435	Pgw	4-44	....	....	....	508		247	9.8	360	400	2.0	....	57	....	2,390	....
7N-1E																		
22dd	116	Pgw	10-54	20	76	44	14	2.4	458	0	11	15	1.3	405	370	0	738	7.2
7N-1W																		
13bb2	100	Pgw	4-54	16	58	36	28	1.6	376	0	8.7	14	8.3	355	292	0	611	7.5
8N-1E																		
10aaa	63	Pgw	10-54	18	35	0.1	5.0	1.7	109	0	7.6	4.5	1.6	129	88	0	207	7.1
8N-1W																		
11abb	76	Pgw	-54	12	73	39	9.7	2.0	392	0	5.9	14	7.9	357	342	22	624	7.2
25ccc	69	Pgw	10-54	16	100	58	58	2.4	430	0	58	104	62	679	490	138	1,190	7.5
8N-2W																		
5baa	567	Pgw	3-43	53	10	4.0	371		410	30	357	45	1.3	....	24	....	1,510	7.9
5dac	635	Pgw	4-44	....	29	14	343		343	0	518	34	0.8	(1,110)	130	....	1,670	....
5dba	562	Pgw	3-43	....	35	15	439		358	12	667	63	0.1	(1,410)	149	....	2,020	....
5ddb	570	Pgw	6-55	....	38	15	498		430	0	805	68	<0.4	1,670	156	0	2,410	7.7
9bba	545	Pgw	3-43	....	86	34	572		292	5.9	1,190	72	<0.1	(2,110)	354	....	2,790	....
9bbb1	237	Pgw	3-43	....	26	13	188		404	0	140	18	27	(612)	118	....	917	....
9bbb2	225	Ph	3-43	....	126	51	703		290	0	1,600	78	41	(2,750)	524	....	3,640	....
23bad1	518	Pgw	4-44	....	....	....	....	....	321	14	....	14	....	....	14	....	556	....
27acd	461	Pgw	3-43	10	3.9	1.4	197	1.8	318	30	106	21	0.2	539	16	....	848	8.0
9N-1W																		
2ddc	100	Pgw	4-54	15	17	9.4	7.6	0.9	94	0	5.6	8.5	1.9	109	81	4	190	6.5
26bbb	58	Pgw	6-43	....	....	....	....	....	47	0	15	16	5.4	....	....	....	273	....
30bcc2	90	Pgw	6-43	....	....	....	....	....	218	0	3	36	1.5	....	....	....	418	....
9N-2W																		
8db	580	Pgw	3-43	....	....	....	222		486	24	24	30	2.5	....	26	....	862	7.9
9cbc	408	Pgw	1-51	....	38	32	42		359	0	9.4	8.5	1.9	320	226	0	546	....
17daa	600	Pgw	1-51	....	19	18	59		254	11	10	7.2	3.0	236	121	0	431	....
19bcc1	617	Pgw	6-43	....	....	....	177		342	31	46	7	0.6	....	6	....	719	....
19cbd	613	Pgw	6-43	....	....	....	175		340	33	45	5	0.6	....	8	....	716	....
20adc	616	Pgw	4-44	....	....	....	144		288	18	61	8	1.0	....	30	....	632	....
21ccc	650	Pgw	3-58	12	2.0	0.0	161	0.6	322	27	39	5	0.6	411	5	0	662	8.9
29a	670	Pgw	3-43	....	....	....	190		324	51	44	15	0.8	....	6	....	750	8.2
29ac2	600	Pgw	4-44	....	....	....	172		317	46	36	6	0.8	....	9	....	705	....
29ccc	605	Pgw	4-44	....	....	....	209		374	39	65	15	1.0	....	8	....	848	....
30aba	640	Pgw	4-44	....	....	....	174		314	41	49	7	0.8	....	9	....	719	....
30acb	591	Pgw	3-43	9.6	2.0	0.8	244	1.4	342	43	175	14	1.0	666	8	....	1,060	8.6
30dbd1	612	Pgw	4-44	....	....	....	248		378	32	141	24	1.5	....	9	....	1,040	....
30dad1	552	Pgw	3-43	....	....	....	285		388	47	191	20	0.6	....	9	....	1,140	8.2

31dad2	661	Pgw	4-44	....	....	....	399		382	20	489	31	1.0	....	32	....	1,750	....
33bab	205	Pgw	3-43	....	12	4.4	325		348	31	202	89	100	(936)	48	....	1,450	....
9N-3W																		
2dca	679	Pgw	4-54	10	2.0	1.5	146	1.0	340	9	17	7.2	1.4	363	11	0	584	8.4
3add	400	Pgw	8-47	....	....	....	....	....	433	....	22	14	2.0	....	16	....	703	....
11dad	670	Pgw	7-45	....	6.0	4.2	136		278	42	18	7	1.5	369	32	....	....	....
13bba	635	Pgw	7-45	....	6.2	3.9	117		251	35	9	7	1.8	322	32	....	....	....
13bba	635	Pgw	3-52	9	5.0	3.4	122	1.0	308	10	14	5.8	1.2	326	26	0	524	8.7
13caa	605	Pgw	5-44	....	....	....	....	....	301	30	....	5	....	....	13	....	586	....
13dcd	615	Pgw	5-44	....	....	....	....	....	290	28	....	4	....	....	9	....	546	....
17dac	625	Pgw	10-44	....	11	3.7	227		346	51	134	20	0.2	(618)	42	....	....	8.3
36ddd2	260	Ph	9-45	....	179	52	1,580		148	8.9	3,600	150	0.0	5,900	660	....	....	....
10N-1E																		
20ddd	100	Pgw	10-54	10	29	8.1	20	9.1	88	0	31	21	28	200	106	34	349	7.1
10N-1W																		
29aab	72	Pgw	10-54	14	72	45	12	2.4	425	0	16	11	1.2	370	364	16	672	7.5
10N-2W																		
21db	784	Pgw	4-44	....	45	34	21		335	0	5	11	2.5	(284)	252	....	525	....
24ddc	500	Pgw	6-43	....	....	....	....	....	298	0	4	9	0.2	....	....	....	479	....
10N-3W																		
3bd1	290	Pgw	6-47	....	8.0	38	26		206	19	9.4	16	0.5	229	176	0	555	....
14caa	204	Pgw	3-43	....	43	29	331		310	9.8	295	230	53	(1,140)	226	....	1,810	7.7
14cad	609	Pgw	1-48	....	40	33	35		304	14	18	14	1.0	288	236	0	571	....
14dbb	501	Pgw	3-43	18	44	36	22	2.0	359	0	4.9	8	0.8	296	258	....	540	7.6
26cd	600	Pgw	7-45	....	16	21	48		208	22	7	10	2.0	246	126	....	....	....
29cdd	317	Pgw	4-44	....	....	....	805		261	20	1,450	26	0.8	....	44	....	3,460	....
29dad	525	Pgw	4-44	....	....	....	....	....	318	44	....	9	....	....	9	....	1,030	....
31ada	650	Pgw	4-44	....	....	....	160		325	41	16	4	0.6	....	9	....	640	....
33dda	305	Ph	8-47	....	....	....	....	....	331	....	945	78	1.0	....	40	....	2,600	....
34dad	225	Ph	8-47	....	....	....	....	....	347	....	729	170	4.0	....	56	....	2,460	....
35bba	313	Pgw	7-45	....	7.8	4.1	153		314	25	43	16	2.5	439	36	....	....	....
35bdc	704	Pgw	4-54	9.4	2.7	1.4	155	1.1	354	13	15	10	2.2	387	12	0	621	8.5
OKLAHOMA COUNTY																		
11N-1E																		
24aa1	132	Pgw	10-54	10	12	1.5	17	1.0	63	0	11	7.5	0.6	101	36	0	138	6.7
11N-1W																		
1bc2	100	Pgw	2-59	11	48	20	35	1.1	80	0	63	114	0.1	359	204	138	616	7.1
22cc	121	Pgw	4-54	12	38	14	4.5	1.0	175	0	5.7	7.5	0.8	166	152	9	297	7.4
11N-2W																		
8cbc	325	Pgw	3-58	20	48	22	11	0.8	268	0	7.4	6.0	1.1	235	210	0	424	7.8
10cdb	763	Pgw	4-44	....	25	16	28		206	0	....	7.0	2.0	(187)	128	0	332	....
11bbc1	793	Pgw	10-51	11	35	18	15	1.6	224	0	6.7	7.5	0.7	192	161	0	362	7.8
11bbc2	706	Pgw	4-44	....	42	20	8.7		236	0	4.0	6.0	0.3	(197)	187	0	369	....
11cbb	800	Pgw	10-51	10	45	24	7.1	1.6	246	0	6.6	10	2.0	222	211	9	407	7.6
11ccb	800	Pgw	10-51	10	42	21	9.1	1.4	237	0	6.7	7.8	0.4	205	191	0	384	7.8
14dab	938	Pgw	10-51	12	48	22	10	1.4	254	0	8.1	8.5	0.7	220	210	2	416	7.5

* Data on temperature, percent sodium, and iron, fluoride, and boron concentrations have been determined for numerous samples but are not given here. A summary of these data is given on pages 50-51, 56. Temperatures ranged from 61 to 69°F in 73 samples; only 8 samples exceeded 66°F.

1 Pgw, Garber Sandstone and Wellington Formation; Ph, Hennessey Shale.

2 Residue on evaporation at 180°C; numbers in parentheses are calculated values.

TABLE 7 (cont.)

Well No.	Depth of Well (Feet)	Geologic Source[1]	Date of Collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids[2]	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific Conductance (Micromhos at 25° C)	pH
11N-2W (cont.)																		
14dbb	884	Pgw	10-51	12	49	22	8.9	1.5	261	0	7.4	8.2	0.5	228	213	0	420	7.6
14dcb	837	Pgw	10-51	12	49	23	9.7	1.8	262	0	6.3	8.5	0.8	224	217	2	422	7.5
14ddb	665	Pgw	10-51	12	46	21	8.2	1.5	247	0	6.1	9.0	0.7	218	201	0	398	7.6
14ddc	829	Pgw	10-51	12	45	21	15	1.4	256	0	7.7	11	0.7	231	199	0	418	7.6
15bbb	780	Pgw	10-51	11	44	22	7.2	1.8	233	0	6.3	12	1.5	205	200	9	394	7.6
15bbc	740	Pgw	10-51	11	42	24	8.7	2.2	238	0	6.4	12	1.8	215	204	8	399	7.8
15bcc	939	Pgw	9-42	....	21	11	....	....	....	....	21	38	....	(564)	97	....	....	....
15cbc	932	Pgw	10-42	12	26	25	....	....	....	....	26	102	....	(400)	168	....	....	....
15ccb	920	Pgw	10-51	10	14	7	377	3.0	387	0	84	325	2.2	1,020	64	0	1,790	8.2
22bbb	755	Pgw	10-51	12	32	21	15	2.2	214	0	7.2	12	2.4	193	166	0	364	7.8
22bbc	792	Pgw	10-51	10	9.6	7.3	58	1.6	204	0	6.8	5.8	1.4	184	54	0	336	8.2
23aac	669	Pgw	10-51	12	48	22	8.4	1.5	256	0	6.3	7.8	0.7	225	210	0	414	7.6
23abc	1,102	Pgw	1-53	13	31	20	....	....	....	....	106	140	....	(624)	194	....	....	....
23adb	1,030	Pgw	10-51	12	50	22	7.6	1.3	258	0	6.8	9.2	0.4	219	215	4	415	7.6
23bab	1,070	Pgw	10-51	11	49	22	7.0	1.4	255	0	6.8	9.0	0.7	224	213	4	411	7.6
23dca	800	Pgw	10-51	11	48	22	6.2	1.4	250	0	6.5	9.5	1.3	221	210	5	404	7.6
23ddc	790	Pgw	10-51	11	50	22	8.7	1.7	259	0	7.1	9.0	0.5	232	215	3	504	7.6
26aad	770	Pgw	10-51	12	49	23	9.4	1.3	265	0	6.6	8.5	0.8	226	217	0	422	7.7
26add	764	Pgw	10-51	12	52	23	9.6	1.4	273	0	7.4	7.8	0.7	233	224	1	438	7.6
26dad	664	Pgw	10-51	12	49	23	10	1.5	271	0	8.0	8.5	0.8	235	217	0	433	7.5
31aa	765	Pgw	4-43	....	50	30		31	284	20	19	17	4.5	(312)	248	....	548	....
11N-3W																		
3db	728	Pgw	4-43	....	30	18		46	268	0	11	12	1.2	(250)	149	....	446	....
6cb1	785	Pgw	4-44	....	28	23		52	299	0	11	0.2	....	(278)	164	0	494	....
10da	728	Pgw	4-44	....	22	24		32	206	6.9	5.0	27	0.05	(219)	154	0	413	....
21dc1	200	Ph	6-47	....	14	37		35	239	8	14	27	1.0	246	187	0	553	....
21dc2	246	Ph	6-47	....	13	36		32	195	23	12	27	0.5	257	180	0	516	....
24ab1	785	Pgw	4-44	....	37	24		29	268	0	8.0	17	1.0	(248)	191	0	462	....
26cb	800	Pgw	4-43	....	22	22		50	246	14	12	10	2.2	(254)	146	....	440	....
33cdc2	273	Pgw	11-48	....	30	19		153	370	0	125	37	0.0	564	153	0	888	....
35bd	600	Pgw	4-44	....	31	24		27	250	5.9	5.0	9.0	2.0	(227)	176	0	420	....
12N-1E																		
26ccc	62	Pgw	10-54	14	29	7.7	32	2.2	99	0	30	30	18	211	104	23	364	6.4
12N-1W																		
20cd	72	Pgw	4-54	22	35	19	26	1.1	85	0	34	48	55	284	165	96	469	6.1
12N-2W																		
22cd	220	Pgw	4-44	....	46	20		23	270	0	7.0	8.0	7.5	(244)	197	0	435	....
12N-3W																		
2abd[3]	745	Pgw	1-64	12	4.5	2.9		104	270	0	13	10	0.2	276	23	0	440	8.0
2abd[3]	745	Pgw	1-64	12	4.4	1.7		111	264	8	16	8.0	0.0	290	18	0	460	8.4
5ab1	811	Pgw	12-51	8.5	3.8	2.7	247	2.2	445	32	65	50	1.3	642	20	0	1,030	8.9
5ab2	816	Pgw	4-43	....	4.5	1.7		190	298	37	40	58	0.2	(480)	18	....	807	....
5dd	815	Pgw	4-43	12	3.8	1.2	413	4.4	436	35	93	296	0.9	1,070	14	....	1,830	8.7
6ad	825	Pgw	6-43	....	90	74		129	234	0	152	325	0.2	(886)	529	....	1,630	....
15ca	800	Pgw	4-44	....	....	....		164	293	37	17	29	0.8	....	4	0	679	....

15ddb1	800	Pgw	4-44	....	70	37		40		417	0	17	33	10	(412)	326	0	749	....
26bc	638	Pgw	4-44	....	37	31		37		264	0	13	49	2.5	(300)	220	4	573	....
32acd	822	Pgw	4-44	....	53	25		137		441	0	74	67	0.6	(574)	236	0	978	....
32ad	870	Pgw	4-44	....	....	....		178		336	42	20	18	1.0	....	8	0	717	....
32dd	817	Pgw	4-44	....	....	....		187		364	35	22	21	1.6	....	6	0	748	....
33dac	780	Pgw	4-43	....	3.5	1.1		171		278	57	20	28	1.0	(419)	13	....	694	....
36cc2	212	Pgw	4-44	....	86	32		120		456	0	100	92	0.1	(655)	346	0	1,120	....
12N-4W																			
14cab	775	Pgw	4-43	....	64	43		191		246	0	152	277	<0.5	(849)	336	....	1,510	....
15b	608	Pgw	4-43	14	39	12	204		3	319	0	260	46	2.0	730	147	....	1,130	7.8
13N-1E																			
27ccb	140	Pgw	10-54	14	58	34	11		4.4	387	0	4.9	10	0.5	326	308	0	612	7.5
13N-1W																			
34abb	240	Pgw	12-51	14	120	68	139		2.0	346	0	189	260	0.1	1,030	538	254	1,600	7.4
33bd	76	Pgw	4-54	14	49	24	8.9		1.0	224	0	13	24	1.7	245	321	37	435	6.8
13N-2W																			
20ba	100	Pgw	4-54	15	64	37	11		0.8	352	0	12	12	12	306	312	23	581	7.4
13N-3W																			
20ccc	650	Pgw	4-44	....	28	18		230		243	0	189	176	0.8	(762)	144	0	1,300	....
29dac	751	Pgw	7-45	....	18	18		146		218	14	51	128	0.8	498	119	....	....	....
29ddd2	803	Pgw	4-43	....	8.5	4.8		262		376	43	58	116	<0.2	(680)	40	....	1,160	....
31ccc2	800	Pgw	4-44	....	26	21		372		258	7.9	86	458	0.9	(1,100)	152	0	2,030	....
34ba	787	Pgw	4-44	....	39	29		79		377	0.0	18	42	0.8	(394)	216	0	700	....
13N-4W																			
12dd	437	Pgw	3-47	....	11	7.0		147		267	25	75	25	1.5	(423)	56	....	692	....
14N-1E																			
28ad	172	Pgw	10-54	21	88	41	40		3.6	319	0.0	47	69	83	554	390	128	972	7.2
14N-2W																			
9cc	90	Pgw	4-54	13	30	15	5.8		1.3	130	0.0	19	11	6.0	166	137	30	286	6.8
17cb	160	Pgw	4-44	....	65	33		18		375	0.0	7	12	5.0	(325)	298	0	582	....
17cd	635	Pgw	4-44	....	57	28		15		328	0.0	5	11	0.8	(278)	258	0	511	....
14N-3W																			
26dac	457	Pgw	4-43	....	69	31		31		332	0.0	21	37	24	(377)	300	....	672	....
31bb	600	Pgw	4-43	....	8.0	2.6		146		292	24	58	6.0	0.2	(388)	30	....	625	....
35aab	751	Pgw	4-43	12	3.5	1.6	311		2.2	411	23	85	166	1.5	802	15	....	1,350	8.5
35aba	750	Pgw	12-49	1.5	20	7.9	243		2.4	409	....	68	150	3.5	712	82	0	1,220	8.2

[3] Samples from same well collected two days apart; first listed sample was collected Jan. 8, the second Jan. 10.

cation concentration, damage to soils may result. Percent sodium was computed for 57 samples from the Garber and Wellington. It exceeded 50 percent in water from 14 wells.

Boron in small amounts is essential for the normal growth of practically all plants, but in amounts greater than about 2 ppm it is exceedingly toxic to all except the most boron-resistant plants. The boron content of 12 samples ranged from 1 to 1.5 ppm.

Most of the water from the Garber and Wellington is suitable for irrigation use, but at some places it is not suitable because of the high sodium hazard. In general, the softest water is most likely to have a high percent sodium. Of 9 samples having more than 90 percent sodium, 7 had 26 ppm hardness or less and the others had 42 and 64 ppm.

Water quality from NATTC wells.—In 1942, the U. S. Navy drilled several wells into the Garber and Wellington in secs. 5, 8, 9, T. 8 N., R. 2 W., to supply water for the Naval Air Technical Training Center (NATTC) south of Norman (locally referred to as the "South Base" or "South Campus of The University of Oklahoma"). These wells, however, were never used. The general opinion of local people has been that salt water was drawn into the aquifer during testing and that it might percolate laterally to contaminate other wells in the area.

Water from wells 8N-2W-5dac, -5dba, -5ddb, and -9bba, all drilled by the Navy, is not salty (table 7). The chloride content of the water from these wells is comparable to that in other wells in the area. The water does contain an excessive amount of sulfate (from 518 to 1,190 ppm), is moderately hard to very hard, and is high in dissolved solids. Apparently the water was not used because of the excessive sulfate and dissolved-solids contents rather than because of excessive sodium chloride.

Eleven samples of water were collected from well 8N-2W-5dba during a 3-day pump test in June 1955. During the test, no significant changes occurred in sulfate content, specific conductance, sodium content, and hardness. At the end of the test the chloride content of water from the well was 54 ppm, nearly identical to the 52 ppm reported in 1943 (table 7). This indicates that no salt water was being drawn into the well during pumping. Norman city well 8N-2W-5baa is 567 feet deep and has been in use since 1942, and the University completed and put into use a deep well in 1961 in SE¼ SE¼ sec. 9, T. 9 N., R. 2 W. Both wells produce soft water of good quality.

Construction records for the NATTC wells are incomplete but indicate that surface pipe was set to only about 200 feet, and that perforated pipe was set in all sandstones below that depth. If this information is correct, the uppermost sandstone layers, which were reported to contain water high in sulfate in that area, may have contributed mineralized water to the wells. If the NATTC wells were properly sealed when they were destroyed, it may be possible to obtain good-quality water from the Garber and Wellington at the site of the base by "casing off" the uppermost sandstones containing water of high sulfate content.

Radiochemical Quality

Radioactive substances may be present in natural water as a result of geochemical processes or the release of radioactive waste and other nuclear debris to the environment. The U. S. Geological Survey has developed methods for measuring certain of these radioactive substances in water, and has described the analytical procedures in Water-Supply Paper 1696 (Barker and Robinson, 1963; Barker and Johnson, 1964).

In Cleveland and Oklahoma Counties, radiochemical analyses were made of water samples collected from three wells and from Lake Hefner. The results of the analyses, which consisted of determinations of radium, uranium, and beta-gamma activity, are given in table 8. No significant concentrations of radionuclides were found in any of the sources.

Although these data cannot be used in geologic interpretations, they are useful for verifying the radiological safety of potable water, and for screening water samples for evidence of contamination resulting from radioactive fallout or from the disposal of radioactive wastes.

Table 8.— Radiochemical Analyses of Water in Cleveland and Oklahoma Counties

(Analyses made by Trace Elements Laboratory, U. S. Geological Survey)

Source and location	Date of collection	Beta activity (pc/l)[1]	Radium (Ra) (pc/l)[1]	Uranium (U) (μg/l)[2]
Ground water, Pgw[3]				
9N-2W-21ccc	3- 5-59	27	0.1	45
9N-3W-13bba	3-11-52	< 200	0.1	9.5
do.	6- 9-54	< 7	0.3	12
11N-2W-8cbc	3- 4-58	< 19	0.2	0.3
Lake Hefner[4]				
13N-4W-23SE¼	7-21-51	12± as of 10-16-61	< 0.1	0.3±0.1

[1] Pico-curies per liter (pc/l; pc= 2.22 disintegrations per minute.) Numerical expressions of "less than" (<) vary with volume sample analyzed converted to a liter basis and instrument deletion level. Includes all beta activity and about 2 percent gamma activity.

[2] μg/l—micrograms per liter

[3] Garber Sandstone and Wellington Formation. See table 9 for records of wells.

[4] Alpha activity (pc/l) <10 as of 10-28-61

POSSIBILITIES FOR ADDITIONAL DEVELOPMENT

The total volume of fresh water stored in the Garber and Wellington can be estimated by multiplying the area, the saturated thickness, and the porosity of the sandstone. In the two counties, the total volume of sandstone which contains fresh water is estimated to be 167 million acre-feet. Based upon a porosity of 30 percent, the total volume of water in the aquifer is about 50 million acre-feet. Specific yield, however, is more useful than porosity in estimating the total volume of water that can be withdrawn from an aquifer. Using a specific yield of 20 percent, the total amount of water available from the Garber and Wellington in the two counties is about 34 million acre-feet, or more than 80 times the amount withdrawn from the aquifer since development began.

Generally the recharge rate is a better indication of aquifer potential than the volume of ground water in storage. The annual recharge to the Garber and Wellington in the two counties is estimated to be 90 acre-feet per square mile of outcrop. The total annual recharge, for the 800-square-mile area, is estimated to be about 72,000 acre-feet. Much of the recharge is discharged naturally in the outcrop area and does not percolate to areas of heavy pumping.

The stage of development can be determined by comparing the current rate of withdrawal to the estimated rate of replenishment. Withdrawals in 1963 for municipal, institutional, industrial, and commercial use are estimated to have been 22 mgd or about 25,000 acre-feet. Because much of the recent pumping was concentrated in the Norman and Del City-Midwest City-Tinker Air Force Base areas, the effects of pumping have been most pronounced in those areas. Now that Del City, Midwest City, and Norman obtain part or all of their municipal supplies from the Lake Thunderbird reservoir pumping from the aquifer should be reduced by about 5.5 mgd. However, pumpage can be expected to increase at Moore, Edmond, Nichols Hills, and Tinker Air Force Base.

Yields of a few gallons per minute can be obtained for domestic use at most places. Some wells, however, may yield water containing excessive amounts of sulfate and therefore be unsuitable as sources of drinking water. Supplies for small communities or for small commercial or industrial plants are available at most locations, provided that the supplies are obtained from a number of widely spaced wells tapping 100 or more feet of saturated sandstone. Large supplies required for municipal use or for large industrial plants should be drawn from a number of widely spaced wells tapping maximum thicknesses of saturated sandstone.

Small to moderate water supplies can be developed also from saturated alluvial deposits in the valleys of the principal streams draining the two counties. Where alluvial deposits have sufficient saturated thickness, as along the Canadian and North Canadian Rivers, yields in excess of 100 gpm may be obtained from individual wells. Unfortunately, water from these deposits may be hard and high in dissolved solids, and in places may be contaminated by industrial wastes. Therefore, such water should be analyzed chemically and bacteriologically before use.

In summary, the Garber Sandstone and Wellington Formation contain a large volume of water only partly developed. Because of the concentration of pumping near Norman and near Del City, Midwest City, and Tinker Air Force Base, pumping effects have been pronounced in those areas. However, total pumpage from the aquifer is only a fraction of the estimated replenishment, and considerable additional water can be developed if wells are adequately spaced.

TABLE 9—RECORDS OF WELLS AND TEST HOLES IN CLEVELAND AND OKLAHOMA COUNTIES

Well number	Location in section	Use[1]	Geologic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
CLEVELAND COUNTY								
6N-1E								
*† 5ddb	NW-SE-SE	P	Pgw	442	......	....	......	......
*† 5ddc	SW-SE-SE	P	Pgw	435	......	....	......	......
6N-1W								
1ccb	NW-SW-SW	D	Pgw	48+	42.52	8-15-52	1,135	1,092.5
7N-1E								
7bbb	NW-NW-NW	D	Ph	35	21.22	8-14-52	1,130	1,108.8
* 16bd	SE-NW	D, S	Pgw	403	......	....	......	......
† 22dd	SE-SE	D, S	Pgw	116	69.02	10-18-54	......	......
* 26ccc	SW-SW-SW	D, I	Pgw	400	80	1-11-43	1,080	1,000
* 30adc	SW-SE-NE	D, S	Pgw	449	......	....	......	......
7N-1W								
2dd	SE-SE	D	Pgw	72	68.19	8-14-52	1,175	1,106.8
3ad	SE-NE	D	Pgw	59	......	....	1,153	......
3dd	SE-SE	S	Pgw	76	31.16	8-14-52	1,146	1,114.8
6aaa	NE-NE-NE	D, S	Pgw	56	36.32	8- 7-52	1,139	1,102.7
* 6bdd	SE-SE-NW	N	Pgw	700	......	....	1,159	......
6ddd	SE-SE-SE	N	Pgw	25	16.98	8-14-52	1,120	1,103.0
* 7cd	SE-SW	N	Pgw	802	......	....	1,112	......
8ad	SE-NE	D, S	Pgw	44	21.31	8-14-52	1,103	1,081.7
* 8cdd	SE-SE-SW	N	Pgw	650	......	....	1,115	......
* 9cdd	SE-SE-SW	N	Pgw	580	......	....	1,125	......
11ccc	SW-SW-SW	D, S	Pgw	61	34.67	8-14-52	1,150	1,115.3
13aa	NE-NE	D	Pgw	19	7.67	8-14-52	1,110	1,102.3
13bb1	NW-NW	D	Pgw	53	36.12	8-14-52	1,147	1,110.9
† 13bb2	NW-NW	D, S	Pgw	100	......	....	......	......
14ccc	SW-SW-SW	N	Pgw	44	17.68	8-14-52	1,140	1,122.3
14ddd	SE-SE-SE	D, S	Pgw	88	51.20	8-15-52	1,141	1,089.8
* 17ddd	SE-SE-SE	N	Pgw	520	......	....	......	......
* 18aaa	NE-NE-NE	N	Pgw	500	......	....	1,121	......
* 18ccd	SE-SW-SW	N	Pgw	577	......	....	1,068	......
22ba	NE-NW	N	Pgw	175	45.93	8-14-52	1,140	1,094.1
23abb	NW-NW-NE	D	Pgw	46	37.78	8-14-52	1,192	1,154.2
24ab	NW-NE	N	Pgw	59	43.96	8-14-52	1,131	1,088.0
24cc	SW-SW	I	Pgw	90	53.32	8-15-52	1,145	1,091.7
24ccc	SW-SW-SW	D	Pgw	51	19.83	8-15-52	1,152	1,132.2
25ca	NE-SW	D, S	Pgw	138	69.98	8-15-52	1,161	1,091.0
25ddd	SE-SE-SE	D	Pgw	54	36.42	8-15-52	1,100	1,063.6
* 30aa	NE-NE	N	Pgw	552	......	....	1,055	......
34ba	NE-NW	D	Pgw	160	30	11- 2-55	......	......
34baa	NE-NE-NW	D, S	Pgw	140	27.33	8-20-52	1,110	1,082.7
34cd	SE-SW	N	Pgw	79	27.68	8-15-52	1,093	1,065.3
36bcb	NW-SW-NW	N	Pgw	140	58.14	8-15-52	1,113	1,054.9
36dad	SE-NE-SE	N	Pgw	50	39.35	8-15-52	1,070	1,030.6
7N-2W								
1daa	NE-NE-SE	D	Pgw	80	53.03	8-20-52	1,150	1,097.0
* 2cdd	SE-SE-SW	N	Pgw	602	......	....	1,094	......
* 10dab	NW-NE-SE	N	Pgw	680	......	....	1,062	......
* 12cdd1	SE-SE-SW	I	Pgw	400	36.35	1- 9-43	1,062	1,025.6
* 12cdd2	SE-SE-SW	N	Pgw	799	......	....	1,100	......
8N-1E								
† 10aaa	NE-NE-NE	D	Pgw	84	16.93	10-20-54	......	......

* Log available.

† Chemical analysis given in table 7.

1 D, domestic; I, irrigation; In, industrial; N, none; P, public supply; S, stock.

2 Ph, Hennessey Shale; Pgw, Garber Sandstone or Wellington Formation.

	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
8N-1W									
	3dc	SW-SE	D, S	Pgw	117	76.54	8-13-52	1,162	1,085.5
	4ad	SE-NE	N	Pgw	39	28.21	8- 5-52	1,060	1,031.8
	4bcc	SW-SW-NW	D	Pgw	104	63	10-19-54	......	......
	5ad	SE-NE	D	Pgw	60	37.01	8- 6-52	1,102	1,065.0
	5bb	NW-NW	D, S	Pgw	70	......	....	......	......
	6cbb	NW-NW-SW	N	Pgw	78	63.16	8- 6-52	1,141	1,077.8
	6ddd	SE-SE-SE	D	Pgw	77	53.97	8-13-52	1,110	1,056.0
	7bbb	NW-NW-NW	N	Pgw	......	37.48	8- 6-52	1,120	1,082.5
	9bcb	NW-SW-NW	D	Pgw	36	25.14	8-13-52	1,175	1,149.9
	9cda	NE-SE-SW	D, S	Pgw	71	47.67	8- 6-52	1,131	1,083.3
	10abb	NW-NW-NE	N	Pgw	70	42.70	8- 8-55	......	......
	11aaa	NE-NE-NE	P	Pgw	......	12.98	8- 6-52	1,055	1,042.0
†	11abb	NW-NW-NE	D	Pgw	75	45	4-20-54	......	......
	12cdc	SW-SE-SW	D, S	Pgw	75	......	....	1,120	......
	14cd	SE-SW	D	Pgw	54	43.08	8- 6-52	1,190	1,146.9
	15ccc	SW-SW-SW	D	Pgw	59	50.83	8-13-52	1,180	1,129.2
	15dcc	SW-SW-SE	D	Pgw	64	56.45	8-13-52	1,185	1,128.5
	16dcd	SE-SW-SE	N	Pgw	28	12.02	8- 6-52	1,135	1,123.0
	17bba	NE-NW-NW	D, S	Pgw	56	32.88	8-13-52	1,155	1,122.1
	17dcc	SW-SW-SE	D	Pgw	46	29.79	8-13-52	1,150	1,120.2
	18ab	NW-NE	D	Pgw	48	22.71	8-13-52	1,160	1,137.3
	18bc	SW-NW	S	Pgw	45	20	....	1,108	1,088.0
*	19bcc1	SW-SW-NW	N	Pgw	501	......	....	1,149	......
*	19bcc2	SW-SW-NW	N	Pgw	1,424	......	....	1,155	......
	23ccc	SW-SW-SW	D	Pgw	65	40.77	8-13-52	1,170	1,129.2
	25bb	NW-NW	D	Pgw	100	90	....	......	......
	25bbb	NW-NW-NW	P	Pgw	......	46.41	8-13-52	1,200	1,153.6
†	25ccc	SW-SW-SW	D, S	Pgw	69	65	10-18-54	......	......
	26abb	NW-NW-NE	....	Pgw	85	39.22	8-13-52	1,185	1,145.8
	26cb	NW-SW	D	Pgw	52	19.41	8- 7-52	1,223	1,203.6
	27bb	NW-NW	D, S	Pgw	165	57.48	8- 7-52	1,231	1,173.5
	28bda	NE-SE-NW	D, S	Pgw	58	32.54	8- 7-52	1,191	1,158.5
	28ddd	SE-SE-SE	D	Pgw	61	15.52	8- 6-52	1,285	1,269.5
	29bbb	NW-NW-NW	N	Pgw	90	53.48	8- 7-52	1,202	1,148.5
	29ddc	SW-SE-SE	D	Pgw	44	24.43	8- 7-52	1,155	1,130.6
	30cdc	SW-SE-SW	N	Pgw	67	41.98	8- 7-52	1,165	1,123.0
*	31b	NW	N	Pgw	502	......	....	1,166	......
	32dd	SE-SE	N	Pgw	34	28.93	8- 7-52	1,145	1,116.1
	33aaa1	NE-NE-NE	D	Pgw	36	20.14	8- 6-52	1,184	1,163.9
	33aaa2	NE-NE-NE	D, S	Pgw	35	14.19	8- 6-52	1,181	1,166.8
	33aaa3	NE-NE-NE	D, S	Pgw	37	16.71	8- 6-52	1,183	1,166.3
	36aa	NE-NE	D	Pgw	80	21	6- 8-52	1,150	1,129.0
	36bb	NW-NW	D	Pgw	62	41.58	8- 7-52	1,220	1,178.4
	36d	SE	S	Pgw	100	50	8- 6-52	1,235	1,185.0
8N-2W									
*	1cbb	NW-NW-SW	N	Pgw	557	......	....	1,145	......
*	3ccc	SW-SW-SW	N	Pgw	621	......	....	1,183	......
	4aba	NE-NW-NE	D	Pgw	208	180	....	......	......
	4abb	NW-NW-NE	D	Ph	46	19.74	9-16-53	1,160	1,140.3
	4bab	NW-NE-NW	D, S	Pgw	200	......	....	......	......
†	5baa	NE-NE-NW	P	Pgw	567	......	....	1,151	......
*†	5dac	SW-NE-SE	P	Pgw	696	......	....	......	......
*†	5dba	NE-NW-SE	P	Pgw	583	......	....	......	......
*	5dbc	SW-NW-SE	P	Pgw	531	......	....	......	......
*	5dbd	SE-NW-SE	P	Pgw	526	......	....	......	......
*	5dca	NE-SW-SE	P	Pgw	525	......	....	......	......
*	5dcb	NW-SW-SE	P	Pgw	526	......	....	......	......
*†	5ddb	NW-SE-SE	P	Pgw	520	......	....	......	......
*	5ddd	SE-SE-SE	N	Pgw	528	......	....	......	......
*	8aab	NW-NE-NE	N	Pgw	560	......	....	......	......
*	8aac	SW-NE-NE	N	Pgw	520	......	....	......	......
*	8ada	NE-SE-NE	N	Pgw	525	......	....	......	......
*	8bbc	SW-NW-NW	O	Pgw	612	122.16	6-27-42	1,145	1,022.8
*†	9bba	NE-NW-NW	O	Pgw	545	......	....	......	......
†	9bbb1	NW-NW-NW	D	Pgw	237	......	....	......	......
†	9bbb2	NW-NW-NW	D	Pgw	225	......	....	......	......

	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
	8N-2W (cont.)								
*	9bbc	SW-NW-NW	N	Pgw	512	......	....	......	......
*	9bcb	NW-SW-NW	N	Pgw	530	......	....	......	......
*	9bcc1	SW-SW-NW	N	Pgw	553	......	....	......	......
*	9bcc2	SW-SW-NW	N	Pgw	617	......	....	......	......
*	11cdd	SE-SE-SW	N	Pgw	541	......	....	1,156	......
	13ddd	SE-SE-SE	N	Pgw	48	31.41	8- 7-52	1,128	1,096.6
*	15abb	NW-NW-NE	N	Pgw	513	......	....	1,177	......
*	22add	SE-SE-NE	N	Pgw	536	......	....	1,192	......
*	22cbb	NW-NW-SW	N	Pgw	626	......	....	1,100	......
†	23bad1	SE-NE-NW	In	Pgw	518	102.88	12-19-42	1,135	1,032.1
*	23bad2	SE-NE-NW	In	Pgw	850	......	....	1,167	......
*	24cbb	NW-NW-SW	N	Pgw	556	......	....	1,210	......
	24ddd	SE-SE-SE	S	Pgw	100	91.53	8- 7-52	1,193	1,101.5
	25bcc	SW-SW-NW	N	Pgw	531	......	....	1,193	......
	25cdc	SW-SE-SW	D	Pgw	96	73.08	8-20-52	1,190	1,116.9
*†	27acd	SE-SW-NE	P	Pgw	461	185	3- -40	1,190	1,005
*	27caa	NE-NE-SW	P	Pgw	496	......	....	1,173	......
*	27dcd	SE-SW-SE	N	Pgw	749	......	....	1,133	......
*	27ddd	SE-SE-SE	P	Pgw	440	......	....	1,150	......
	9N-1W								
	2ccd1	SE-SW-SW	N	Pgw	87	73.47	2-25-43	1,165	1,091.5
	2ccd2	SE-SW-SW	D, S	Pgw	80	......	....	1,160	......
†	2ddc	SW-SE-SE	D, S	Pgw	100	......	....	......	......
	6da	NE-SE	S	Pgw	600	......	....	......	......
	19ccc	SW-SW-SW	D, S	Pgw	33	21.26	8- 5-52	1,160	1,138.7
	23ddd	SE-SE-SE	D	Pgw	54	46.84	8- 5-52	1,140	1,093.2
†	26bbb	NW-NW-NW	D	Pgw	58	......	....	1,085	......
	26bbc	SW-NW-NW	D	Pgw	42	29.20	8- 5-52	1,080	1,050.8
	28aaa	NE-NE-NE	D	Pgw	39	33.55	8- 5-52	1,047	1,013.4
	29aa	NE-NE	D	Pgw	70	33.01	8- 5-52	1,048	1,015.0
	29ccc	SW-SW-SW	D	Pgw	110	35	2-24-43	1,150	1,115
	29cdd	SE-SE-SW	D	Pgw	60	26.79	2-24-43	1,125	1,098.2
*	30bcc1	SW-SW-NW	D, S	Pgw	90	......	....	1,170	......
†	30bcc2	SW-SW-NW	D, S	Pgw	90	......	....	1,170	......
	30dbb	NW-NW-SE	N	Pgw	400	135	4-13-40	1,175	1,040
	31aa	NE-NE	D, S	Pgw	100	......	....	1,185	......
	31dbb	NW-NW-SE	D, S	Pgw	52	38.97	8- 5-52	1,155	1,116.0
	31dcb	NW-SW-SE	D	Pgw	65	55	8- 5-52	1,134	1,084
	32dad	SE-NE-SE	D, S	Pgw	90	......	....	1,072	......
	33daa	NE-NE-SE	D	Pgw	29	24.10	8- 5-52	1,072	1,047.9
	34ddc	SW-SE-SE	D, S	Pgw	30	26.80	8- 5-52	1,120	1,093.2
	35bab	NW-NE-NW	D, S	Pgw	55	17.63	8- 5-52	1,019	1,001.4
	36bbb	NW-NW-NW	D	Pgw	68	15	8- 5-52	1,020	1,005
	36cd	SE-SW	D	Pgw	26	24.09	8- 5-52	1,050	1,025.9
	9N-2W								
†	8db	NW-SE	D, In	Pgw	580	......	....	......	......
†	9cbc	SW-NW-SW	D, S	Pgw	408	142	12- -50	......	......
	9daa	NE-NE-SE	S	Pgw	90	30	9- 7-55	......	......
	11bc	SW-NW	D	Pgw	80	65	9- 8-55	......	......
	11daa	NE-NE-SE	D	Pgw	80	68.16	9- 8-55	......	......
	15add	SE-SE-NE	P	Pgw	726	185	8-16-63	......	......
*	15ddd	SE-SE-SE	P	Pgw	693	167	7-12-63	......	......
	16daa	NE-NE-SE	In	Pgw	267	166.79	2- 8-41	1,195	1,028.2
†	17daa	NE-NE-SE	D, S	Pgw	600	......	....	......	......
*	19bcb	NW-SW-NW	P	Pgw	616	......	....	......	......
*†	19bcc1	SW-SW-NW	N	Pgw	617	......	....	......	......
	19bcc2	SW-SW-NW	P	Pgw	637	......	....	......	......
*†	19cbd	NE-NW-SW	P	Pgw	613	......	....	......	......
*	19cdb1	NW-SE-SW	P	Pgw	615	217	3- 3-52	1,183.5	966.5
*	19cdb2	NW-SE-SW	P	Pgw	638	......	....	1,186	......
*†	20adc	SW-SE-NE	P	Pgw	616	200	8- -43	......	......
	20ccb	NW-SW-SW	D, S	Ph	100	15.07	9- 7-55	......	......
	20dcd	SE-SW-SE	P, S	Pgw	662	310	- -45	......	......
†	21ccc	SW-SW-SW	P	Pgw	650	320	12- -57	......	......

Footnotes are on page 60.

	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
	9N-2W (cont.)								
*	21cdd	SE-SE-SW	P	Pgw	625	......	....	1,205	......
*	22add	SE-SE-NE	P	Pgw	638	145	8- 1-63	......	......
	24ccc	SW-SW-SW	D	Pgw	45	26.64	9-10-53	......	......
	24dcd	SE-SW-SE	D	Pgw	54	22.85	9-10-53	......	......
*	27add	SE-SE-NE	P	Pgw	577	......	....	......	......
*	27bbb	NW-NW-NW	P	Pgw	602	......	....	......	......
*	28bdc	SW-SE-NW	P	Pgw	663	......	....	......	......
	29abb	NW-NW-NE	P	Pgw	......	......	....	......	......
*†	29a	S-NE	P	Pgw	670	195	- -34	......	......
	29abd	SE-NW-NE	P	Pgw	650	295	- -50	......	......
	29ac1	S-NE	P	Pgw	655	180	11-11-30	......	......
†	29ac2	S-NE	P	Pgw	600	......	....	......	......
*†	29ccc	SW-SW-SW	In	Pgw	605	......	....	......	......
*	29dc	SW-SE	P	Pgw	643	288.6	7-22-55	1,164.9	876.3
*†	30aba	NE-NW-NE	P	Pgw	640	198.9	9-13-39	1,187.5	988.6
†	30acb	NW-SW-NE	P	Pgw	591	228	5- 9-42	......	......
*	30dba	NE-NW-SE	P	Pgw	629	259.3	4-25-40	1,172	912.7
†	30dbd	SE-NW-SE	P	Pgw	612	267.3	3-25-40	1,168.7	901.4
	30dacd	SW-NE-SE	P	Pgw	540	269.1	3-23-40	1,173.2	904.0
†	30dad1	SE-NE-SE	In	Pgw	552	180	- -40	......	......
	30dad2	SE-NE-SE	In	Pgw	525	......	....	......	......
	30dbb	NW-NW-SE	P	Pgw	600	264.2	3-25-40	1,171	906.8
*	30dbd	SE-NW-SE	P	Pgw	643	213.4	3-23-40	1,164.9	951.5
	30ddb1	NW-SE-SE	P	Pgw	535	264.9	3-23-40	1,171.7	906.8
	30ddb2	NW-SE-SE	P	Pgw	525	266.5	3-23-40	1,171.1	904.6
*	30ddc	SW-SE-SE	In	Pgw	520	......	....	1,170	......
	31da	NE-SE	P	Pgw	552	210	4- -40	......	......
*	31dad1	SE-NE-SE	P	Pgw	650	217	4- -40	1,161.5	944.5
*†	31dad2	SE-NE-SE	P	Pgw	661	......	....	......	......
*	32acc	SW-SW-NE	P	Pgw	630	......	....	1,147.3	......
	33aab	NW-NE-NE	D	Pgw	215	184.29	4- 1-52	......	......
†	33bab	NW-NE-NW	D, S	Pgw	205	103.35	3-11-43	......	......
	34ccd	SE-SW-SW	D	Ph	75	......	....	......	......
	35cc	C-SW-SW	N	Pgw	631	......	....	1,199	......
	36aba	NE-NW-NE	D	Pgw	88	30	4-18-50	1,180	1,150
	36ad1	SE-NE	D	Pgw	60	......	....	......	......
	36ad2	SE-NE	S	Pgw	90	......	....	......	......
	36ddc	SW-SE-SE	D, S	Pgw	70	......	....	......	......
	9N-3W								
*	2baa	NE-NE-NW	P	Pgw	698	202.90	6- 8-53	1,178.4	975.5
*	2bd	SE-NW	P	Pgw	729	202.38	6- 8-53	1,169.1	966.7
*†	2dca	NE-SW-SE	P	Pgw	679	216	6- 1-53	1,169.7	954
*	3abb	NW-NW-NE	In	Pgw	400	......	....	1,190	......
†	3add	SE-SE-NE	D, S	Pgw	408	272	9- 8-55	......	......
*	11ab	NW-NE	P	Pgw	672	257.9	6- 8-53	1,147.8	890.9
	11adb	NW-SE-NE	P	Pgw	......	......	....	......	......
*†	11dad	SE-NE-SE	P	Pgw	671	174.5	12-23-44	......	......
	12ccc	SW-SW-SW	P	Pgw	......	......	....	......	......
*†	13bba	NE-NW-NW	P	Pgw	635	296	11-11-44	......	......
*†	13caa	NE-NE-SW	P	Pgw	605	......	....	1,177.0	......
*	13dbc	SW-NW-SE	P	Pgw	609	......	....	......	......
*†	13dcd	SE-SW-SE	P	Pgw	614	......	....	......	......
*†	17dac	SW-NE-SE	In	Pgw	625	150	10- -44	......	......
*	24aab	NW-NE-NE	P	Pgw	622	......	....	......	......
*	24cbb	NW-NW-SW	P	Pgw	620	162.09	12- 6-41	1,180	1,017.9
*	25dcc1	SW-SW-SE	I	Pgw	521	......	....	......	......
†	36ddd2	SE-SE-SE	S	Ph	260	......	....	......	......
	10N-1E								
†	20ddd	SE-SE-SE	D	Pgw	100	80	....	......	......
	28bbb	NW-NW-NW	N	Pgw	92	82	10-19-54	......	......
	10N-1W								
†	29aab	NW-NE-NE	D, S	Pgw	85	41.93	10-25-54	......	......

Footnotes are on page 60.

Well number	Location in section	Use[1]	Geologic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
10N-2W								
4ccb	NW-SW-SW	D, S	Pgw	228	160	....	......	......
* 16cd	SE-SW	In	Pgw	795	......	....	......	......
16dcc	SW-SW-SE	D	Pgw	790	90	- -36	1,190	1,100
† 21db	NW-SE	In	Pgw	784	......	....	......	......
† 24ddc	SW-SE-SE	D, S	Pgw	500	......	....	......	......
10N-3W								
1cc	SW-SW	N	Pgw	152	146.05	12- 4-56	......	......
3bb	NW-NW	N	Pgw	256	219.73	12- 4-56	......	......
3bad	SE-NE-NW	D	Ph	268	77	3-13-50	......	......
† 3bd1	SE-NW	In	Pgw	290	......	....	......	......
† 3bd2	SE-NW	In	Pgw	310	......	....	......	......
3abb	NW-NW-NE	In	Pgw	600	200	8- 1-55	......	......
10abb	NW-NE-NE	P	Pgw	842	248	2- -63	......	......
* 10baa	NE-NW-NW	P	Pgw	701	300	1- -62	......	......
14abb	NW-NW-NE	P	Pgw	701	250	4-28-63	......	......
14c	C-SW	D	Pgw	200	107	- -28	......	......
† 14caa	NE-NE-SW	P	Pgw	204	100	11-12-42	......	......
*† 14cad	SE-NE-SW	P	Pgw	609	215.13	7-23-45	......	......
* 14cbb	NW-NW-SW	P	Pgw	700	......	....	......	......
* 14cdc	SW-SE-SW	P	Pgw	690	......	....	......	......
*† 14dbb	NW-NW-SE	P	Pgw	501	160	11-10-42	......	......
* 15abb	NW-NW-NE	P	Pgw	802	......	....	......	......
* 15cab	NW-NE-SW	P	Pgw	735	220	6- 8-62	......	......
* 22dad	SE-NE-SE	P	Pgw	791	......	....	......	......
* 26b	NW	S	Pgw	294	165	1-17-51	......	......
† 26cd	SE-SW	In	Pgw	600	188.43	7-23-45	......	......
27dab	NW-NE-SE	In	Pgw	320	......	....	......	......
27dba	NE-NW-SE	In	Pgw	320	......	....	......	......
*† 29cdd	SE-SE-SW	D, S	Pgw	317	100	....	......	......
† 29dad	SE-NE-SE	D	Pgw	511	155.5	1-31-44	......	......
† 31ada	NE-SE-NE	In	Pgw	650	......	....	......	......
32da	NE-SE	S	Ph	305	......	....	......	......
† 33dda	NE-SE-SE	D, S	Pgw	305	......	....	......	......
† 34dad	SE-NE-SE	D, S	Ph	225	150	8-26-47	......	......
† 35bba	NE-NW-NW	D, In	Pgw	313	56	7-16-45	......	......
*† 35bdc	SW-SE-NW	P	Pgw	704	175	4-21-53	1,186.1	1,011.1
* 35cac	SW-NE-SW	P	Pgw	700	170	5-19-53	1,159.3	989.3
10N-4W								
* 22a	NE	In	Pgw	688	......	....	......	......
			OKLAHOMA COUNTY					
11N-1E								
* 15dc	SW-SE	In	Pgw	430	......	....	......	......
* 19dd1	SE-SE	In	Pgw	415	......	....	......	......
* 19dd2	SE-SE	In	Pgw	210	......	....	......	......
21aa	NE-NE	N	Pgw	....	34.8	11-21-56	......	......
† 24aa	NE-NE	D	Pgw	132	80	....	......	......
26aa1	NE-NE	D	Pgw	100	43.2	11-21-56	......	......
26aa2	NE-NE	D	Pgw	29	14.9	11-21-56	......	......
31da	NE-SE	D	Pgw	100	25	....	......	......
32cbc	SW-NW-SW	N	Pgw	42	34.4	11-21-56	......	......
35cd	SE-SW	S	Pgw	27	21.1	11-21-56	......	......
11N-1W								
1bc1	SW-NW	N	Pgw	80	75.7	11-20-50	......	......
† 1bc2	SW-NW	D	Pgw	100	40	....	......	......
6cd	SE-SW	D	Pgw	60	36.0	11-26-56	......	......
7dd	SE-SE	D	Pgw	....	11.6	11-26-56	......	......
10cc	SW-SW	N	....	21	17.7	11-26-56	......	......
13da	NE-SE	D	....	85	15	....	......	......
16ca	NE-SW	D, S	....	30	19	....	......	......
17aa	NE-NE	N	....	13	12.3	11-21-56	......	......

Footnotes are on page 60.

Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
11N-1W (cont.)								
† 22cc	SW-SW	N	Pgw	121	90			
25ab	NW-NE	N	....	47	45.8	11-26-56		
25bc	SW-NW	D, S	Pgw	106	66			
27aa	NE-NE	D	Pgw	100+	69.7	11-26-56		
31bc	SW-NW	D	Pgw	....	81.3	12- 4-56		
11N-2W								
* 2bab	NW-NE-NW	P	Pgw	779				
* 2bbc	SW-NW-NW	P	Pgw	387				
* 3abd	SE-NW-NE	P	Pgw	758				
* 3baa	NE-NE-NW	P	Pgw	750				
* 3bcc	SW-SW-NW	P	Pgw	758				
* 3dbb	NW-NW-SE	P	Pgw	750				
* 3dda	NE-SE-SE	P	Pgw	780				
* 4ddd	SE-SE-SE	P	Pgw	756				
5acc	SW-SW-NE	P	Pgw	730	180.0	- -61		
* 6cbc	SW-NW-SW	P	Pgw	743				
7abb	NW-NW-NE	P	Pgw	....				
7acc	SW-SW-NE	P	Pgw	303				
7adc	SW-SE-NE	P	Pgw	301	30			
7baa	NE-NE-NW	P	Pgw	......				
* 7bcb	NW-SW-NW	P	Pgw	409				
7cad	SE-NE-SW	P	Pgw	425				
7dbc	SW-NW-SE	P	Pgw	743	235.0	- -61		
7ddb	NW-SE-SE	P	Pgw	300				
* 8baa	NE-NE-NW	P	Pgw	749	176			
* 8adc	SW-SE-NE	P	Pgw	743				
8bbb	NW-NW-NW	P	Pgw	325				
* 8bcd	SE-SW-NW	P	Pgw	398				
8cdd	SE-SE-SW	P	Pgw	576				
8ccd	SE-SW-SW	P	Pgw	....				
8cbc	SW-NW-SW	P	Pgw	....				
8dda	NE-SE-SE	P	Pgw	398				
* 10aab	NW-NE-NE	P	Pgw	750				
10dbb	NW-NW-SE	P	Pgw	750				
10dbd	SE-NW-SE	P	Pgw	....				
10ad	SE-NE	P	Pgw	383				
10bb	NW-NW	P	Pgw	747				
10cac	SW-NE-SW	P	Pgw	325				
*† 10cdb	NW-SE-SW	P	Pgw	763	178			
*† 11ccb	NW-SW-SW	P	Pgw	800				
*† 11cbb	NW-NW-SW	P	Pgw	800				
* 11bbc1	SW-NW-NW	P	Pgw	793	163	10- -43		
*† 11bbc2	SW-NW-NW	P	Pgw	706	163.0	10- -43	1,241	1,078
* 11bab	NW-NE-NW	P	Pgw	745				
*† 14ddc	SW-SE-SE	P	Pgw	829			1,264	
*† 14ddb	NW-SE-SE	P	Pgw	665			1,253	
*† 14dab	NW-NE-SE	P	Pgw	938			1,269	
*† 14dcb	NW-SW-SE	P	Pgw	837			1,276	
*† 14dbb	NW-NW-SE	P	Pgw	884			1,276	
*† 15bbb	NW-NW-NW	P	Pgw	780			1,224	
*† 15bbc	SW-NW-NW	P	Pgw	740			1,214	
*† 15bcc	SW-SW-NW	P	Pgw	939			1,227	
*† 15cbc	SW-NW-SW	P	Pgw	932			1,217	
*† 15ccb	NW-SW-SW	P	Pgw	920			1,219	
* 17add	SE-SE-NE	P	Pgw	740				
* 18cac	SW-NE-SW	P	Pgw	721				
*† 22bbb	NW-NW-NW	P	Pgw	755				
*† 22bbc	SW-NW-NW	P	Pgw	792				
*† 23adb	NW-SE-NE	P	Pgw	1,030			1,272	
* 23daa	NE-NE-SE	P	Pgw	850	390	5- -43	1,294	
*† 23bab	NW-NE-NW	P	Pgw	1,070			1,297	
*† 23dca	NE-SW-SE	P	Pgw	800			1,283	
* 23dda	NE-SE-SE	P	Pgw	800			1,297	
*† 23ddc	SW-SE-SE	P	Pgw	790			1,298	
*† 23aac	SW-NE-NE	P	Pgw	669			1,258	

Footnotes are on page 60.

	Well number	Location in section	Use[1]	Geologic unit[2]	Depth of well (feet)	Water level		Altitude above mean sea level (feet)	
						Depth below land surface (feet)	Date	Land Surface	Water level
11N-2W (cont.)									
*†	23abc	SW-NW-NE	P	Pgw	768	......	....	1,276	......
*†	26aad	SE-NE-NE	P	Pgw	770	......	....	1,280	......
*†	26add	SE-SE-NE	P	Pgw	764	......	....	1,257	......
*†	26dad	SE-NE-SE	P	Pgw	664	......	....	1,257	......
	28dcb	NW-SW-SE	S	Pgw	143	121.9	12- 4-56	......	......
	30dcb	NW-SW-SE	D	Pgw	700	......	....	......	......
†	31aa	NE-NE	In	Pgw	765	......	....	......	......
	31ddd	SE-SE-SE	In	Pgw	904	......	....	......	......
	32cbb	NW-NW-SW	In	Pgw	800	......	....	......	......
11N-3W									
*	1ca	NE-SW	In	Pgw	800	218.2	11-17-42	......	......
*	1bbd	SE-NW-NW	In	Pgw	886	300	- -34	......	......
*	2ab	NW-NE	In	Pgw	571	......	....	......	......
*	2bc	SW-NW	In	Pgw	260	......	....	......	......
*	2ccb	NW-SW-SW	In	Pgw	820	205	6- -37	......	......
	2cc	SW-SW	In	Pgw	824	275	....	......	......
*	2c1	SW	In	Pgw	416	130	3- -36	......	......
*	2c2	SW	In	Pgw	680	150	12-14-32	......	......
*	2dad	SE-NE-SE	In	Pgw	651	......	....	......	......
†	3db	NW-SE	In	Pgw	728	156	- -41	1,247	......
*	4cbd1	SE-NW-SW	In	Pgw	803	......	....	......	......
*	4cbd2	SE-NW-SW	P	Pgw	730	165	5- -55	1,181	......
	5aaa	NE-NE-NE	In	Pgw	650	......	....	......	......
*	5aba	NE-NW-NE	N	Pgw	773	......	....	......	......
*	6ca1	NE-SW	In	Pgw	680	......	....	......	......
*	6ca2	NE-SW	In	Pgw	785	......	....	......	......
*†	6cb1	NW-SW	In	Pgw	785	200	- -39	......	......
*	6cb2	NW-SW	In	Pgw	782	250	- -36	......	......
*	6cb3	NW-SW	In	Pgw	783	250	- -36	......	......
*	6cd	SE-SW	In	Pgw	779	......	....	......	......
*	8ba	NE-NW	N	Pgw	802	......	....	......	......
*	8bad	SE-NE-NW	P	Pgw	792	309	5- -55	1,186	877
*	8cbb	NW-NW-SW	N	Pgw	802	......	....	......	......
*	8cba	NE-NW-SW	P	Pgw	790	265	3- -55	1,200	935
	10bd	SE-NW	In	....	800	......	....	1,190	......
†	10da	NE-SE	In	Pgw	728	......	....	......	......
	10dca	NE-SW-SE	In	Pgw	457	......	....	1,225	......
*	12bbb	NW-NW-NW	In	Pgw	728	......	....	......	......
*	12bbd	SE-NW-NW	In	Pgw	728	......	....	......	......
*	12ccc	SW-SW-SW	N	Pgw	800	......	....	......	......
	14bda	NE-SE-NW	In	....	....	......	....	1,240	......
	16aa	NE-NE	In	Pgw	633	......	....	......	......
*	16bbd	SE-NW-NW	D	Pgw	210	......	....	......	......
*	18aaa1	NE-NE-NE	N	Pgw	803	......	....	......	......
*	18aaa2	NE-NE-NE	P	Pgw	792	200	4- -55	1,206	1,006
*	19aa	NE-NE	N	Pgw	805	......	....	......	......
†	21dc1	SW-SE	In	Pgw	200	......	....	......	......
†	21dc2	SW-SE	In	Pgw	276	......	....	......	......
	23bad	SE-NE-NW	In	Pgw	930	......	....	......	......
†	24ab1	NW-NE	In	Pgw	785	......	....	......	......
	24ab2	NW-NE	In	Pgw	790	......	....	......	......
*	26acc	SW-SW-NE	In	Pgw	564	......	....	......	......
*†	26cbb	NW-NW-SW	In	Pgw	751	......	....	......	......
*†	26cb	NW-SW	In	Pgw	800	276.8	11-17-42	......	......
	26ccb	NW-SW-SW	In	Pgw	800	291.0	11-17-42	......	......
	30bca	NE-SW-NW	D	Pgw	750	......	....	......	......
	31db1	NW-SE	In	Pgw	815	......	....	......	......
	31db2	NW-SE	In	Pgw	827	......	....	......	......
	33ac	SW-NE	D	Pgw	122	112.4	12- 4-56	......	......
	33cdc1	SW-SE-SW	D	Pgw	305	206.9	8- 4-55	......	......
†	33cdc2	SW-SE-SW	D	Pgw	273	......	....	1,268	......
†	35bd	SE-NW	In	Pgw	600	75	....	......	......
	36aaa	NE-NE-NE	In	Pgw	751	......	....	......	......
11N-4W									
*	27da	NE-SE	P	Pgw	980	......	....	......	......

	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
	12N-1E								
	3bc	SW-NW	D	Pgw	102	79.4	11-18-56	......	......
	12aa	NE-NE	....	Pgw	....	14.3	11-18-56	......	......
	14cc	SW-SW	In	Pgw	600	......	....	......	......
	16ab	NW-NE	In	Pgw	45	18.0	....	......	......
*	22acb	NW-SW-NE	In	Pgw	352	......	....	......	......
	22dac	SW-NE-SE	In	Pgw	372	......	....	......	......
	24ad	SE-NE	D	Pgw	38	35.7	11-19-56	......	......
*	26ac	SW-NE	P	Pgw	346	......	....	......	......
†	26ccc	SW-SW-SW	D	Pgw	....	21.0	10-22-54	......	......
	12N-1W								
†	20cd	SE-SW	In	Pgw	72	62	....	......	......
	22dc	SW-SE	D	Pgw	48	23.0	....	......	......
	22bb1	NW-NW	D, S	Pgw	81	31.5	11-20-56	......	......
	22bb2	NW-NW	D	Pgw	64	34.0	....	......	......
*	23dab	NW-NE-SE	D	Pgw	600	......	....	......	......
	29ab1	NW-NE	D	Pgw	150	......	....	......	......
	29ab2	NW-NE	D	Pgw	95	53.0	....	......	......
	29bc	SW-NW	D	Pgw	110	......	....	......	......
	33bb	NW-NW	S	Pgw	55	34.8	11-26-56	......	......
	12N-2W								
	4ab	NW-NE	In	Pgw	95	......	....	......	......
	4ba	NE-NW	D	Pgw	102	65.0	....	......	......
	11ddd	SE-SE-SE	P	Pgw	350	90	....	......	......
	13bb	NW-NW	P	Pgw	150	60	....	......	......
†	22cd	SE-SW	P	Pgw	220	......	....	......	......
*	33dcc	SW-SW-SE	P	Pgw	751	......	....	......	......
*	34bbc	SW-NW-NW	P	Pgw	752	......	....	......	......
*	34bd	SE-NW	P	Pgw	774	......	....	......	......
	34cbb	NW-NW-SW	P	Pgw	....	......	....	......	......
*	34ccc	SW-SW-SW	P	Pgw	758	......	....	1,230	......
	34caa	NE-NE-SW	P	Pgw	....	......	....	......	......
	34ddd	SE-SE-SE	P	Pgw	....	......	....	......	......
	12N-3W								
*	1ad1	SE-NE	In	Pgw	750	......	....	......	......
*	1ad2	SE-NE	In	Pgw	748	......	....	......	......
	2aab	NW-NE-NE	P	Pgw	760	124.5	1- 7-63	......	......
	2abb	NW-NW-NE	N	Pgw	92	73.3	9-28-62	......	......
†	2abd	SE-NW-NE	P	Pgw	745	167.9	1- 7-63	......	......
*	4aa	NE-NE	In	Pgw	798	140.0	7-30-52	......	......
†	5ab1	NW-NE	P	Pgw	811	......	....	......	......
†	5ab2	NW-NE	P	Pgw	816	......	....	......	......
*	5ddd	SE-SE-SE	P	Pgw	764	......	....	1,149	......
†	5dd	SE-SE	P	Pgw	815	......	....	......	......
†	6ad	SE-NE	P	Pgw	825	......	....	......	......
*	8ca	NE-SW	In	Pgw	808	......	....	......	......
*	8cb	NW-SE	In	Pgw	801	......	....	......	......
*	8dc	SW-SE	In	Pgw	840	......	....	......	......
*	9bb	NW-NW	P	Pgw	803	205.0	- -36	......	......
*	9ddd	SE-SE-SE	N	Pgw	811	......	....	......	......
*	9ddc	SW-SE-SE	P	Pgw	738	195.0	4- -55	1,143	......
*	12bcd	SE-SW-NW	P	Pgw	797	130.0	2- -55	1,135	......
*	12bd	SE-NW	N	Pgw	795	......	....	......	......
*	13bbb1	NW-NW-NW	P	Pgw	778	138.0	2- 8-55	1,156	......
*	13bbb2	NW-NW-NW	N	Pgw	803	......	....	......	......
*	13bcc	SW-SW-NW	P	Pgw	790	100.0	6-17-55	1,132	......
*	13cbb	NW-NW-SW	N	Pgw	805	......	....	......	......
*	13ccc1	SW-SW-SW	N	Pgw	721	......	....	......	......
*	13ccc2	SW-SW-SW	P	Pgw	760	180.0	6-17-55	1,135	......
*	15ac	SW-NE	In	Pgw	480	......	....	......	......
	15ad1	SE-NE	In	Pgw	800	......	....	......	......
	15ad2	SE-NE	In	Pgw	800	......	....	......	......
†	15ca	NE-SW	In	Pgw	800	......	....	......	......
	15da	NE-SE	N	Pgw	817	......	....	......	......
*	15db	NW-SE	In	Pgw	153	......	....	......	......

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	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
	12N-3W (cont.)								
†	15ddb	NW-SE-SE	In	Pgw	800	......	....	......	......
	15dd	SE-SE	N	Pgw	817	275.0	5-18-36	......	......
*	16ccd1	SE-SW-SW	N	Pgw	803	......	....	......	......
*	16ccd2	SE-SW-SW	P	Pgw	754	160.0	3- -56	1,165	......
*	17abc	SW-NW-NE	P	Pgw	785	175.0	3- -55	1,171	......
*	17ab	NW-NE	N	Pgw	773	......	....	1,160	......
	18dca	NE-SW-SE	P, In	Pgw	925	......	....	......	......
	22adc1	SW-SE-NE	In	Pgw	540	......	....	1,197	......
	22adc2	SW-SE-NE	In	Pgw	630	......	....	1,204	......
*	22adb	NW-SE-NE	In	Pgw	790	......	....	......	......
*	22da	NE-SE	In	Pgw	795	192.5	11-17-42	......	......
*	22dc	SW-SE	In	Pgw	812	......	....	......	......
	23ac	SW-NE	In	Pgw	817	......	....	......	......
*	23cb	NW-SW	In	Pgw	830	......	....	......	......
	23bd	SE-NW	In	Pgw	749	......	....	......	......
	23cc	SW-SW	In	Pgw	817	......	....	......	......
*	23db	NW-SE	N	Pgw	791	177.5	2-18-43	1,190	......
	24cca	NE-SW-SW	D	....	168	120.0	3- -50	......	......
*	24db1	NW-SE	In	Pgw	827	275.0	4-22-36	......	......
*	24db2	NW-SE	In	Pgw	825	290.0	5- 7-36	......	......
	25cca	SE-SW-SW	D	Pgw	100	......	....	......	......
	25cc	SW-SW	D	Pgw	200	60.0	....	......	......
	26abb	NW-NW-NE	In	Pgw	660	176.1	6-23-43	......	......
*	26ba	NE-NW	In	Pgw	760	......	....	......	......
	26bdb	NW-SE-NW	N	Pgw	827	193.5	6-21-43	......	......
	26bcd	SE-SW-NW	In	Pgw	....	......	....	1,244	......
†	26bc	SW-NW	In	Pgw	638	......	....	......	......
*	27ab1	NW-NE	In	Pgw	827	......	....	......	......
*	27ab2	NW-NE	In	Pgw	825	......	....	......	......
*	27bad	SE-NE-NW	P	Pgw	720	......	....	......	......
	27bb1	NW-NW	In	Pgw	804	......	....	......	......
	27bb2	NW-NW	P	Pgw	810	425	....	......	......
*	27dac1	SW-NE-SE	P	Pgw	816	......	....	......	......
	27da2	NE-SE	P	Pgw	800	......	....	......	......
*	27da3	NE-SE	P	Pgw	816	......	....	......	......
*	27dd	SE-SE	P	Pgw	795	280.0	7- -37	......	......
†	32acd	SE-SW-NE	In	Pgw	822	......	....	......	......
†	32ad	SE-NE	In	Pgw	870	400.0	....	......	......
*	32dcd	SE-SW-SE	In	Pgw	780	210.0	4- -55	1,191	......
†	32dd	SE-SE	In	Pgw	817	......	....	......	......
*	33add1	SE-SE-NE	In	Pgw	754	413.0	6- -42	......	......
	33add2	SE-SE-NE	....	Pgw	400	......	....	......	......
	33cb	NW-SW	In	Pgw	810	......	....	......	......
*	33dcd	SE-SW-SE	D, In	Pgw	682	......	....	......	......
*	33daa1	NE-NE-SE	In	Pgw	675	192.0	1- -43	......	......
*	33daa2	NE-NE-SE	In	Pgw	701	350.0	11-24-34	......	......
*	33daa3	NE-NE-SE	In	Pgw	640	......	....	......	......
†	33dac	SW-NE-SE	D, In	Pgw	841	250.0	....	......	......
	33dad1	SE-NE-SE	D, In	Pgw	800	480.0	....	......	......
	33dad2	SE-NE-SE	....	Pgw	500	......	....	......	......
*	33da	NE-SW	....	Pgw	565	200.0	- -41	......	......
	33dda	NE-SE-SE	D, In	Pgw	817	400.0	....	......	......
	34bbb	NW-NW-NW	In	Pgw	400	......	....	......	......
*	34cac	SW-NE-SW	In	Pgw	781	430.0	5- -43	......	......
	36cc1	SW-SW	....	Pgw	812	231	6-28-43	......	......
†	36cc2	SW-SW	In	Pgw	212	......	....	......	......
	12N-4W								
	1bdd	SE-SE-NW	D	Ph	53	14.9	6- 9-50	......	......
	2ad	SE-NE	N	Ph	....	25.5	6- 9-50	1,235	......
	2cdc	SW-SE-SW	S	Ph	125	35.0	6- 9-50	1,270	......
	2ddd	SE-SE-SE	N	Ph	300	198.5	6- 9-50	1,268	......
	3dad	SE-NE-SE	D	Ph	65	20.3	6- 9-50	......	......
	3ddd1	SE-SE-SE	D	Ph	36	12.0	....	......	......
	3ddd2	SE-SE-SE	S	Ph	90	15	....	......	......
	4cac	SW-NE-SW	D	Ph	63	18.4	6- 3-50	......	......

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Well number	Location in section	Use[1]	Geologic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
12N-4W (cont.)								
4da	NE-SE	D	Ph	108	20.6	6- 3-50	......	......
4dbd	SE-NW-SE	D	Ph	70	20.3	6- 3-50	......	......
9ddc1	SW-SE-SE	P, In	Pgw	606	300	....	......	......
* 9ddc2	SW-SE-SE	P, In	Pgw	611	287.0	9- -37	......	......
10cbd	SE-NW-SW	P	Pgw	......	......	....	......	......
10cba	NE-NW-SW	P, In	Pgw	608	300.0	....	......	......
* 11dc	SW-SE	N	Pgw	809	......	....	......	......
* 11dca	NE-SW-SE	P	Pgw	770	32.5	4- -55	1,308	......
13cb	NW-SW	In	Pgw	600	......	....	......	......
* 13ccd	SE-SW-SW	P	Pgw	729	235.0	3- -56	1,218	......
13da	NE-SE	In	Pgw	565	......	....	......	......
14b	NW	In	Pgw	668	300.0	....	......	......
† 14cab	NW-NE-SW	In	Pgw	775	300.0	....	......	......
* 14cad1	SE-NE-SW	P	Pgw	660	340.0	5- -47	......	......
* 14cad2	SE-NE-SW	In	Pgw	577	......	....	......	......
14cda	NE-SE-SW	P	Pgw	....	......	....	......	......
*† 15b	NW	In	Pgw	608	......	....	......	......
* 24bb	NW-NW	N	Pgw	802	......	....	......	......
* 24bcc1	SW-SW-NW	P	Pgw	764	240.0	5- -55	1,202	......
* 24bcc2	SW-SW-NW	N	Pgw	802	......	....	......	......
* 24dda1	NE-SE-SE	P	Pgw	791	230.9	4- -55	1,224	......
* 24dda2	NE-SE-SE	N	Pgw	781	......	....	......	......
* 25ddb1	NW-SE-SE	P	Pgw	675	250.0	3- -55	1,240	......
* 25ddb2	NW-SE-SE	N	Pgw	777	......	....	......	......
13N-1E								
1bb	NW-NW	D, S	Pgw	....	16.5	11-15-56	......	......
4aa	NE-NE	N	Pgw	80	47.3	11-15-56	......	......
7cc	SW-SW	N	Pgw	27	17.4	11-16-56	......	......
10cd	SE-SW	D, S	Pgw	80	12	....	......	......
26ac	SW-NE	N	Pgw	46	17.0	11-16-56	......	......
† 27ccb	NW-SW-SW	D	Pgw	140	......	....	......	......
28dd	SE-SE	N	Pgw	77	74.7	11-16-56	......	......
30bc	SW-NW	N	Pgw	40	39.4	11-16-56	......	......
13N-1W								
8aa	NE-NE	D, S	Pgw	72	54.4	11- 7-56	......	......
8ad	SE-NE	D, S	Pgw	90	50	....	......	......
12cb	NW-SW	D	Pgw	40	25.6	11-15-56	......	......
22dc	SW-SE	D, S	Pgw	....	20.6	11- 9-56	......	......
† 33bd	SE-NW	D	Pgw	76	......	....	......	......
34aab	NW-NE-NE	P	Pgw	257	......	....	......	......
† 34abb	NW-NW-NE	P	Pgw	240	......	....	......	......
13N-2W								
6ab	NW-NE	D, S	Pgw	25	16.9	11- 2-56	......	......
6bb	NW-NW	D	Pgw	115	65.0	....	......	......
8ad	SE-NE	D	Pgw	72	50.0	....	......	......
14dd	SE-SE	D	Pgw	107	73.1	11- 9-56	......	......
19cb1	NW-SW	S	Pgw	42	26.9	11- 7-56	......	......
19cb2	NW-SW	D, S	Pgw	106	31	11- 7-56	......	......
† 20ba	NE-NW	D, S	Pgw	100	......	....	......	......
23aa	NE-NE	D	Pgw	72	67	11- 7-56	......	......
26dd	SE-SE	N	Pgw	53	52.1	11- 9-56	......	......
13N-3W								
1aa	NE-NE	D	Pgw	100	......	....	......	......
5dd	SE-SE	D	Pgw	105	......	....	......	......
15aa	NE-NE	N	Pgw	105	97.6	11- 1-56	......	......
17dc	SW-SE	D, S	Pgw	162	60.0	....	......	......
† 20ccc	SW-SW-SW	In	Pgw	650	125.0	....	......	......
20dc	SW-SE	N	Pgw	650	125.0	....	......	......
22aa	NE-NE	S	Pgw	128	63	11- 1-56	......	......
28bbc	SW-NW-NW	P	Pgw	789	......	....	......	......
28cac	SW-NE-SW	P	Pgw	796	280	5- 6-55	......	......
28bda	NE-SE-NW	P	Pgw	801	184.0	4- 2-48	......	......
29bbd	SE-NW-NW	N	Pgw	750	151.2	2-15-43	......	......

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Well number	Location in section	Use[1]	Geologic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
13N-3W (cont.)								
† 29dca	NE-SW-SE	P	Pgw	751	223.0	9- -43	......	......
29ddd1	SE-SE-SE	P	Pgw	790	230.0	9- -55	......	......
† 29ddd2	SE-SE-SE	P	Pgw	803	......	....	......	......
30c	SW	In	Pgw	702	200.0	7-25-38	......	......
30ccc	SW-SW-SW	N	Pgw	133	12.0	6- 5-50	......	......
31a	NE	P	Pgw	800	284.0	11- -49	......	......
* 31bba	NE-NW-NW	In	Pgw	568	120.0	6- -44	......	......
31ccc1	SW-SW-SW	P	Pgw	796	275.0	5- -50	......	......
† 31ccc2	SW-SW-SW	P	Pgw	800	......	....	......	......
* 31dbd	SE-NW-SE	In	Pgw	570	175.0	....	......	......
* 31dcb1	NW-SW-SE	In	Pgw	530	......	....	......	......
* 31dcb2	NW-SW-SE	In	Pgw	530	......	....	......	......
32aad	SE-NE-NE	P	Pgw	....	......	....	......	......
* 32a	NE	D	Pgw	163	......	....	......	......
* 32b	NW	D	Pgw	852	175	- -30	......	......
† 34ba	NE-NW	In	Pgw	787	300.0	....	......	......
35dbb	NW-NW-SE	D	Pgw	102	75.2	9-28-62	......	......
35dcc	SW-SW-SE	P	Pgw	750	178.8	11-12-62	......	......
35dcb	NW-SW-SE	....	Pgw	58	35.8	9-28-62	......	......
35dcd	SE-SW-SE	....	Pgw	68	67.9	10- 8-62	......	......
35dbc	SW-NW-SE	....	Pgw	102	75.2	9-28-62	......	......
36ccc	SW-SW-SW	N	Pgw	122	58.5	9-26-62	......	......
13N-4W								
1ad	SE-NE	D	Ph	125	24.0	10-26-56	......	......
1db	NW-SE	D	....	175	85.0	10-26-56	......	......
2dc	SW-SE	S	Ph	141	69.3	10-26-56	......	......
4cb	NW-SW	S	Ph	38	29.6	10-26-56	......	......
4c	SW	N	Pgw	750	......	....	......	......
6bc	SW-NW	D	Ph	73	47.4	10-26-56	......	......
6dd	SE-SE	D	Ph	90	26.1	10-26-56	......	......
10bbb	NW-NW-NW	D	Ph	68	......	....	......	......
11dd	SE-SE	D	Pgw	765	......	....	......	......
* 11ddd	SE-SE-SE	....	Pgw	595	......	....	......	......
*† 12dd	SE-SE	D, S	Pgw	540	......	....	......	......
12c	SW	D	Pgw	224	75	- -54	......	......
13aa	NE-NE	D, S	Pgw	500	......	....	......	......
13dd	SE-SE	D, S	Pgw	200	165	....	......	......
16dc	SW-SE	D, S	Pgw	200	147.1	10-30-50	......	......
17bb	NW-NW	N	Ph	53	45.3	10-26-56	......	......
18aa	NE-NE	N	Ph	65	......	....	......	......
20ad	SE-NE	D	Ph	50	20.9	....	......	......
* 22cc	SW-SW	D, In	Pgw	465	180	....	......	......
24bcb	NW-SW-NW	S	Ph	180	25.0	....	......	......
24cc	SW-SW	P	Ph	129	15.9	6- 5-50	......	......
28add	SE-SE-NE	N	Ph	42	12.0	....	......	......
28dbc	SW-NW-SE	D	Pgw	630	170.3	6- 5-50	......	......
33aa	NE-NE	N	Pgw	200	191.6	6- 5-50	......	......
33da	NE-SE	D	Ph	85	27.5	6- 3-50	......	......
34ccb	SW-SW-NW	S	Ph	44	19.7	6- 3-50	......	......
34cdc	SW-SE-SW	D	Ph	40	17.6	6- 3-50	......	......
14N-1E								
9ba	NE-NW	D, S	Pgw	77	45.0	....	......	......
11ba	NE-NW	N	Pgw	85	81.5	11-14-56	......	......
23aa	NE-NE	S	Pgw	31	23.9	11-14-56	......	......
27bdc	SW-SE-NW	P	Pgw	178	90	....	......	......
27ca	NE-SW	P	Pgw	168	90	....	......	......
† 28ad	SE-NE	D, In	Pgw	172	30.0	....	......	......
14N-1W								
3bac	SW-NE-NW	D	Pgw	290	......	....	......	......
6da	NE-SE	N	Pgw	300	48.6	11-14-56	......	......
16bb1	NW-NW	D	Pgw	40	24.5	....	......	......
16bb2	NW-NW	D, S	Pgw	83	25.0	11-13-56	......	......
20cb	NW-SW	....	Pgw	43	31.3	11-13-56	......	......
25bb	NW-NW	D, S	Pgw	73	30.0	....	......	......
25cc	SW-SW	D, In	Pgw	....	48.4	11-14-56	......	......

	Well number	Location in section	Use[1]	Geo-logic unit[2]	Depth of well (feet)	Water level: Depth below land surface (feet)	Water level: Date	Altitude above mean sea level (feet): Land Surface	Altitude above mean sea level (feet): Water level
	14N-2W								
	3bc	SW-NW	D	Pgw	105	30.0	....	......	......
	6cc	SW-SW	D, S	Pgw	80	80.0	....	......	......
	9ab	NW-NE	D, S	Pgw	40	37.0	....	......	......
	9bb	NW-NW	S	Pgw	48	34.0	4-22-54	......	......
†	9cc	SW-SW	D	Pgw	90	......	....	......	......
	13cc	SW-SW	D, S	Pgw	....	......	....	......	......
†	17cb	NW-SW	In	Pgw	160	......	....	......	......
*†	17cd	SE-SW	In	Pgw	635	85.0	....	......	......
	20dd	SE-SE	N	Pgw	46	41.3	11- 2-56	......	......
	22cc	SW-SW	D, S	Pgw	142	20.0	....	......	......
	24cc	SW-SW	N	Pgw	....	20.8	11-13-56	......	......
	30ab1	NW-NE	D, S	Pgw	....	30.0	11- 1-56	......	......
	30ab2	NW-NE	D	Pgw	150	......	....	......	......
	14N-3W								
	1dd	SE-SE	N	Pgw	80	44.5	11- 1-56	......	......
	7dc	SW-SE	D	Pgw	120	85.0	....	......	......
	14bb	NW-NW	D	Pgw	47	35.2	11- 1-56	......	......
	15aa	NE-NE	D	Pgw	39	30.5	11- 1-56	......	......
*	25dba	NE-NW-SE	P	Pgw	724	......	....	......	......
*	26c	SW	P	Pgw	743	......	....	......	......
*†	26dac	SW-NE-SE	P	Pgw	457	175	- -39	......	......
*	26ddc	SW-SE-SE	P	Pgw	400	175	- -39	......	......
	28bb	NW-NW	N	....	77	9.4	6-11-58	......	......
	29aa	NE-NE	D, S	Pgw	100	......	....	......	......
	30cc1	SW-SW	D, In	Pgw	600	150.0	....	......	......
	30cc2	SW-SW	D, S	Pgw	600	150.0	....	......	......
*	30dd	SE-SE	In	Pgw	700	......	....	......	......
	31ac	SW-NE	D, In	Pgw	800	175.0	....	......	......
†	31bb	NW-NW	D, In	Pgw	600	150.0	11-29-56	......	......
*†	35aab	NW-NE-NE	P	Pgw	751	......	....	......	......
*	35aac	SW-NE-NE	P	Pgw	738	288.0	2-23-50	......	......
	35aad	SE-NE-NE	P	Pgw	453	100	1- -52	......	......
†	35aba	NE-NW-NE	P	Pgw	750	175	- -39	......	......
*	35abc	SW-NW-NE	P	Pgw	465	120.0	....	......	......
*	35acd	SE-SW-NE	P	Pgw	461	120	8- -54	......	......
	35dcd	SE-SW-SE	P	Pgw	741	......	....	......	......
	14N-4W								
	6cdc	SW-SE-SW	S	Ph	62	......	....	1,140	......
	9dd	SE-SE	D, S	Pgw	200	......	....	......	......
	10cb	NW-SW	S	Ph	....	20.8	11-29-56	......	......
	12dd	SE-SE	N	Ph	....	55.8	11-29-50	......	......
	14dd	SE-SE	S	Ph	54	23.9	11-28-59	......	......
	25dd	SE-SE	D, S	Pgw	600	147.0	....	......	......
	26ba	NE-NW	S	Ph	63	23.2	11-29-56	......	......
	34ccd	SE-SW-SW	D	Pgw	500	112.1	7-25-45	......	......

Footnotes are on page 60.

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APPENDIX

Emergency Supplies for Civil Defense

Basic considerations in a well-integrated civil defense program are to make adequate provisions for safeguarding water supplies against contamination and destruction and to plan for emergency water supplies in the event that normal service is interrupted.

If a nuclear explosion were to occur in the area, a wide variety of problems involving water would arise. Among the more serious of these problems are direct radioactive contamination of water sources, destruction of water plants and distribution systems, and interruption of water service through breakage of water and sewer mains. If one or more of these problems occurred, it would be necessary to provide water for an undetermined period of time from emergency sources that had not been seriously contaminated by radioactive fallout.

Surface-water sources are exposed to the atmosphere at all times and are subject to immediate contamination from radioactive fallout. Surface sources in which the water is held in quiet storage, such as in reservoirs or ponds, might be rendered useless for some time. Ground water, however, would be least likely to be contaminated immediately because it is not in direct contact with the atmosphere and the materials overlying the water-bearing zone would remove much of the fallout material by filtration and adsorption. Deep wells tapping the water-bearing zone in the Garber Sandstone and Wellington Formation would be least subject to contamination. Records of many of these wells are given in table 9, and their locations are shown on plate I. Most wells given in table 9 are equipped with deep-well turbine pumps driven by electric motors which would be inoperative in the event of a power failure. For this reason wells selected for emergency-water supplies should be equipped with auxiliary gasoline engines or other standby power facilities. An alternate possibility is to obtain belt-drive or right-angle gear-drive pump heads which would permit operation of the deep-well turbine by means of a tractor power take-off, or direct-drive engines.

In addition to the deep wells already in existence, small to moderate supplies of ground water might be developed quickly by means of shallow wells dug or drilled in the alluvium-filled valleys of streams draining the area. Water could be obtained from shallow wells by means of hand-operated or power-operated lift pumps. Water from shallow wells near stream channels used as sluiceways for industrial or sanitary wastes should be tested to determine whether or not it is chemically and bacteriologically acceptable for domestic use.

Large quantities of water required for fire fighting and the washing down of streets, buildings, and other contaminated areas could be obtained quickly by dredging large pits a few feet below the water table in the alluvium underlying the flood plains of the Canadian and North Canadian Rivers.