UNITED STATES
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Geological Survey

A PRELIMINARY APPRAISAL OF THE GARBER-WELLINGTON AQUIFER SOUTHERN LOGAN AND NORTHERN OKLAHOMA COUNTIES OKLAHOMA

By Jerry E. Carr and Melvin V. Marcher

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PAGE III FOLLOWS

CONTENTS

ILLUSTRATIONS

TABLES

ENGLISH-METRIC EQUIVALENTS

English units used in this report may be converted to metric units by the following conversion factors:

English	Multiply by	Metric
in. (inches)	25.40	mm (millimeters)
ft (feet)	.3048	m (meters)
mi (miles)	1.609	km (kilometers)
ft/mi (feet per mile)	.1894	m/km (meters per kilometer)
mi^2 (square miles)	2.590	km^2 (square kilometers)
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometers)
ft^3/s (cubic feet per second)	.02832	m^3/s (cubic meters per second)
gal/min (gallons per minute)	.06309	L/s (liters per second)
gal/day (gallons per day)	3.785×10^{-3}	m^3/day (cubic meters per day)
(gal/min)/ft (gallons per minute per foot)	.207	(L/s)/m (liters per second per meter)
acre-ft/mi^2 (acre-feet per square mile)	4.76	m^3/hm^2 (cubic meters per square hectometer)

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ABSTRACT

The Garber-Wellington aquifer, which dips westward at 30 to 40 feet per mile, consists of about 900 feet of interbedded sandstone, shale, and siltstone. Sandstone comprises 35 to 75 percent of the aquifer and averages about 50 percent. Water-table conditions generally exist in the upper 200 feet in the outcrop area of the aquifer; semi-artesian or artesian conditions exist below a depth of 200 feet and beneath rocks of the Hennessey Group (predominantly shale) where the aquifer is fully saturated. Water containing more than 1,000 milligrams per liter dissolved solids occurs at various depths through the area. The altitude of the base of fresh water ranges from 250 feet above sea level in the south-central part of the area to 950 feet in the northwestern part. The thickness of the fresh-water zone ranges from less than 150 feet in the northern part of the area to about 850 feet in the southern part. The total amount of water stored in the fresh-water zone is estimated to be 21 million acre-feet based on specific yield of 0.20.

Minimum recharge to the aquifer in 1975 is estimated to be 190 acre-feet per square mile or about 10 percent of the annual precipitation. Total minimum recharge to the aquifer in the study area in 1975 is estimated to be 129,000 acre-feet. Streams in the area are the principal means of ground-water discharge; the amount of discharge is essentially the same as recharge. The amount of ground water used for municipal and rural water supply in 1975 is estimated to have been 5,000 acre-feet; a similar amount may have been used for industrial purposes. As a result of pumping, the potentiometric surface in 1975 had been lowered about 200 feet in the vicinity of Edmond and about 100 feet in the vicinity of Nichols Hills.

Chemical analyses of water from the aquifer indicates that hardness is greater in the upper part of the aquifer than in the lower part, and that sulfate, chloride, and dissolved solids increase with depth.

Reported yields of wells more than 250 feet deep range from 70 to 475 gallons per minute and average 240 gallons per minute. Potential well yields range from 225 gallons per minute where the fresh-water zone is 350 feet thick to about 550 gallons per minute where the fresh water zone is 850 feet thick. These estimates of potential yield are based on an available drawdown of half the thickness of the fresh-water zone and a specific capacity of 1.3 gallons per minute per foot.

Intrusion of saline water into the fresh-water zone is a potential threat to water quality in the aquifer if the pressure head in the fresh-water zone is reduced sufficiently to allow upconing of saline water. One way to avoid the problem of upconing is by steady pumping at low rates from widely spaced wells; however, information required to determine pumping rates and well spacing is not available.

For proper aquifer management the distribution of wells and rates of withdrawals should be designed to capture maximum recharge to the ground-water system. This may be accomplished by developing regional ground-water gradients that are sufficiently large to move water to pumpage centers but not so steep as to cause upconing of saline water or excessive water-level declines.

INTRODUCTION

Purpose and Scope

Construction of a reservoir on Cottonwood Creek in southwestern Logan County, Oklahoma (fig. 1) has been proposed by the U.S. Bureau of Reclamation to provide for water supply, flood control, and recreation. The area in and adjacent to Cottonwood Creek basin is underlain by the Garber-Wellington aquifer, which is the principal source of ground water for municipal, industrial, and domestic use in central Oklahoma. A possible alternative in meeting the long-term water-supply needs of southern Logan and northern Oklahoma Counties is conjunctive use of water from the reservoir and from the Garber-Wellington aquifer. However, assessment of the long-term availability of large amounts of water from the Garber-Wellington aquifer would require an in-depth hydrologic study. Accordingly, the Bureau of Reclamation requested that the U.S. Geological Survey make a preliminary appraisal to determine whether the aquifer has sufficient potential to warrant such an in-depth study; the results of that appraisal are presented in this report.

Data used in preparing this report were obtained in the field and from published and unpublished records of the Geological Survey, State agencies, and municipalities. Field data collected include well-construction records and ground-water-level measurements. Water samples were collected for chemical analysis; additional data on chemical quality were obtained by field determinations of specific conductance of selected water samples. Geophysical logs were used to define the geologic framework of the aquifer and, in part, to determine the base of fresh water. Base-flow measurements made on Wildhorse Creek were used to estimate recharge to the aquifer.

Acknowledgments

The cooperation and assistance of State agencies, city officials, well drillers, and officials of industries and institutions are gratefully acknowledged. Acknowledgment is also extended to the owners of private wells who allowed their wells to be measured and permitted collection of water samples.

Particular acknowledgment is due Messrs. John H. Marsh and John S. Fryberger, Engineering Enterprises Consulting Engineers and Hydrogeologists, who provided specific-capacity data from wells at Norman, Oklahoma, that were used to prepare figure 11.

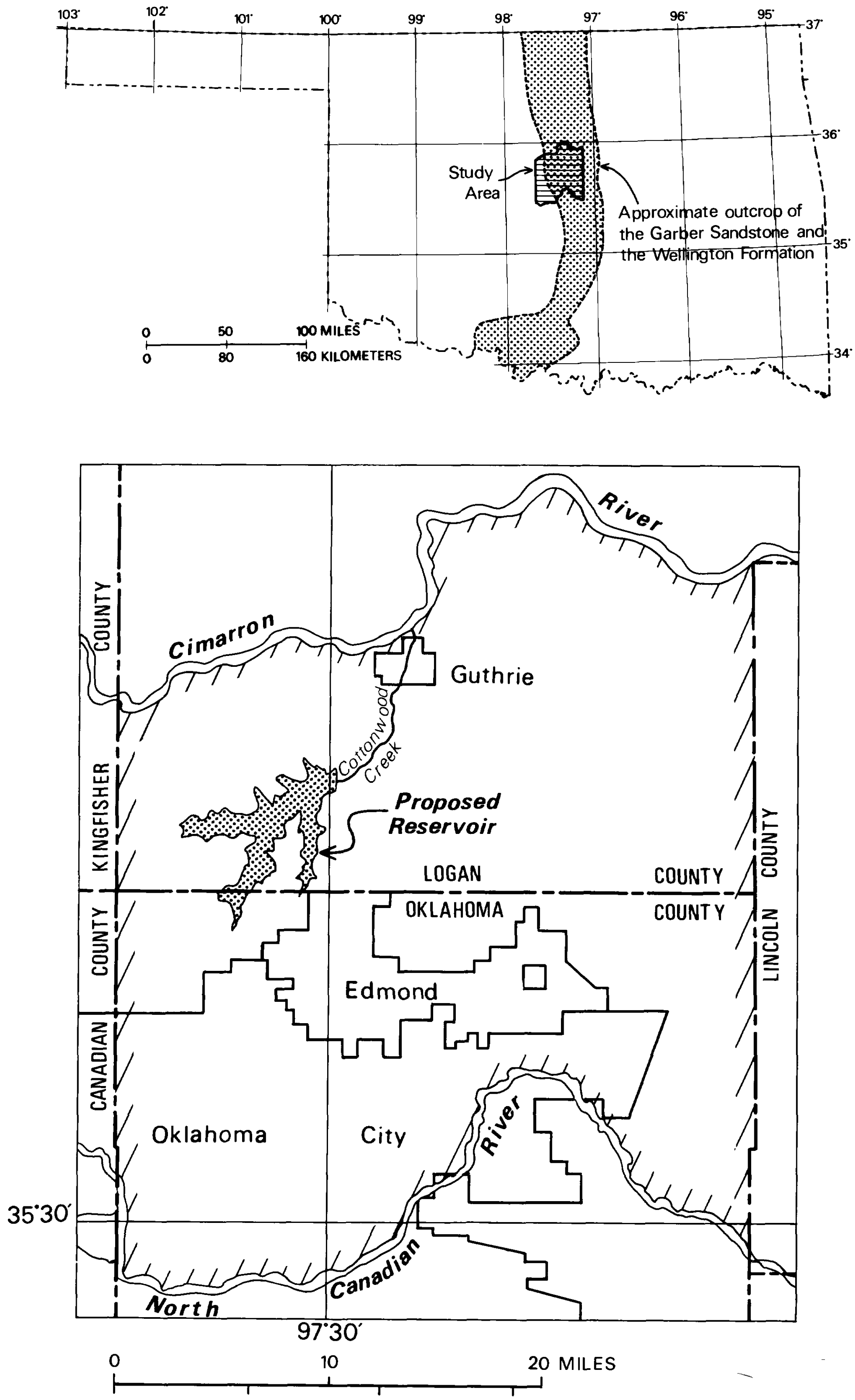

Figure 1.--Location of the study area and approximate outcrop of the Garber Sandstone and the Wellington Formation.

Well-Numbering System

The standard method of giving the location of a well site by fractional section, section, township, and range is replaced by the method illustrated in the diagram below (fig. 2). The location of the well indicated by the dot normally would be described as SW 1/4 NW 1/4 NW 1/4 sec. 6, T. 14 N., R. 2 W. By the method used in this report quarter subdivisions of the section are indicated by letters and the location of the well is given as 14N-02W-06BBC 1.

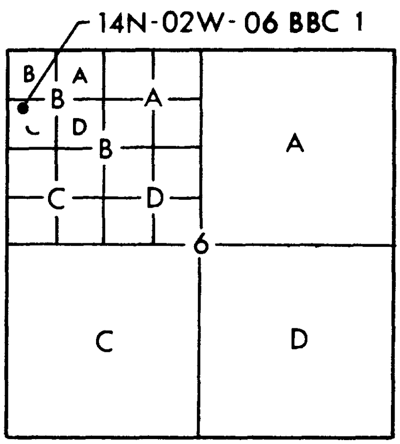

Figure 2.--Well-numbering system.

GENERAL SETTING

Southern Logan and northern Oklahoma Counties, hereinafter generally referred to as the study area, include about 895 mi^2. The study area is bounded on the north by the Cimarron River and on the south by the North Canadian River.

Geologic units that crop out in the study area are described in table 1. The table, which is based on recently published work by R.O. Fay (Bingham and Moore, 1975), Oklahoma Geological Survey, indicates that the Hennessey Group (formerly Hennessey Shale) consists of four formations; in ascending order, they are Fairmont Shale, Kingman Siltstone, Salt Plains Formation, and Bison Formation. However, for purposes of this report, they are shown as a single unit on the geologic map (fig. 3) and are collectively referred to as the Hennessey Group.

These bedrock formations, which have a regional westward dip of 30 to 40 ft/mi, are overlain by alluvium along the streams and are veneered with terrace deposits in the southwestern part of the area.

The eastern three-fourths of the study area, which is underlain by the Garber Sandstone and Wellington Formation, is characterized by low forested hills formed by differential erosion of interbedded sandstone and shale. The western fourth of the area, which is underlain by the Hennessey Group, is gently rolling, grass-covered prairie.

Climate in the study area is moist subhumid. Normal annual precipitation (1931-60) ranges from 30 in. in the western part to 33 in. in the eastern part. May is normally the wettest month and January the driest. Average annual runoff (1931-60) ranges from about 3 in. in the west to 3.5 in. in the east. Water discharged from the Garber Sandstone and Wellington Formation provides perennial flow in most streams in the eastern part of the area, whereas streams draining the Hennessey Group flow only during and after precipitation.

Table 1.--Geologic units exposed in southern Logan and northern Oklahoma Counties, Oklahoma.

System	Series	Group	Unit	Maximum Thickness (ft)	Lithology
Quaternary	Holocene		Alluvium	50	Sand, silt, clay and thin layers of gravel.
Quaternary	Pleistocene		Terrace deposits	50	Lenticular beds of sand, silt, clay and gravel.
Permian	Lower Permian	Hennessey Group	Bison Formation	95	Mostly reddish-brown shale.
Permian	Lower Permian	Hennessey Group	Salt Plains Formation	200	Reddish-brown blocky shale and orange-brown siltstone.
Permian	Lower Permian	Hennessey Group	Kingman Siltstone	30	Orange-brown to greenish-gray even-bedded siltstone, and some fine-grained sandstone and reddish-brown shale.
Permian	Lower Permian	Hennessey Group	Fairmont Shale	30	Reddish-brown blocky shale; grades into Garber Sandstone at base.
Permian	Lower Permian		Garber Sandstone	400	Mostly orange-brown to reddish brown fine-grained sandstone irregularly bedded with red-brown shale and some chert and mudstone conglomerate.
Permian	Lower Permian		Wellington Formation	500	Reddish-brown shale and orange-brown fine-grained sandstone

GROUND-WATER SYSTEM

Definition of the Garber-Wellington Aquifer

The study area is everywhere underlain by the Garber Sandstone and Wellington Formation, which have a combined maximum thickness of about 900 ft. Although the two units can be mapped separately on the surface, they are virtually indistinguishable in the subsurface owing to similar lithology and lack of key beds or index fossils. Furthermore, the two units have similar hydrologic properties and are hydrologically interconnected. For these reasons, the water-bearing unit comprising all or parts of the Garber Sandstone and Wellington Formation in the study area is considered to be a single aquifer (Wood and Burton, 1968, p. 18), and is referred to as the Garber-Wellington aquifer.

Geologic Framework

The geologic framework of the Garber-Wellington aquifer largely controls the occurrence and movement of ground water. Principal components of the geological framework are (1) geologic structure, including regional and local dip and faulting, (2) lateral and vertical distribution of sandstone and shale units, and (3) characteristics of the rock units, particularly permeability of the sandstone beds.

The regional westward dip of bedrock units is interrupted by local flexures that reflect deeply buried structures as described by Travis (1930, p. 452-455). The principal flexure is an anticline in T.12 N., R.3 W. that underlies the Oklahoma City oilfield. A fault striking northwest along the east side of the anticline has been identified in the subsurface but apparently is not expressed at the surface. Adjacent to the anticline on the east, in the vicinity of Forest Park, is a structural trough (Wood and Burton, 1968, p. 30).

The lateral and vertical distribution of rock units and their physical characteristics are directly related to the depositional history of the rocks. Sediments that now comprise these rocks represent deltaic deposits laid down by streams flowing from the east into a broad basin that extended into western Oklahoma and Texas. The main part of the delta apparently was in the latitude of central Oklahoma County (Patterson, 1933, p. 255) where sandstone comprises about 75 percent of the aquifer. North and south of this part of the area, the proportion of sandstone to shale decreases and the deltaic deposits interfinger with and grade into marine-type rocks consisting mainly of shale. Although these north-south changes are not very pronounced within the limited area of this study, the change downdip is more apparent. From near central Oklahoma County, the sandstone grades into siltstone and shale toward the west, and these are the dominant rock units near the Canadian-Oklahoma County line.

Because of its origin as part of a delta system with shifting channels and changing currents, the Garber-Wellington aquifer is a complex of interfingering beds of sandstone, siltstone, and shale. The thickness of individual beds changes over short distances and beds may end abruptly, so that correlation for more than short distances is virtually impossible.

The maximum thickness of individual beds of sandstone is about 40 ft but beds 5 to 10 ft thick are more common. Based on data published by Patterson (1933, p. 250), sandstone comprises an estimated 65 percent of the aquifer in Logan County. Analysis of geophysical logs in both Logan and Oklahoma Counties shows that sandstone comprises 35 to 75 percent of the aquifer and averages about 50 percent.

Hydraulic properties of the sandstone beds are directly related to shape, size, and sorting of the sand grains. For example, the permeability of coarse, well-rounded and well-sorted sand is greater than that of fine, angular, poorly-sorted sand. Most of the sand grains are angular to subangular but locally as much as 10 percent may be subrounded. According to Jacobsen and Reed (1944, p. 17) none of the sand grains are larger than 0.014 in. and the average diameter is 0.006 in. which is a fine sand. Sorting coefficients range from 1.12 to 1.62 and average 1.26, indicating a well-sorted sediment. Grain-size analyses of sandstone samples from Logan County show that the maximum grain size is less than 0.010 in. (Patterson, 1933, p. 246), thus suggesting a decrease in grain size toward the north. Except for local beds, the sandstone throughout the area is poorly cemented and crumbles easily.

Shale beds in the Garber-Wellington aquifer are as thick as 50 ft locally but most beds are less than 5 ft. Individual beds thicken and thin abruptly and may disappear completely where they abut massive, channel-like sandstone layers. Most of the shale is blocky and nonlaminated and contains a high proportion of clay. In the upper part of the aquifer the shale becomes more silty and sandy.

Upper Confining Layer

The Hennessey Group, which overlies the Garber-Wellington aquifer in the western part of the area (fig. 3), consists of shale, siltstone, and thin beds of very fine grained sandstone. In general, the unit thickens to the west and south. The maximum thickness northwest of Cottonwood Creek is about 100 ft but increases to about 400 ft at the Canadian County-Oklahoma County line west of Lake Hefner.

Because of its low hydraulic conductivity, the Hennessey Group acts as a confining layer for the Garber-Wellington aquifer in localities where the aquifer is fully saturated. Limited ground-water-level data indicate that the confining effects begin about 4 mi west of and parallel to the Hennessey-Garber contact shown in figure 3.

Base of Fresh Water

Water in the Garber-Wellington aquifer becomes more mineralized with depth throughout the study area. The position of the base of fresh water, that is, water containing less than 1,000 mg/L (milligrams per liter) dissolved solids, is a significant factor controlling potential development of the aquifer because overpumping may induce upward movement of saline water containing more than 1,000 mg/L dissolved solids.

Delineation of the base of fresh water, shown in figure 4, was determined from about 175 geophysical logs of oil and gas wells, supplemented with chemical analyses of water samples from selected wells. The interface between fresh water and the underlying saline water probably is not as well defined as represented by the map but is gradational through a brackish zone that may range from a few feet to several tens of feet thick.

Although the zone of fresh water generally has concentrations less than 1,000 mg/L dissolved solids, local exceptions occur. These exceptions apparently are caused by local geologic or hydrologic conditions; because of the limited extent, they are not shown on the map.

The configuration of the base of fresh water reflects the geologic structure in some places. For example, the lowest altitude of the base of fresh water, 250 ft, coincides with the structural depression in the vicinity of Forest Park. Southwest of and adjacent to this low, the base of fresh water rises rather abruptly to an altitude of about 550 ft reflecting the structural high in the vicinity of the Oklahoma City oil field. The rise of the base of fresh water along the western edge of the study area may be caused by the change in rock type from predominantly sandstone on the east to predominantly shale on the west (Wood and Burton, 1968, p. 30).

The depth to the base of fresh water at a particular locality can be estimated by comparing the altitude of the land surface determined from topographic maps with the altitude of the base of fresh water. The approximate depths below land surface to the base of fresh water in the following vicinities are: Arcadia, 400 ft; Edmond, 725 ft; Forest Park, 900 ft; Guthrie, 250 ft; Lake Hefner, 850 ft; Langston, 250 ft; and Seward, 325 ft.

Occurrence of Ground Water

Vertical and lateral variations in hydraulic characteristics of the Garber-Wellington aquifer caused by variations in lithology result in ground water occurring under unconfined, semi-artesian, and artesian conditions. Unconfined conditions generally exist at depths of less than 200 ft where the aquifer is exposed at the surface. Artesian conditions exist below 200 ft and in most of the area where the aquifer is overlain by the Hennessey Group.

Vertical variations in the hydraulic characteristics of the aquifer present a particularly significant problem in defining the hydrologic system. In most of the area, potentiometric levels can be measured only in domestic-supply or stock wells that generally penetrate only a few of the upper sandstone beds. Water levels in these wells represent the upper part of the aquifer and, except for local anomalies, define a relatively uniform surface. Deep wells commonly are perforated opposite all significant sands below 250 ft; thus, measurements made in deep wells represent a composite of water levels that may differ markedly from those in the upper part of the aquifer, as diagrammatically illustrated in figure 5.

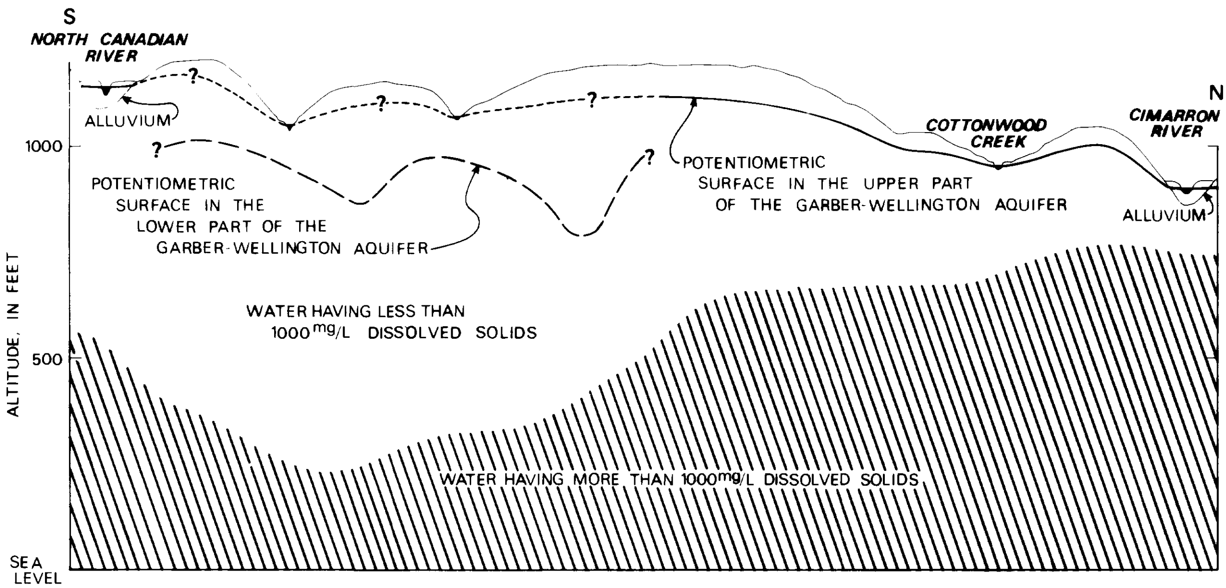

Figure 5.--Diagrammatic north-south section showing generalized potentiometric surfaces and approximate thickness of the zone of water having less than 1,000 mg/L dissolved solids in the Garber-Wellington aquifer.

Water-level data are meager where the aquifer is overlain by the Hennessey Group. However, the available data suggest that the upper part of the aquifer is not saturated in a belt about 4 mi west of and parallel to the Hennessey-Garber contact. Consequently, water in this belt is under water-table or semi-artesian conditions. West of this belt, the aquifer is fully saturated and the Hennessey serves as a confining layer so that artesian conditions prevail.

Movement of Ground Water

Water in the upper part of the aquifer has two components of movement. The principal component is essentially lateral from areas of recharge to points of discharge. As shown by the potentiometric map (fig. 6), water levels are highest in the upland area of south-central Logan County. From this area the water moves toward the stream valleys, where it discharges as springs or streamflow. This discharge maintains the flow of some streams during dry periods.

A secondary component of movement is vertical--either downward or upward depending on differences in head. Although the lower part of the aquifer is under artesian conditions, the head is lower than that in the upper part and, as a consequence, water can move downward. The rate of downward movement probably is very slow under natural conditions in most places because the upper and lower parts of the aquifer are interconnected by shale beds of low hydraulic conductivity. The poor degree of interconnection is demonstrated by an aquifer test at Nichols Hills where a 745-ft well was pumped for 3 days without noticeably affecting the water level in a nearby well in the upper part of the aquifer (Wood and Burton, 1968, p. 42).

Upward flow occurs in localities where major streams, such as the North Canadian River, are entrenched into the aquifer. For example, the water level in a Garber-Wellington well 95 ft deep in the NE 1/4, sec. 1, T. 12 N., R. 1 W., was 8 ft higher than that in a nearby test hole in the alluvium. This difference in head would cause the water to move upward into the alluvium.

Movement of water in the lower part of the aquifer is difficult to define because of the lack of water-level data in most of the area. The few available water-level measurements in deep wells in the Oklahoma City area indicate that the regional direction of movement is southwest in the same general direction as the regional structural dip. The locations of points or areas of discharge of water from lower parts of the aquifer are unknown.

Cones of depression caused by pumping are superimposed on the natural potentiometric surface (fig. 6). The deepest cones are in the Edmond and Nichols Hills areas. Delineation of these cones, however, is based on measurements made in operating wells that are believed to be inefficient because of their method of construction. If the wells are inefficient the position of the potentiometric surface inside the casing may be much lower than that in the aquifer outside the casing; consequently, the cones may not be as deep as shown on the map.

Fresh Water in Storage

The thickness of the fresh-water zone, shown in figure 7, was prepared by drawing lines connecting points of equal difference in elevation between the base of fresh water (fig. 4) and the potentiometric surface (fig. 6) determined from wells in the upper part of the aquifer. The lines of equal thickness are shown as approximate in the southwestern part of the area, because little information is available regarding the potentiometric surface in the upper part of the aquifer. Similarly, little information is available for localities in and near the Edmond and Nichols Hills well fields. However, comparison of figures 4 and 6 shows that the thickness of fresh water beneath the cone of depression is 350 to 400 ft in the Edmond area and 550 to 600 ft in the Nichols Hills area.

Figure 7 also shows that the thickness of the fresh-water zone ranges from less than 150 ft in the northern part of the area to about 850 ft near Forest Park. The thickest zone coincides with the low in the base of fresh water which, in turn, coincides with a low in the geologic structure.

The total volume of water available from storage in the fresh-water zone can be estimated by multiplying the area, one-half the thickness of the fresh-water zone, and the porosity of the sandstone. One-half the thickness of the fresh-water zone is used because the aquifer consists of about equal amounts of sandstone and shale as previously indicated (page 9). Even though the shale contains large amounts of water it is available only by very slow drainage over a long period of time.

Although porosity determines the amount of water the aquifer can hold, the amount of water that the rocks will yield is less because some of the water is retained in the pore spaces. Thus, a better estimate of water available from storage is based on specific yield rather than porosity. Specific yield is the ratio of the volume of water that a rock, after being saturated, will yield by gravity to the volume of rock. Little information is available on the specific yield of the Garber-Wellington aquifer; however, the aquifer is similar to the Upper Permian Rush Springs Sandstone which, as determined from 32 analyses, has an average specific yield of 0.25 (Tanaka and Davis, 1963, p. 28). Based on these data, the specific yield of the Garber-Wellington aquifer is conservatively estimated to be 0.20. With this value, the total amount of fresh water available from storage in the sandstone beds is estimated to be 21 million acre-ft.

Changes in storage reflect a net difference of water movement, either naturally or man-caused, into or out of the aquifer. A regional loss in storage would be indicated by lowering of the water level over a broad area. Local lowering of the water level is of little significance because the net loss relative to the total amount in storage is small.

The annual highest and lowest water levels in a well 791 ft deep in northern Oklahoma City are shown by the hydrograph (fig. 8) for 1943-70 (the well was destroyed in 1970). Although the lowest water level fluctuated more than 30 ft, the highest water level fluctuated only about 10 ft. This indicates that for the period of record net gains and losses in storage have tended to balance. Except in the areas around Nichols Hills and Edmond, water levels in the aquifer have not been markedly affected by pumping, indicating no significant decrease in storage. Furthermore, storage is inferred to be presently near a maximum within the study area because total rainfall for the past 3 years (1973-75) is nearly 23 in. above normal.

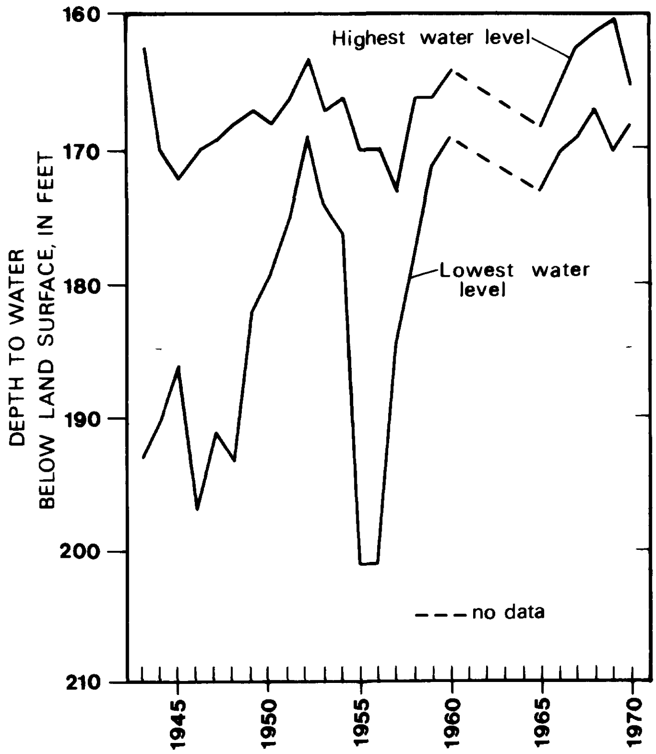

Figure 8.--Hydrograph of a well in the Garber-Wellington aquifer in northern Oklahoma City.

Recharge and Discharge

Recharge to deeper parts of the aquifer probably is mainly derived from downward movement of water in the study area. However, deeper parts of the aquifer crop out east of the study area and may receive recharge that moves westward down the regional geologic structure. Water-level data supporting this possible westward movement of recharge are not available.

Wood and Burton (1968, p. 42) estimated recharge to the Garber-Wellington aquifer to be 5 percent of the average annual precipitation. However, using pumpage and water-level data, they calculated (p. 45) that recharge in the area south of the North Canadian River was greater than 5 percent in 1957-61.

An estimate of minimum recharge to the Garber-Wellington aquifer is determined from base-flow measurements of Wildhorse Creek in the eastern part of the study area and from precipitation records at Oklahoma City, the nearest weather station. The drainage basin of Wildhorse Creek is geologically and topographically typical of most of the outcrop area of the aquifer; hence, recharge is assumed to be of the same magnitude throughout the area where the aquifer is at the surface.

Water discharged as base flow represents recharge derived from direct precipitation that entered the aquifer, where it was temporarily stored until it was gradually discharged to the stream. Water-level measurements in the wells show that the volume of water in the upper part of the aquifer did not significantly change because rises in water levels were accompanied by increases in base flow and declines in water levels were accompanied by decreases in base flow. Thus, storage in the aquifer in the basin of Wildhorse Creek is essentially in equilibrium so that water leaves in about the same proportion as it enters.

During 1975 the average base flow of Wildhorse Creek was about 4.6 ft^3/s from 17.6 mi^2 of drainage area; thus, the amount of water discharged from the aquifer during the year was about 190 $acre\text{-}ft/mi^2$. Based on these values, recharge for the basin is estimated to be 10 percent of the precipitation. Precipitation during 1975 was about 10 percent above normal so the percentage of recharge during a normal year probably would be somewhat less. However, the estimate of 10 percent for recharge is the same as that determined for the Rush Springs Sandstone (Tanaka and Davis, 1963, p. 34) which is hydrologically similar to the Garber-Wellington aquifer.

Considering that part of the study area where the Garber-Wellington is exposed at the surface, which includes an area of about 680 mi^2, and applying a recharge value of 190 $acre\text{-}ft/mi^2$, total minimum recharge was calculated to be 129,000 acre-ft during 1975. In a year of normal rainfall, total minimum recharge can be expected to be about 10 percent less or 116,000 acre-ft.

Most recharge takes place during those months when vegetation is dead or dormant and when evapotranspiration is at a minimum. During the warm growing season most of the precipitation does not reach the saturated zone but is transpired by plants or evaporated from the soil.

Areas of ground-water discharge are indicated by the troughs in the potentiometric surface along the valleys of Deep Fork, Bear Creek, Cottonwood Creek, and the Cimarron River (fig. 6). Ground water also discharges southward into the alluvium underlying the flood plain of the North Canadian River; similar conditions probably exist along the Cimarron River. Because the aquifer is essentially in a state of equilibrium in most of the area, the volume of water discharged to the streams is nearly equal to the amount of recharge. Some water is lost from the aquifer by evaporation and transpiration, but in most of the area the potentiometric surface is several tens of feet below the land surface and therefore direct losses from the water table cannot be great. However, evapotranspiration probably is substantial in the valleys where the water table is near the surface.

In addition to natural discharge, water is discharged from the aquifer by pumping for municipal, industrial, and rural supplies. Based on data taken from a report by Phelps, Spitz, Ammerman, and Thomas, Inc. (1975, p. 59) ground-water use for municipal and rural supply is estimated to have been 5,000 acre-ft in 1975. The amount of ground water used for industrial purposes is unknown but if it is as much as 5,000 acre-ft, total ground water usage would be less than 5 percent of the annual recharge and an insignificant percentage of the amount in storage.

Chemical Quality

Information on the chemical quality of water from the Garber-Wellington aquifer is provided by published and unpublished records of the Geological Survey and by analyses of 28 water samples collected for this study. To supplement this information, specific conductance was measured in the field on water samples from 72 wells. These measurements were used to estimate the dissolved-solids concentration of the water based on the relation illustrated in figure 9.

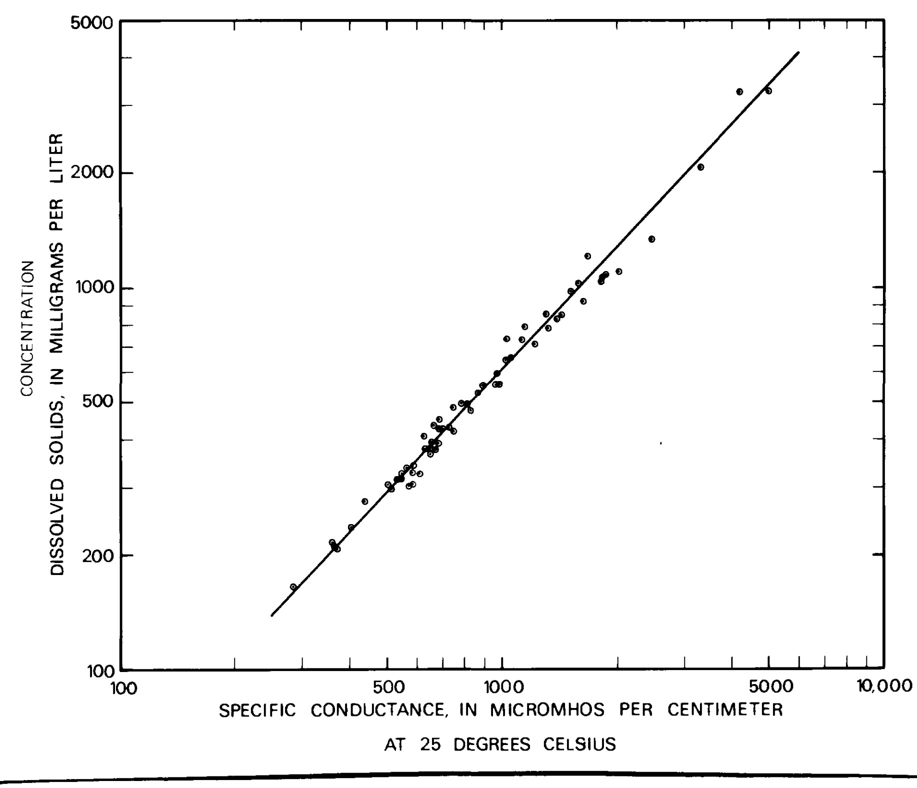

Figure 9.--Relation of specific conductance to dissolved solids in water from the Garber-Wellington aquifer.

The location of the wells sampled, their depths, and the range of dissolved-solids concentration are shown in figure 10; the results of the analyses at these wells are summarized in table 2. As indicated by the map, dissolved-solids concentrations in wells generally do not exceed 1,000 mg/L. Local degradation of water quality may be the result of oil-field activities, such as seepage from waste pits, defective well casing, defective well plugging, water-flooding operations, or improper brine disposal.

Table 2.--Summary of chemical analyses of water from the Garber-Wellington aquifer.

Chemical analyses of water from wells less than 250 ft deep

	Concentrations (mg/L)					Number of samples
	Maximum	Upper quartile 1/	Median 2/	Lower quartile 3/	Minimum	
Hardness as $CaCO_3$	1,300	380	285	240	7	38
Sulfate (SO_4)	1,900	67	26	17	4.9	39
Chloride (Cl)	740	69	17	11	4.8	39
Nitrate (NO_3)	83	12	3.4	.6	0.0	39
Dissolved solids (ROE at 180°C)	3,260	594	393	326	166	39

Chemical analyses of water from wells more than 250 ft deep

	Concentrations (mg/L)					Number of samples
	Maximum	Upper quartile 1/	Median 2/	Lower quartile 3/	Minimum	
Hardness as $CaCO_3$	620	258	147	30	6	31
Sulfate (SO_4)	360	82	49	16	5	32
Chloride (Cl)	458	163	48	20	6	32
Nitrate (NO_3)	24	1.6	.8	.3	.0	31
Dissolved solids (ROE at 180°C)	1,140	829	485	378	208	31

Chemical analyses of water from all wells

	Concentrations (mg/L)					Number of samples
	Maximum	Upper quartile 1/	Median 2/	Lower quartile 3/	Minimum	
Hardness as $CaCO_3$	1,300	330	250	140	6	69
Sulfate (SO_4)	1,900	75	35	17	4.9	71
Chloride (Cl)	740	98	30	12	4.8	71
Nitrate (NO_3)	83	6.2	1.1	.5	.0	70
Dissolved solids (ROE at 180°C)	3,260	755	450	331	166	70

1/ Upper quartile - 75 percent of the samples had a concentration less than the amount shown.

2/ Median - 50 percent of the samples had a concentration less than the amount shown.

3/ Lower quartile - 25 percent of the samples had a concentration less than the amount shown.

Development of additional water from the Garber-Wellington aquifer depends on hydrologic conditions and economic considerations. An evaluation of economic considerations is beyond the scope of this report. Hydrologic conditions, particularly saturated thickness and hydraulic conductivity, control the amount of water theoretically available from wells. However, the actual yield of a well is also affected by its efficiency, which is largely determined by the methods used to construct that well.

Well Construction

Because of the influence of well-construction methods commonly used the petroleum industry, most deep wells in the Garber-Wellington aquifer are completed by gun-perforating or slotting the casing after it has been cemented into the hole. This method of construction results in an inefficient water well because (1) openings cannot be closely spaced, (2) the percentage of open area is low, (3) openings are irregular in shape and differ in size, and (4) openings small enough to control fine or medium sand are difficult to produce (Johnson, Inc., 1966, p. 152).

Specific capacity, which is the amount of water a well will yield per foot of drawdown, provides a quantative means of comparing different methods of well construction (Johnson, Inc., 1966, p. 153-154). Tests of 40 perforated wells and 6 screened wells in the Garber-Wellington aquifer at the city of Norman, a few miles south of the study area, show that the average specific capacity of slotted and perforated wells is only about half that of the screened wells as illustrated in figure 11. Thus, a screened well will yield about twice as much water as a slotted or perforated well with the same amount of drawdown.

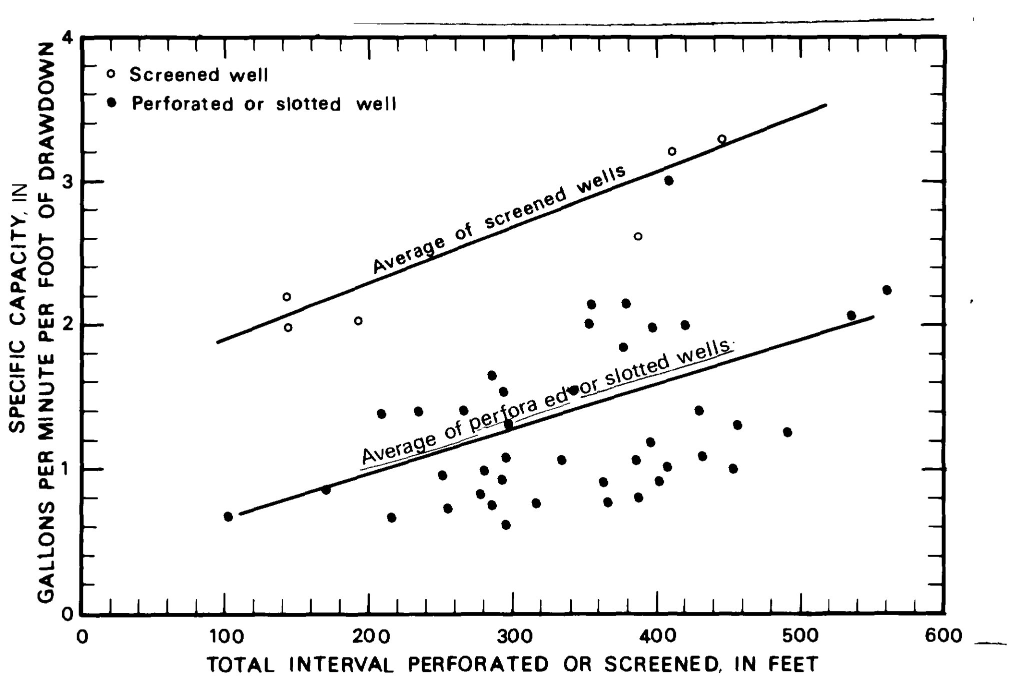

Figure 11.--Relation of specific capacity to interval open to the aquifer for screened wells and perforated or slotted wells.

Well Yields

In the study area, reported yields of wells more than 250 ft deep in the Garber-Wellington aquifer range from 70 to 475 gal/min and average 240 gal/min. Reported yields of wells less than 250 ft deep range from 5 to 115 gal/min and average 35 gal/min. These yields agree in a general way with the thickness of the fresh-water zone but many variations occur because of differences in hydrologic conditions, the thickness of saturated material penetrated, and well-construction methods.

The potential yield of a well can be estimated by multiplying the specific capacity of a well by the available drawdown at a given site. Specific capacities in the study area range from 0.63 to 2.19 (gal/min)/ft and average about 1.3 (gal/min)/ft. The amount of available drawdown may differ from well to well depending on the depth of perforations or screen. However, water levels should not be drawn down below the perforations or screen because chemical changes will cause encrustation and eventual plugging of the openings.

For purpose of discussion, the available drawdown is assumed to be half the thickness of the fresh-water zone. Based on this assumption and an average specific-capacity value of 1.3 (gal/min)/ft, a perforated well in an area where the fresh-water zone is 350 ft thick would have a potential yield of about 225 gal/min or about 324,000 gal/day. Where the fresh-water zone is 850 ft thick, the potential yield would be about 550 gal/min or about 792,000 gal/day.

Specific capacities, and hence well yields, could be significantly increased by using properly selected screens, gravel packing, and proper well development. If the specific capacity of a well can be increased from 1.3 to 2 (gal/min)/ft the potential yield would be increased 54 percent.

At present, the upper 250 ft of most deep wells is sealed behind casing because the water in that part of the aquifer is harder than in the lower part. By utilizing water in the upper part of the aquifer the amount of water available could be significantly increased but with a deterioration in water quality. This problem could be alleviated by proper treatment or by mixing the hard water with water of lower hardness.

Salt-Water Intrusion

The principal hydrologic condition that may affect development of the Garber-Wellington aquifer is the presence of saline water at different depths throughout the area. This condition is not unique or even unusual but occurs in many areas of the United States.

If the pressure head in the fresh-water zone is reduced by pumping, the fresh-water to saline-water interface rises in response to the density head of the saline water. As long as the equilibrium level of the resulting interface is below the bottom of a well, fresh water is skimmed off as has been done from the Garber-Wellington aquifer for many years. However, if the pressure head is reduced to the point where the equilibrium level of the saline-water to fresh-water interface is at or above the intake point in the well, then the water quality will be degraded. One way of avoiding the problem is steady pumping at low rates from widely spaced wells. Pumping rates or well spacing cannot be determined from the hydrologic information presently available.

Aquifer Management

Even though a considerable amount of fresh ground water is in storage, the percentage of this amount that can be recovered and the cost per unit volume recovered depends on aquifer management. Two primary hydrological variables of importance to aquifer management are (1) the number and distribution of wells, and (2) the pumping rate of each well. Several combinations of these variables are possible; however, economic considerations limit the use of most. Hydrologically, an optimum combination of the variables should result in the development of regional hydraulic gradients large enough to move the desired volume of ground water to pumpage centers, and to obtain the maximum capture of recharge. However, the gradients should not be so large as to cause saline-water upconing beneath well fields or to cause excessive water-level declines that would result in decreased well efficiencies or in dry wells. Although this balance is desired, the information obtained during this project is not adequate to determine the best plan of development for the aquifer. To permit such a determination, additional data on aquifer hydraulics would have to be collected and analyzed. An optimum plan of development probably could be best determined with a digital model of the aquifer that would provide a basis to forecast the useful life of the aquifer in terms of water-level declines in response to various distributions and levels of development.

CONCLUSIONS

This preliminary appraisal indicates that the amount of water stored in the Garber-Wellington aquifer and the amount of annual recharge are substantial. At present, only a small amount of this water is being put to use. The ready availability of ground water suggests that its use in conjunction with water from the proposed reservoir on Cottonwood Creek is a viable alternative to meet the water-supply needs of southern Logan and northern Oklahoma Counties. Therefore, additional hydrologic study seems warranted.

The Garber-Wellington aquifer is a complex hydrologic system; a reasonable understanding of how that system functions is necessary to plan for full utilization of the large amount of water available. When making such plans, two closely related hydrologic problems should be considered: (1) the amount of water that can be withdrawn annually over a long period of time and (2) the potential hazard of degradation of water quality by upconing of saline water as a result of regional or local overpumping. In order to answer these questions, a variety of geologic and hydrologic data will have to be collected and analyzed.

In terms of potential well yields, the most favorable areas for development of the aquifer are those where the fresh water zone is thickest and contains a large proportion of sandstone with favorable hydraulic characteristics. Individual well yields on the order of 200 gal/min probably can be obtained in most of the area where the fresh-water zone is at least 350 ft thick (see fig. 7); actual well yields would, in part, be affected by methods used to construct the wells. Thickness and physical characteristics of the sandstone beds as well as the position of the base of fresh water can be determined by careful test drilling supplemented with geophysical logging. Hydraulic characteristics can be determined by aquifer tests of each significant water-bearing sandstone. Variations in water levels that would result from pumping, as well as any change in the base of fresh water, can be determined by monitor wells tapping various zones within the aquifer.

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