Ground-Water Resources of Olmsted Air Force Base Middletown, Pennsylvania

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-H

Prepared for the Corps of Engineers, U.S. Army

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By HAROLD MEISLER *and* STANLEY M. LONGWILL

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GROUND-WATER RESOURCES OF OLMSTED AIR FORCE BASE, MIDDLETOWN, PENNSYLVANIA

By HAROLD MEISLER and STANLEY M. LONGWILL

ABSTRACT

Olmsted Air Force Base is underlain by the Gettysburg shale of Triassic age. The Gettysburg shale at the Air Force Base consists of interbedded red sandstone, siltstone, and shale. The average strike of the strata is N. 43° E., and the strata dip to the northwest at an average angle of 26°.

The transmissibility of known aquifers in the warehouse area of the Air Force Base is low. Therefore, wells in the warehouse area have low specific capacities and yield only small supplies of water. Wells on the main base, however, yield relatively large supplies of water because the transmissibilities of the aquifers are relatively high. Pumping tests in the warehouse area and the eastern area of the main base indicated the presence of impermeable boundaries in both areas. Pumping tests in the central and western parts of the main base revealed that the Susquehanna River probably is acting as a source of recharge (forms a recharge boundary) for wells in those areas.

Data obtained during this investigation indicate that additional supplies of ground water for Olmsted Air Force Base could best be obtained from the western part of the main base.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

The investigation described in this report was made by the U.S. Geological Survey in response to a request for the Corps of Engineers, U.S. Army, to help locate an adequate water supply for the new warehouse area of Olmstead Air Force Base, Middletown, Pa. The investigation was to answer the following questions: (a) What geologic factors affect the yield of wells? (b) Where are the most favorable well sites and what are the recommended well depths and optimum pump settings necessary for producing a yield of 640 gpm (gallons per minute) from wells in the warehouse area? (c) What are the possibilities of obtaining the water needed by increasing the yield from one or more existing wells on the Air Force Base? (d) What would be the effect of new wells on existing wells?

The investigation was under the immediate supervision of Joseph E. Barclay, district geologist, Harrisburg, Pa.

LOCATION AND GEOGRAPHIC SETTING

Olmsted Air Force Base lies just west of Middletown, Pa., in south-central Dauphin County, at lat 40°12′ N.; long 76°45′ W. (See fig. 1.) The main part of the base is bordered on the south by the

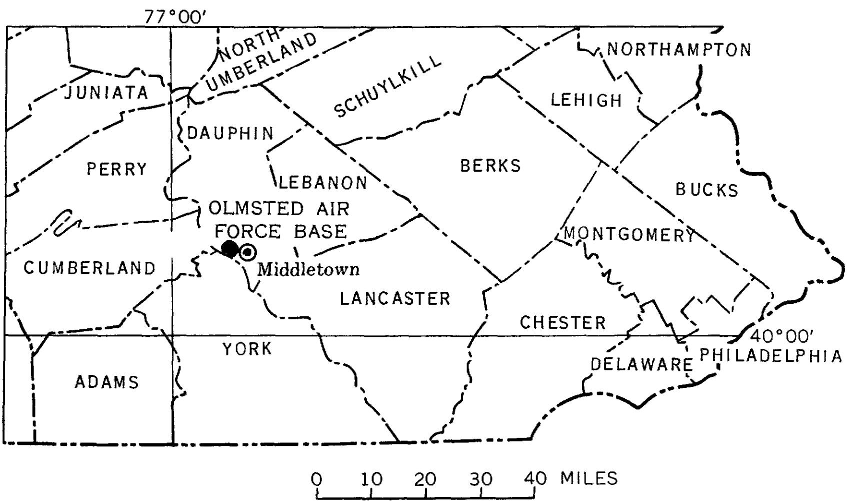

FIGURE 1.—Map of southeastern Pennsylvania showing location of Olmsted Air Force Base.

Susquehanna River and on the north by U.S. Highway 230. The warehouse area, now under development, is bordered on the south by U.S. Highway 230 and on the north by the Pennsylvania Turnpike.

Olmsted Air Force Base is in the Triassic lowland of the Piedmont province. The Triassic lowland is characterized by a gently undulating surface which slopes generally to the south and is traversed by many ridges of diabase.

Altitudes on the Air Force Base range from 280 feet above mean sea level at the Susquehanna River to 385 feet at the northern boundary. The main part of the base is on an alluvial terrace along the Susquehanna River, at an altitude of approximately 300 feet. This terrace was named the Binghamton terrace by Peltier (1949). The present flood plain has apparently been filled in to the level of this terrace in the vicinity of the Air Force Base. North of the main base the land surface rises abruptly; in the warehouse area there are remnants of two higher terraces at altitudes of 360 and 380 feet.

METHODS OF INVESTIGATION

Fieldwork for this investigation was begun on January 19, 1959, and completed on February 6, 1959. An inventory was made of existing wells on the Air Force Base and in part of the surrounding territory, and pumping tests were made on 3 wells (fig. 2) on the main base and 1 well in the warehouse area. A brief geologic investigation of the area was made in order to determine local stratigraphy and structure, and rock samples from well Da-77 (see sample log, below) in the new warehouse area were studied with the aid of a binocular microscope. Chemical analyses of 43 water samples from 14 wells on the Air Force Base were made by the Quality of Water Laboratory of the Geological Survey, Philadelphia, Pa. Electric and gamma-ray logs were obtained from 1 well on the main base and from 3 wells in the warehouse area. The electric logs include curves showing self potential, single-point resistance, 16- and 64-inch normal resistivity, and fluid resistivity.

PREVIOUS INVESTIGATIONS

The geology and ground-water resources of southeastern Pennsylvania were described by Hall (1934). The geology of the Middletown quadrangle, which includes the eastern part of Olmsted Air Force Base, was discussed in a report by Stose and Jonas (1933).

ACKNOWLEDGMENTS

Acknowledgment is due Mr. Russell Conrad of the Air Installations Office, U.S. Air Force, for supplying data on the wells on Olmsted Air Force Base.

GEOLOGY

GENERAL FEATURES

Olmsted Air Force Base is underlain by the Gettysburg shale, which is part of the Newark group of Triassic age. The Gettysburg shale in its type locality at Gettysburg, Pa., consists of soft red shale and soft red sandstone (Stose and Jonas, 1933). The Newark group as a whole occupies a series of disconnected, downfaulted basins that extend from Nova Scotia to North Carolina. In Pennsylvania the Newark group is part of the largest Triassic basin in the eastern United States—a basin which extends from New Jersey to Virginia.

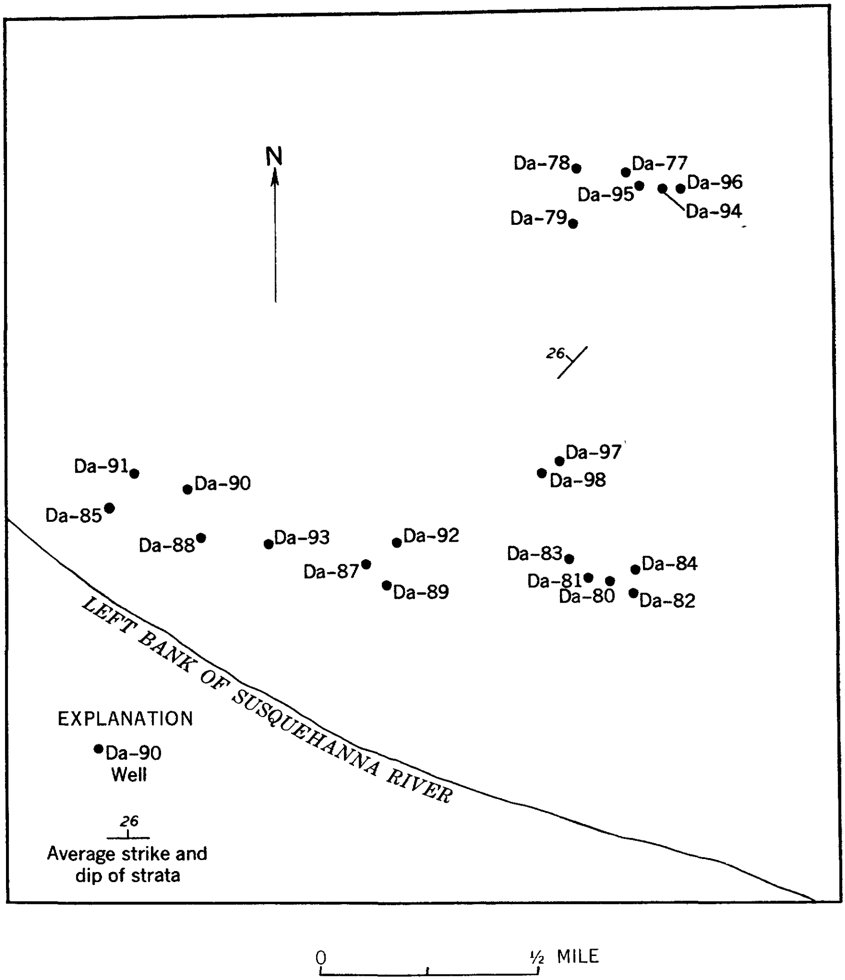

FIGURE 2.—Map showing location of wells.

The Newark group consists of conglomerate, sandstone, arkose, siltstone, shale, argillite, and lava flows. The sedimentary rocks of the group are intruded by diabase dikes and sills. In the general area of Olmsted Air Force Base, the Newark group is divided into the New Oxford formation and the overlying Gettysburg shale.

The Triassic rocks in southeastern Pennsylvania dip generally to the northwest at angles ranging from 10° to 50°. Large faults form the northern boundary of the basin.

STRATIGRAPHY

The Gettysburg shale on Olmsted Air Force Base consists of alternating beds of red sandstone, siltstone, and shale. The beds of sandstone and siltstone are poorly sorted and weakly cemented with calcium carbonate. Quartz grains, ranging in size from silt to very small pebbles, and red clay are the chief constituents of the formation. The siltstone is sandy and contains substantial amounts of clay, and most of the sandstone contains considerable amounts of both silt and red clay. Little pure shale is present. As most of the rocks are composed of the same materials (differing from one another only in the proportion of constituents) they appear to be uniform in composition unless they are examined in detail.

The following sections and the log of Da–77 show the complex interbedded nature of the sedimentary rocks.

Section exposed at Capehart housing unit, 1,600 feet north of U.S. Route 230

	Thickness (feet)
Siltstone, red, sandy, clayey	4
Sandstone, red, fine-grained, very clayey	4
Siltstone, red	3.5
Sandstone, red, medium-grained, clayey, friable	3
Shale, red	2
Sandstone, red, very fine to fine-grained, clayey	2.5

Section exposed in gutter along road in southern part of warehouse area, sampled every 5 feet of thickness

	Sample taken at— (feet)
Siltstone to very fine grained sandstone, red, shaly	5–15
Shale, red	20
Siltstone, red, shaly	25
Sandstone, red, fine- to medium-grained, clayey	30–35
Siltstone to very fine grained sandstone, red, shaly	40
Shale, red	45
Siltstone to very fine grained sandstone, red, shaly	50
Siltstone, red, coarse, sandy	55
Sandstone, red, fine- to medium-grained, clayey	60–65
Sandstone, red, fine-grained, clayey	70–80
Siltstone, red	85
Sandstone, red, fine- to coarse-grained, clayey	90
Siltstone, red, sandy	95
Sandstone, red, very fine grained, clayey	100–110
Siltstone, red, sandy, shaly	115–150
Sandstone, red, very fine grained, clayey	155
Sandstone, orange, medium- to coarse-grained, feldspathic	160
Sandstone, red, medium-grained	165
Sandstone, red, fine-grained, clayey	170
Siltstone to very fine grained sandstone, red	175

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Sample log of well Da–77, warehouse area, Olmsted Air Force Base

	Depth (feet)
Siltstone, red, sandy, quartz grains, calcareous; also some fine-grained angular quartz and poorly sorted sandstone	100–110
Siltstone, red, as above; soft clay pocket encountered by drill	110–120
Siltstone, red, as above; some medium and coarse quartz sand	120–130
Siltstone, red, as above	130–140
Siltstone, red, as above; some medium and coarse quartz sand	140–150
Shale, red; a little coarse quartz sand	150–160
Sandstone, red, fine- to medium-grained, quartz, subangular, fairly well sorted, calcareous	160–180
Sandstone, medium grained, as above; a little red shale	180–200
Sample missing	200–210
Sandstone as above; red siltstone and shale	210–220
Sandstone as above; a little red siltstone	220–230
Siltstone, red; some sandstone; a little red shale; soft clay pocket encountered by drill	230–240
Siltstone, red, as above	240–270
Siltstone, red, as above; a little coarse quartz sand	270–280
Sandstone, fine- to medium-grained, as above; red siltstone as above	280–300
Sandstone, medium- to coarse-grained; red siltstone as above; calcite or limestone	300–310
Siltstone, red; sandstone	310–320
Siltstone, red; some sandstone	320–330
Sandstone, medium-grained; siltstone	330–350
Sandstone, fine- to medium-grained; red siltstone	350–360
Sandstone, medium- to coarse-grained; little siltstone	360–370
Sandstone, coarse-grained; little siltstone	370–390
Sandstone, coarse-grained; siltstone	390–400
Siltstone, red; medium- to coarse-grained sandstone	400–420
Sandstone, medium- to coarse-grained; some red siltstone	420–440
Sandstone, medium- to coarse-grained; some red siltstone; a little red shale	440–450
Sandstone, medium-grained; some red siltstone	450–460
Sandstone, medium- to coarse-grained; some red siltstone	460–480
Siltstone, sandy, red; medium- to coarse-grained sandstone	480–490
Sandstone, medium- to coarse-grained; red siltstone	490–500
Sandstone, medium- to coarse-grained; some red siltstone	500–510
Sandstone, fine- to medium-grained; some red siltstone	510–530
Sandstone, coarse-grained; some siltstone	530–540
Siltstone, red; some sandstone	540–550
Sandstone, medium- to coarse-grained; some red siltstone	550–560
Sandstone, medium- to coarse-grained; some red siltstone and calcite	560–570
Siltstone, red	570–580
Sandstone, medium-grained; red shale and siltstone	580–590
Sandstone, medium- to coarse-grained; some siltstone and shale	590–600
Sandstone, medium- to coarse-grained; some red siltstone	600–640
Sandstone, medium-grained, red siltstone	640–650
Siltstone, red; fine- to medium-grained sandstone	650–660
Siltstone, red; clay pocket encountered by drill at 675 ft	660–690

Electrical-resistivity logs from the Air Force Base show that electrically most of the rocks in the area are fairly uniform. The rocks have a fairly low electrical resistivity, which indicates a high clay content. Variations in resistivity do occur, apparently because of lithological changes such as decreased clay content or greater degree of cementation and density of the rock. Figure 3 shows electrical-

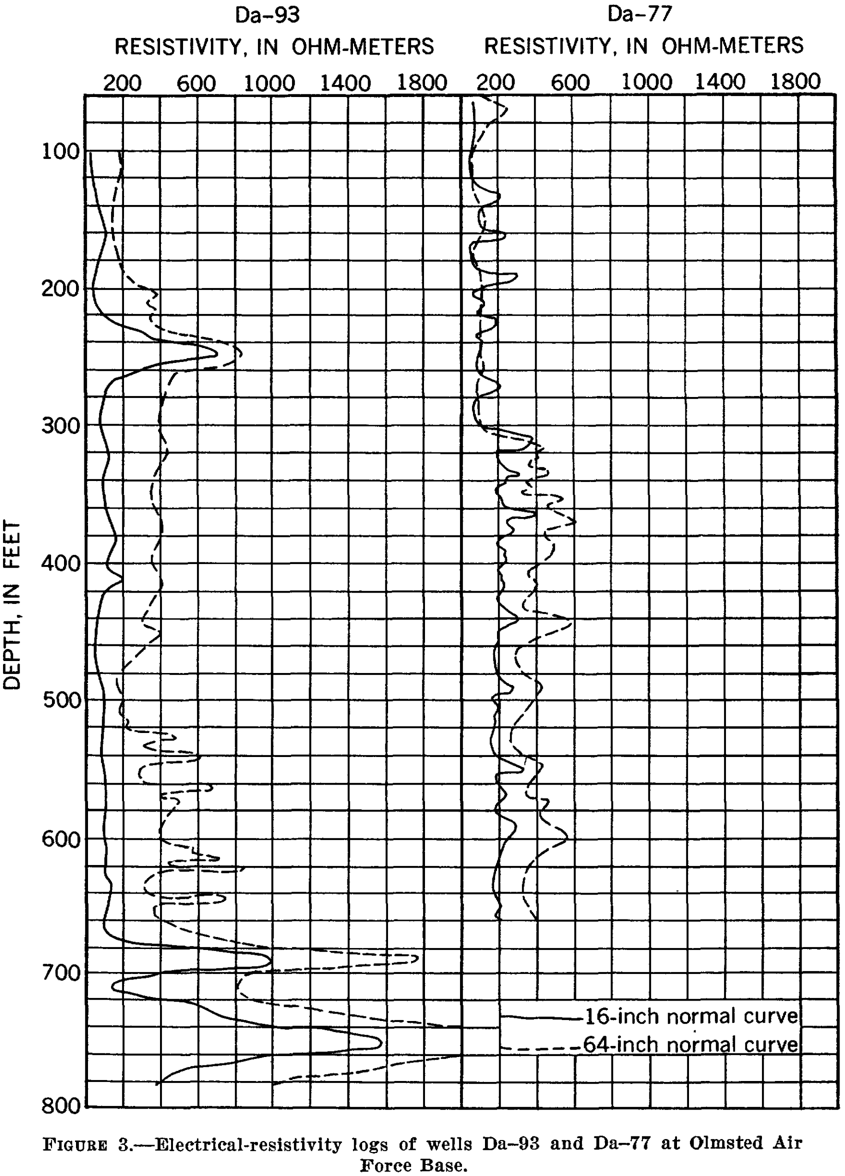

FIGURE 3.—Electrical-resistivity logs of wells Da–93 and Da–77 at Olmsted Air Force Base.

resistivity logs of well Da–93 (AFB–14), on the main base, and well Da–77, in the warehouse area. An increase in resistivity take place at 300 feet in Da–77 and is interpreted as indicating a greater proportion of sandstone below that depth. The log of Da–93 (AFB–14), on the main base, shows distinct zones of high resistivity at depths of 250, 690, and 750 feet. These zones are believed to be occupied by beds of water-bearing sandstone that contain very little clay. The logs from the warehouse area show no zones of comparably high resistivity; therefore, beds of relatively clay-free sandstone are believed to be absent near the wells in that area.

STRUCTURE

Beds of the Gettysburg shale at Olmsted Air Force Base dip to the northwest at angles ranging from 19° to 38°. The average of 9 dip measurements made in or near the warehouse area is approximately N. 26° W. The strike of the beds ranges from N. 5° E. to N. 65° E. and the average strike is N. 43° E.

ALLUVIAL DEPOSITS

Throughout most of Olmsted Air Force Base, the Gettysburg shale is covered by alluvial terrace deposits of Quaternary age. The lowest terrace deposit, the top of which is at an altitude of 300 feet above mean sea level and on which the main part of the base is situated, consists of gravel and sand approximately 30 feet thick. Alluvium of the higher terraces consists of thin, discontinuous deposits as much as 20 feet thick. In general, however, the alluvium of the higher terraces is less than 10 feet thick.

The alluvium is believed not to be a significant aquifer at the Air Force Base, but it is rather permeable and rainfall infiltrates rapidly. Thus it is a major source of recharge to the Gettysburg shale.

GROUND-WATER HYDROLOGY

PRINCIPLES

Ground water may occur under either water-table or artesian conditions. Where the ground water is not confined, the upper surface of the zone of saturation is called the "water table." Where ground water is confined under hydrostatic pressure by relatively impermeable rocks, the water occurs under artesian conditions. When an artesian aquifer is penetrated by a well, the water will rise in the well above the bottom of the confining bed to a level called the "piezometric surface."

Recharge to a water-table aquifer comes from local precipitation or streamflow that infiltrates downward to the zone of saturation. Recharge to artesian aquifers comes from precipitation or streamflow in the area where the aquifer is at or near the surface and is under water-table conditions.

On Olmsted Air Force Base, ground water occurs in the Gettysburg shale under artesian conditions. However, where a bed in the Gettysburg shale crops out at the surface, or beneath the alluvium, the water in this bed occurs under water-table conditions. The primary source of recharge to the artesian aquifer in the Air Force Base is precipitation percolating through the alluvium within and adjacent to the base.

Various terms are used to describe the hydraulic properties of an aquifer. The field coefficient of permeability is defined as the rate of flow, in gallons per day, through a cross-sectional area of 1 square foot under a unit hydraulic gradient and at the prevailing temperature of the water. The coefficient of transmissibility is defined as the field coefficient of permeability times the thickness of the aquifer, in feet. The coefficient of storage of an aquifer is 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. The specific capacity of a well is defined as the yield of the well in gallons per minute per foot of drawdown of water level in the well. Specific capacity is related directly to the transmissibility of the aquifer at discharge rates that are low enough to allow water to enter the well by laminar flow.

When a well is pumped, the piezometric surface or the water table is drawn down to form a "cone of depression." As pumping proceeds, the cone continues to deepen and broaden until one of the following conditions is realized: (a) recharge to the aquifer is increased in an amount equal to the pumping rate; (b) natural discharge from the aquifer is decreased in an amount equal to the pumping rate; or (c) the sum of the increased recharge and decreased natural discharge is equal to the pumping rate.

Figure 4 shows a theoretical plot of drawdown against time in a well pumping from a homogeneous, isotropic aquifer of infinite areal extent and uniform thickness. Other assumptions made in constructing the theoretical curve are: (a) the discharge well has an infinitesimal diameter and completely penetrates the aquifer; (b) no recharge occurs; (c) the water taken from storage in the aquifer is discharged instantaneously with the decline in head; and (d) the coefficient of transmissibility is constant at all places and all times. A plot of recovery against time should coincide with a plot of draw-

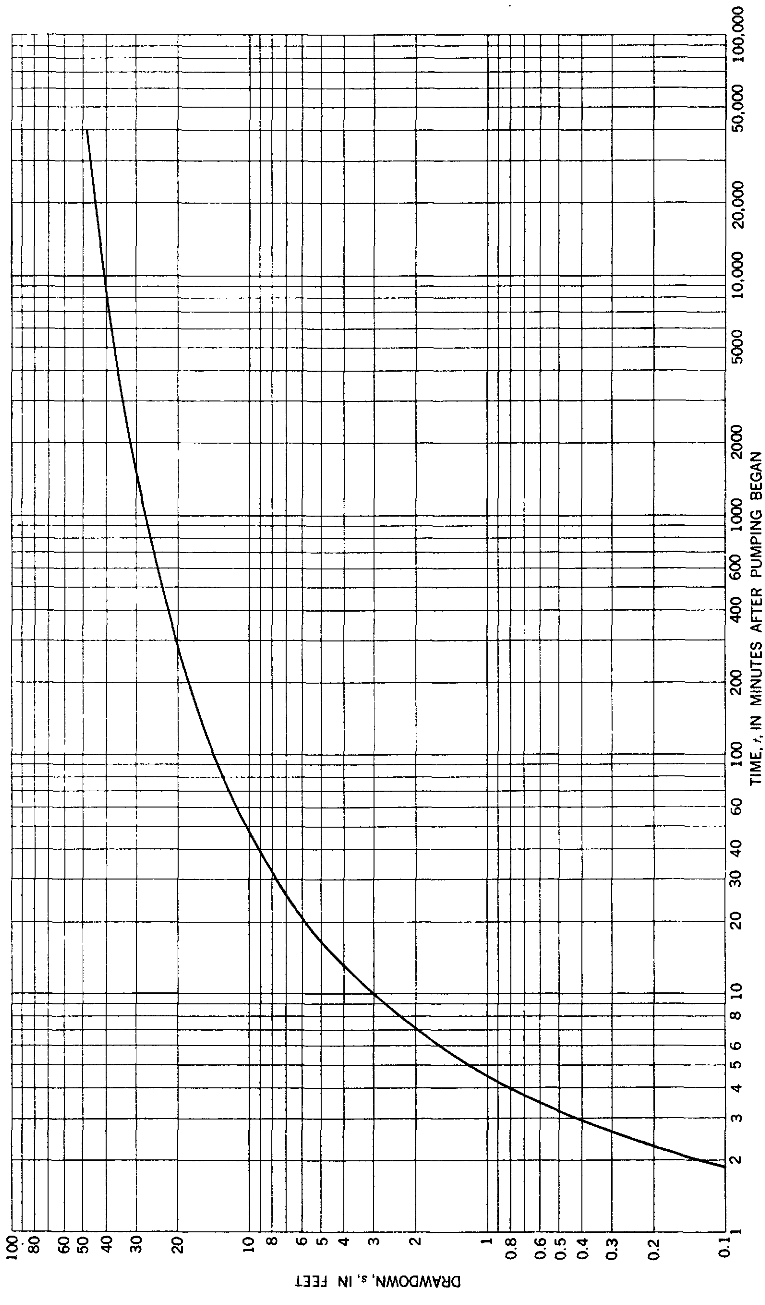

FIGURE 4.—Logarithmic graph of drawdown in a typical well penetrating a theoretical aquifer of infinite extent.

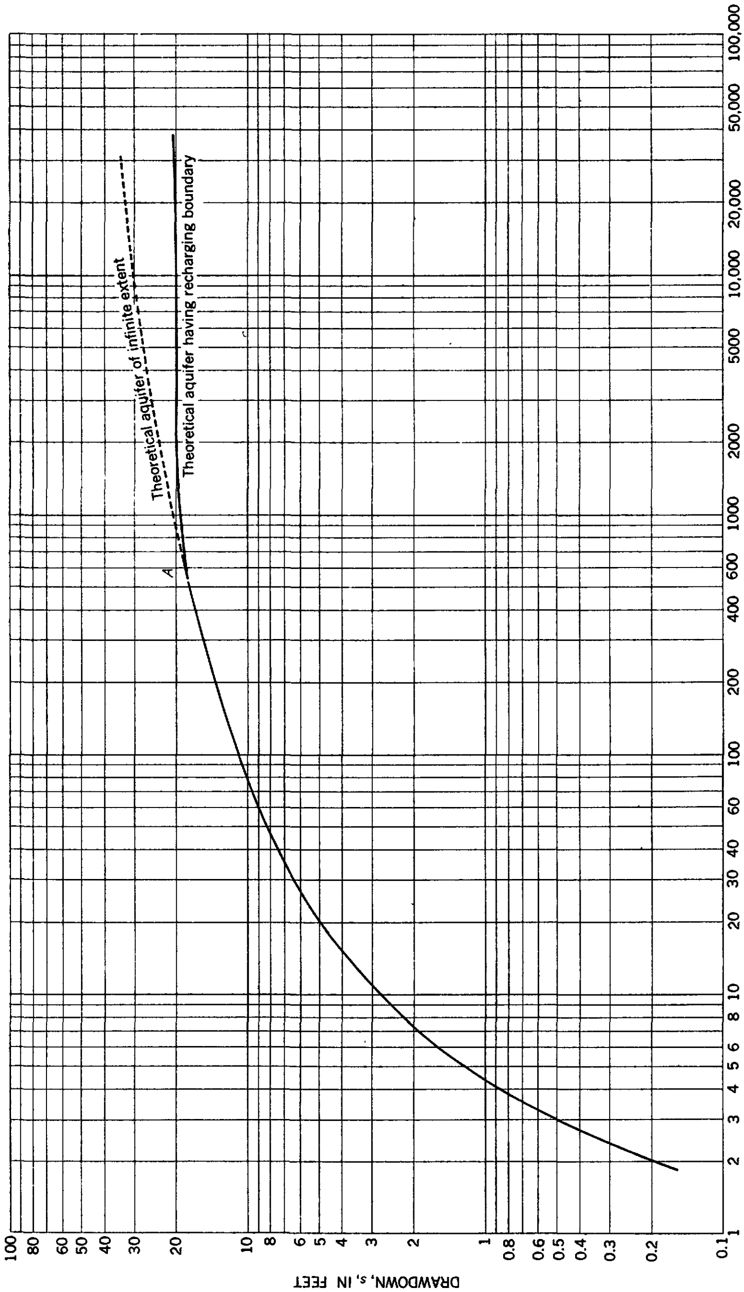

FIGURE 5.—Logarithmic graph of drawdown showing effect of a recharging boundary in a theoretical aquifer of infinite extent.

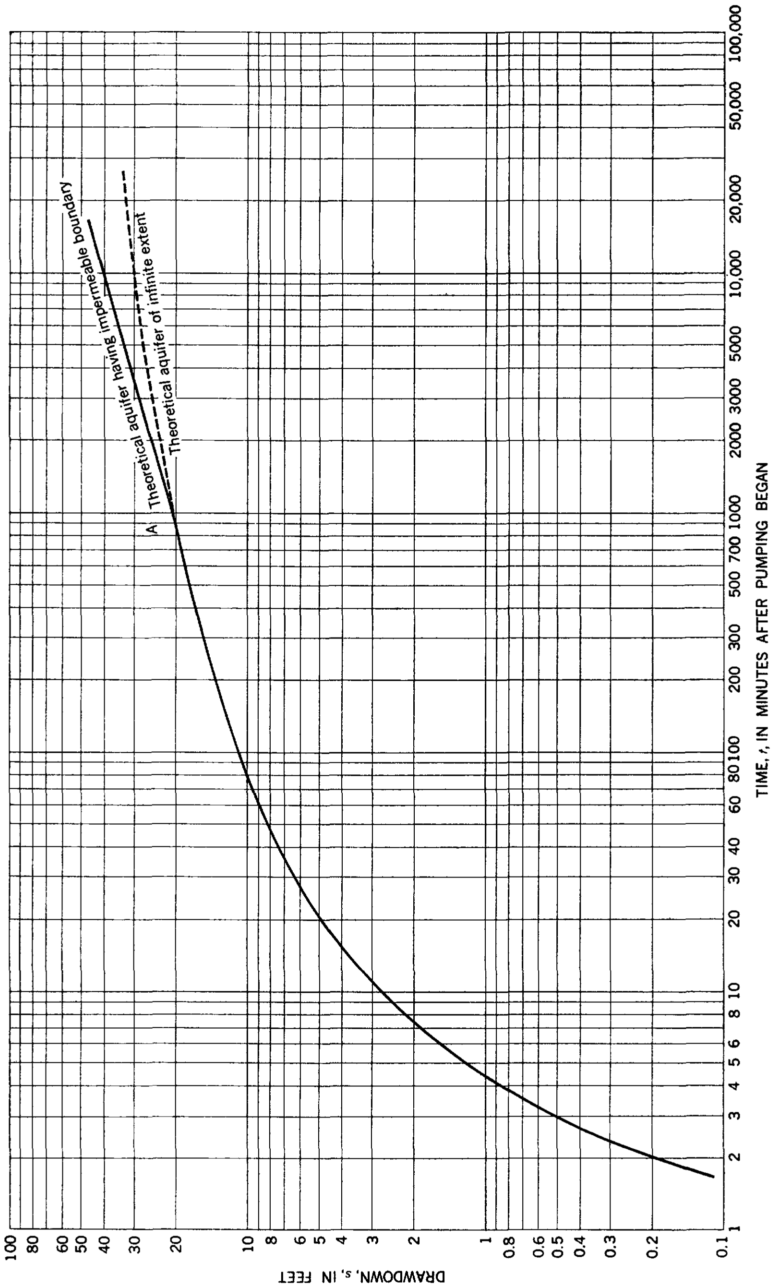

FIGURE 6.—Logarithmic graph of drawdown showing effect of a discharging boundary in a theoretical aquifer of infinite extent.

down against time. Any deviation from the above criteria will cause a plotted curve to differ from the theoretical curve. For example, figure 5 shows a drawdown curve whose slope decreases abruptly from that of the theoretical curve at point A, indicating that expansion of the cone of depression has induced recharge to the aquifer from some outside source.

Figure 6 shows a drawdown curve whose slope increases abruptly from that of the theoretical curve at point A, indicating that the cone of depression has expanded to an impermeable boundary—that is, a boundary formed by a formation that yields less water than the major aquifer. An impermeable-boundary condition may appear, for example, when the cone of depression reaches the end of the aquifer and lateral expansion of the cone is stopped or retarded. An impermeable-boundary condition may also indicate a marked decrease in the permeability of the aquifer due to a change in the lithologic character of the aquifer at some distance from the well.

WAREHOUSE AREA

Rocks underlying the warehouse area do not yield large supplies of ground water. Pumping rates from existing wells in the area range from 66 gpm (gallons per minute) from well Da–79 to 85 gpm from wells Da–94 and Da–96. Reported specific capacities ranged from 0.33 in well Da–77 to 2.3 in one of the Gulf Oil Co. service-station wells (Da–94, 95, or 96). The measured specific capacity of well Da–78 is 0.42 and the coefficient of transmissibility of the aquifer tapped by well Da–78 is about 1,250 gpd (gallons per day) per foot.

A pumping test was made on well Da–78 with a submersible pump. The pump was set at a depth of 135 feet and was pumped at a constant rate of 25 gpm. Water levels during the test were measured in wells Da–77, 78, and 79. (See fig. 2.) No drawdown occurred in wells Da–77 and 79 because these wells penetrate rocks stratigraphically lower than those penetrated in the pumped well. (See fig. 7.) The lack of drawdown in the two observation wells indicates that there is little or no leakage between aquifers. Water levels in well Da–77 fluctuated over a range of half a foot during the test, but the fluctuations appear to be related to pumping of Gulf Oil Co. well Da–95 because the entire stratigraphic section penetrated in well Da–95 is penetrated also in well Da–77.

Figures 8 and 9 show drawdown and recovery, respectively, of the pumped well (Da–78) plotted against time. The data yield curves which deviate from the theoretical curve (see fig. 4) at two points. Point A on the recovery curve (fig. 9) shows that the effect

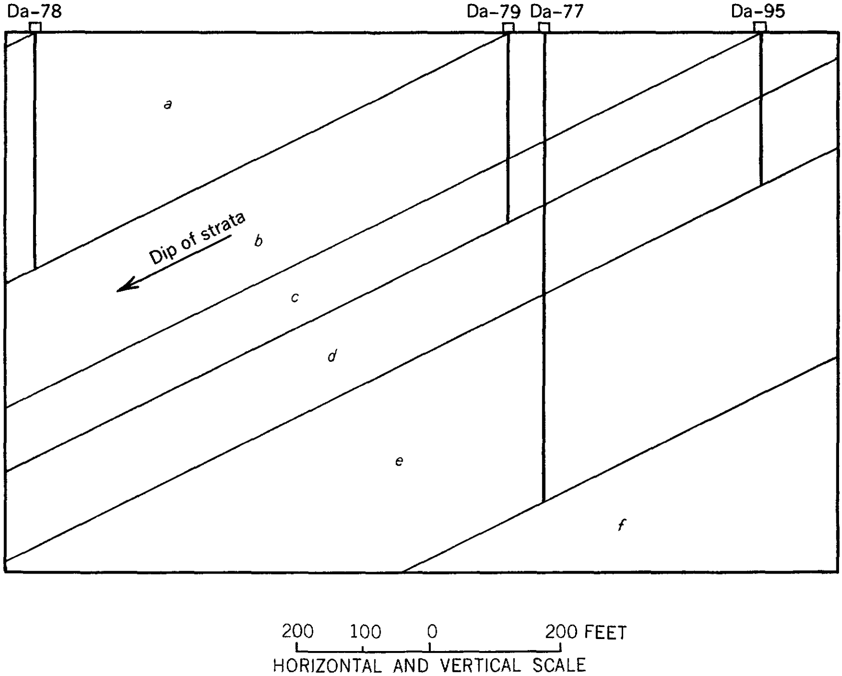

FIGURE 7.—Cross section showing relation of strata penetrated by wells in warehouse area, Olmsted Air Force Base.

a. Strata penetrated only by Da–78.
b. Strata penetrated only by Da–77 and 79.
c. Strata penetrated only by Da–77, 79, and 95.
d. Strata penetrated only by Da–77 and 95.
e. Strata penetrated only by Da–77.
f. Strata not penetrated.

of an impermeable boundary appeared 5 minutes after pumping stopped. Point B on figures 8 and 9 shows the effect of another impermeable boundary. The effect of this boundary, best shown on the drawdown curve (fig. 8), occurred 500 minutes after pumping began.

One of the impermeable boundaries, the more distant one, is believed to be at the place where the water-bearing strata come to an end at their outcrop. The other impermeable boundary is believed to represent a place at some distance from the well where the aquifer becomes thinner.

MAIN BASE

Wells in the main part of Olmsted Air Force Base generally yield large supplies of water. Pumping rates range from 130 gpm to 758 gpm. (See table 1.) The total consumption of ground water is about 1 mgd (million gallons per day).

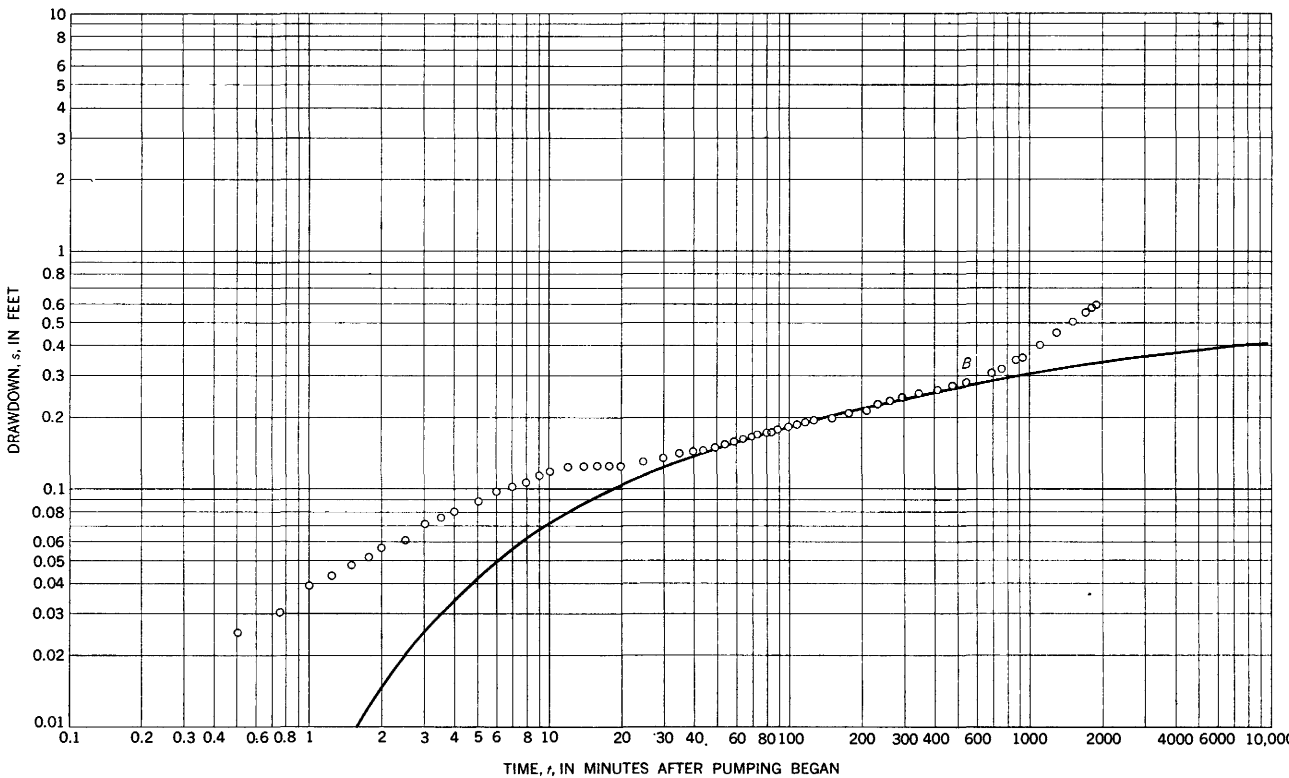

FIGURE 8.—Logarithmic graph of drawdown in well Da-78. Pumping test, drawdown cycle; data plot, drawdown of discharge well Da-78; location, warehouse area; discharging well, Da-78; observation wells, Da-77 and Da-79; date of test, Feb. 4-5, 1959. As pump discharge was not accurately regulated during the initial part of the test, a computation of the aquifer coefficient could not be made from this data plot.

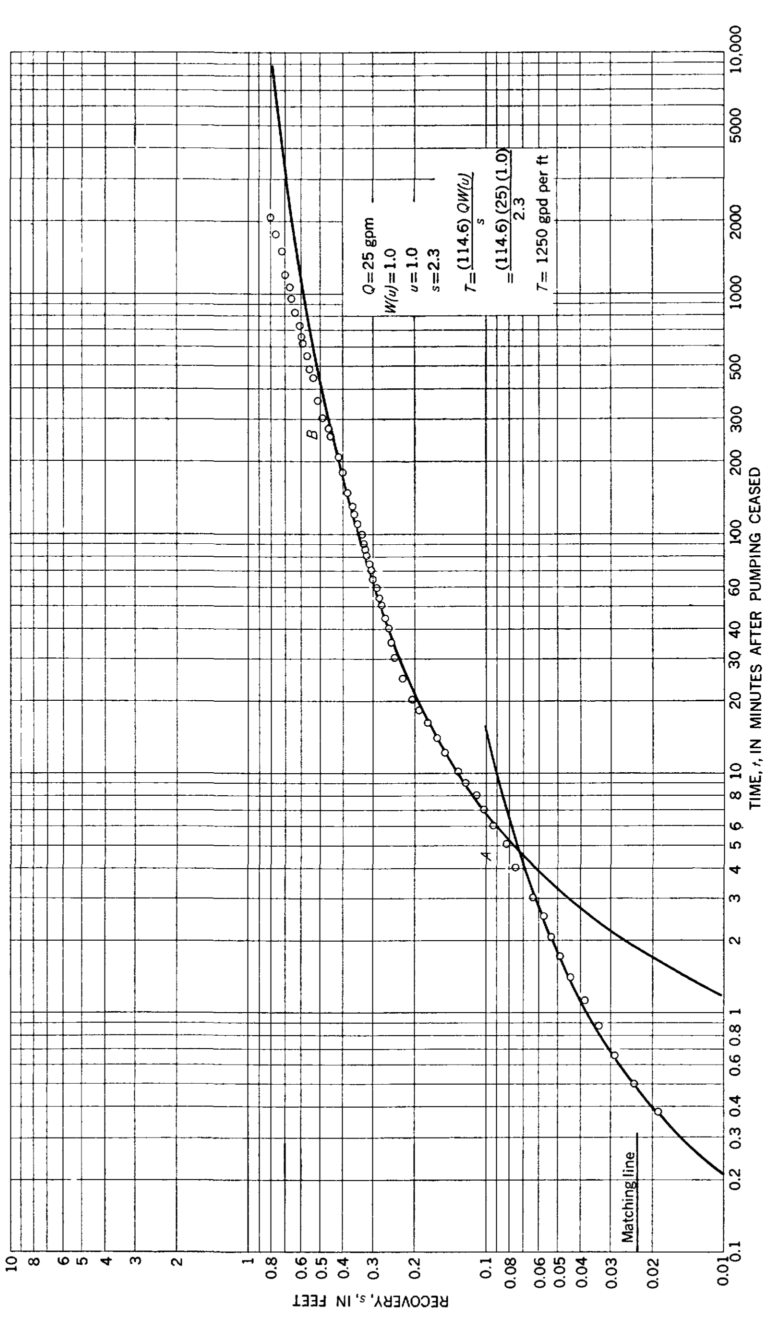

FIGURE 9.—Logarithmic graph of recovery in well Da–78. Pumping test, recovery cycle; data plot, recovery of discharge well Da–78; location, warehouse area; discharging well, Da–78; observation wells, Da–77 and Da–79; date of test, Feb. 4–5, 1959.

Wells on the main base can be classified in three groups that occupy three different areas: (a) the eastern area, comprising wells Da-80, 81, 82, 83, and 84 (AFB-1, 2, 3, 4, and 5); (b) the central area, comprising wells Da-87, 89, and 92 (AFB-8, 10, and 13); and (c) the western area, comprising wells Da-85, 88, 90, 91, and 93 (AFB-6, 9, 11, 12, and 14).

All wells in the eastern area (Da-80 to 84) were drilled in 1941 except Da-84 which was drilled earlier. Original pump settings were 140 feet below the land surface. However, after a time it was necessary to lower the pump settings to 200 feet in Da-80 (AFB-1), to 190 feet in Da-81 (AFB-2), and to 250 feet in Da-82 (AFB-3). It was also necessary to deepen Da-80 an additional 179 feet to a depth of 629 feet. Apparently the drawdown was greater than was anticipated when the wells were first drilled.

TABLE 1.—*Hydrologic characteristics of wells on the Olmsted Air Force Base*

[Specific capacity: r, reported; m, measured]

Well No.	Depth (feet)	Pumping rate (gpm)	Specific capacity (gpm per ft drawdown)	*T* (gpd per ft)	*S*
Eastern area					
Da-80 (AFB-1)	629	260	1.9^{r}		
81 (AFB-2)	450	150	2.3^{m}		
82 (AFB-3)	450	185	$.93^{r}$	25,000	28×10^{-5}
83 (AFB-4)	459	185	$.80^{r}$		
84 (AFB-5)	776	235			
Central area					
Da-87 (AFB-8)	452	130			
89 (AFB-10)	450	750	2.3^{r}	<12,000	$<12\times10^{-5}$
92 (AFB-13)	800	485			
Western area					
Da-85 (AFB-6)	500	330	2.5^{r}		
88 (AFB-9)	451	265	1.4^{r}		
90 (AFB-11)	600	660	15^{m}	<55,000	$<10\times10^{-5}$
91 (AFB-12)	600	640	18^{r}		
93 (AFB-14)	800	758	4.6^{r}		
Warehouse area					
Da-77	700		$.33^{r}$		
78	300		$.42^{m}$		
79	300	66		1,200	
94		85			
95		70	2.3^{r}		
96		85			

Pumping rates of wells in the eastern area range from 150 to 260 gpm and the specific capacities of the wells range from 0.80 to 2.3 gpm per foot of drawdown (table 1). The average transmissibility of aquifers in this area, as determined from drawdown data for wells Da–80 and Da–83, is about 25,000 gpd per foot. These wells were used for the observations because it is believed that they have greater hydraulic connection with the pumped well than does well Da–82.

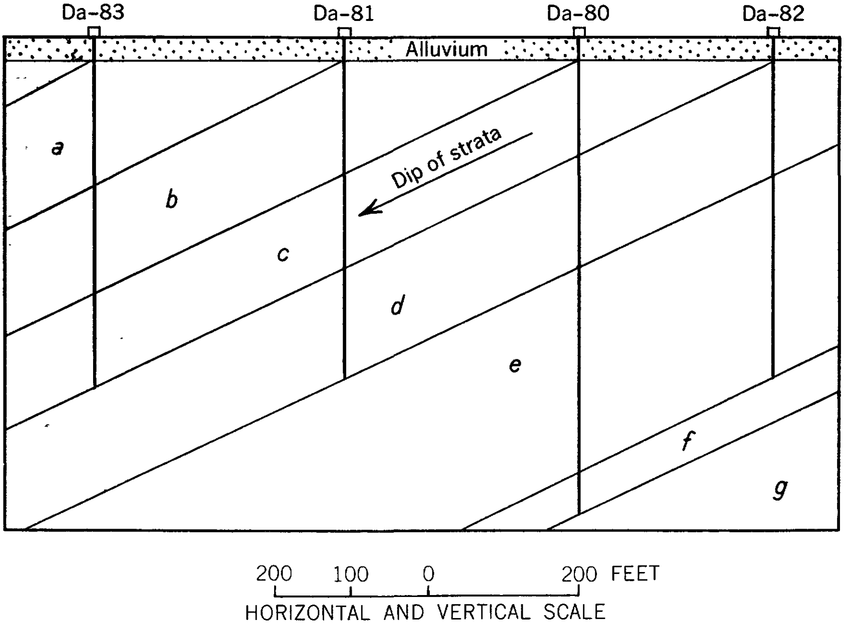

FIGURE 10.—Cross section showing relation of strata penetrated by wells in eastern part of Olmsted Air Force Base.

a. Strata penetrated only by Da–83.
b. Strata penetrated only by Da–81 and 83.
c. Strata penetrated only by Da–80, 81, and 83.
d. Strata penetrated only by Da–80, 81, and 82.
e. Strata penetrated only by Da–80 and 82.
f. Strata penetrated only by Da–80.
g. Strata not penetrated.

(See fig. 10.) The storage coefficient of the aquifer is 28×10^{-5}, a figure typical of artesian aquifers.

One pumping test was made in the eastern area. Da–81 (AFB–2) was pumped at 200 gpm for 859 minutes, and wells Da–80, 82, and 83 (AFB–1, 3 and 4) were used as observation wells. Water levels in the observation wells declined during the pumping test, indicating hydraulic connection among the wells. Maximum drawdowns were as follows: Da–81 (AFB–2), 90 feet; Da–80 (AFB–1), 5.6 feet; Da–82 (AFB–3), 0.6 foot; Da–83 (AFB–4), 6.5 feet. Wells Da–80 and 83 are approximately 325 feet from the pumped well, and Da–82 is 630 feet from the pumped well. Figure 10 shows the relation between strata penetrated by these four wells.

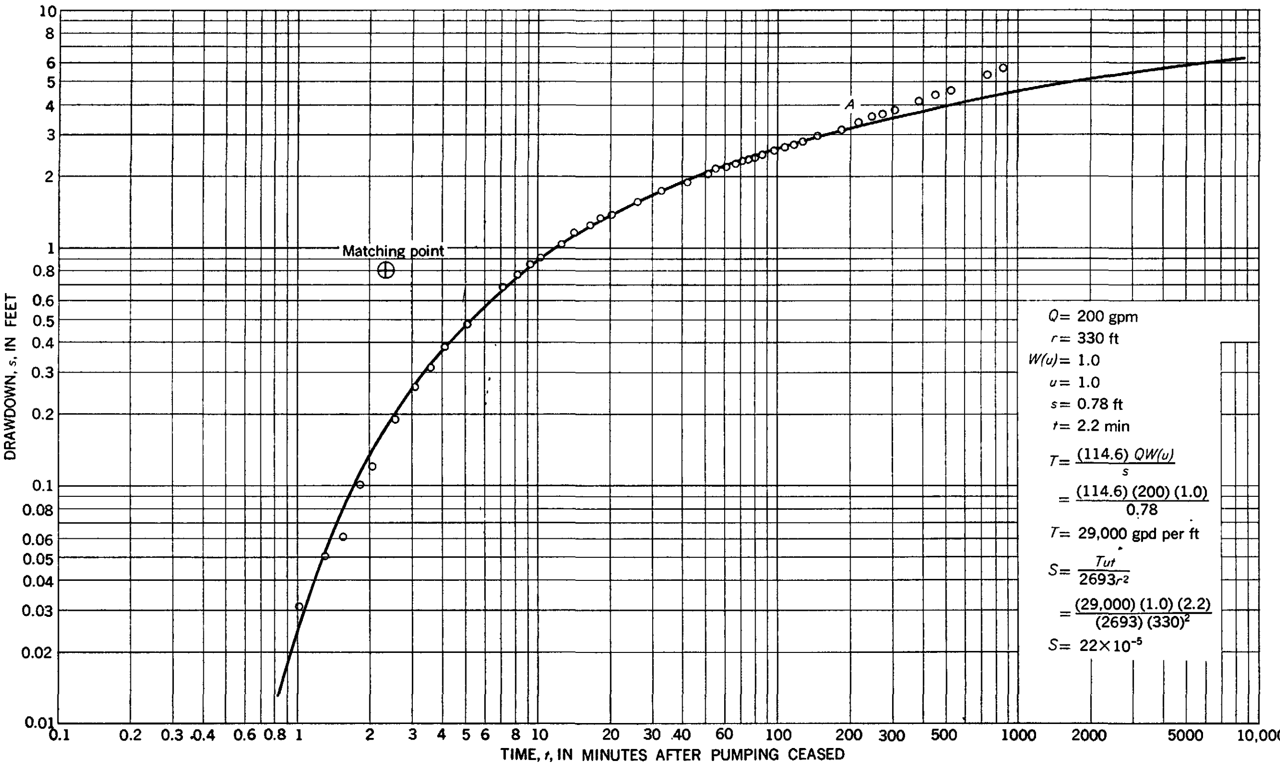

FIGURE 11.—Logarithmic graph of drawdown in well Da–80. Pumping test, drawdown cycle; data plot, drawdown of observation well Da–80; location, main base (eastern area); discharging well Da–81; observation wells, Da–80, 82, and 83; date of test, Feb. 2, 1959.

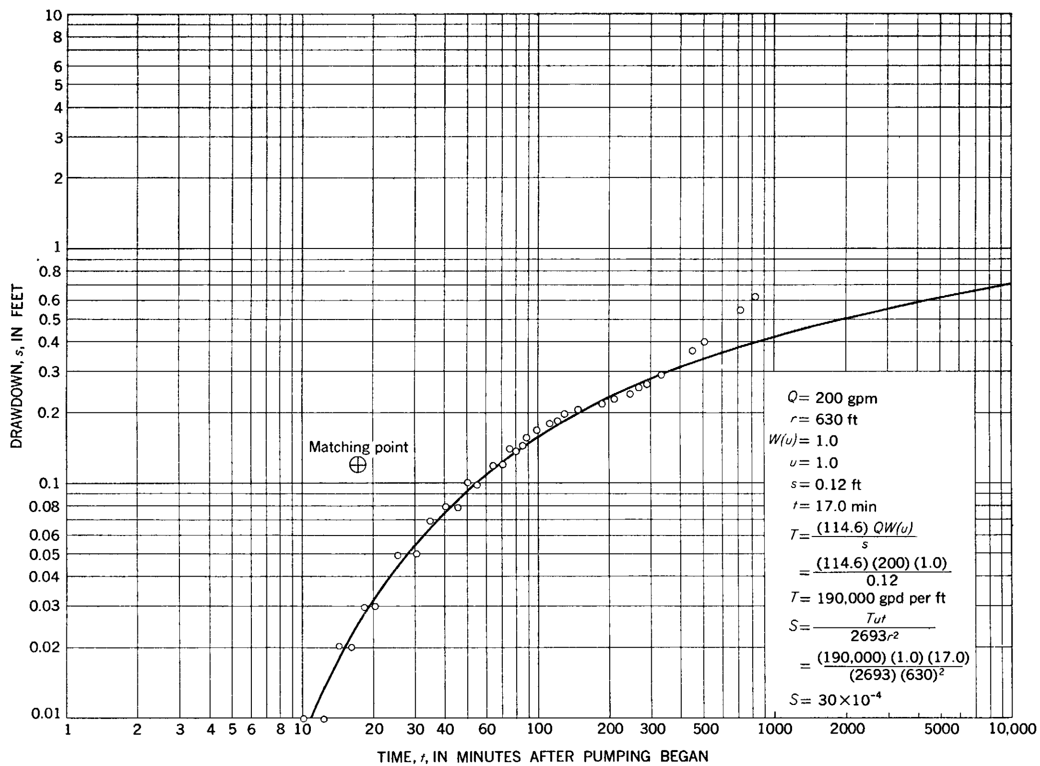

FIGURE 12.—Logarithmic graph of drawdown in well Da–82. Pumping test, drawdown cycle; data plot, drawdown of observation well, Da–82; location, main base (eastern area); discharging well, Da–81; observation wells, Da–80, 82, and 83; date of test, Feb. 2, 1959.

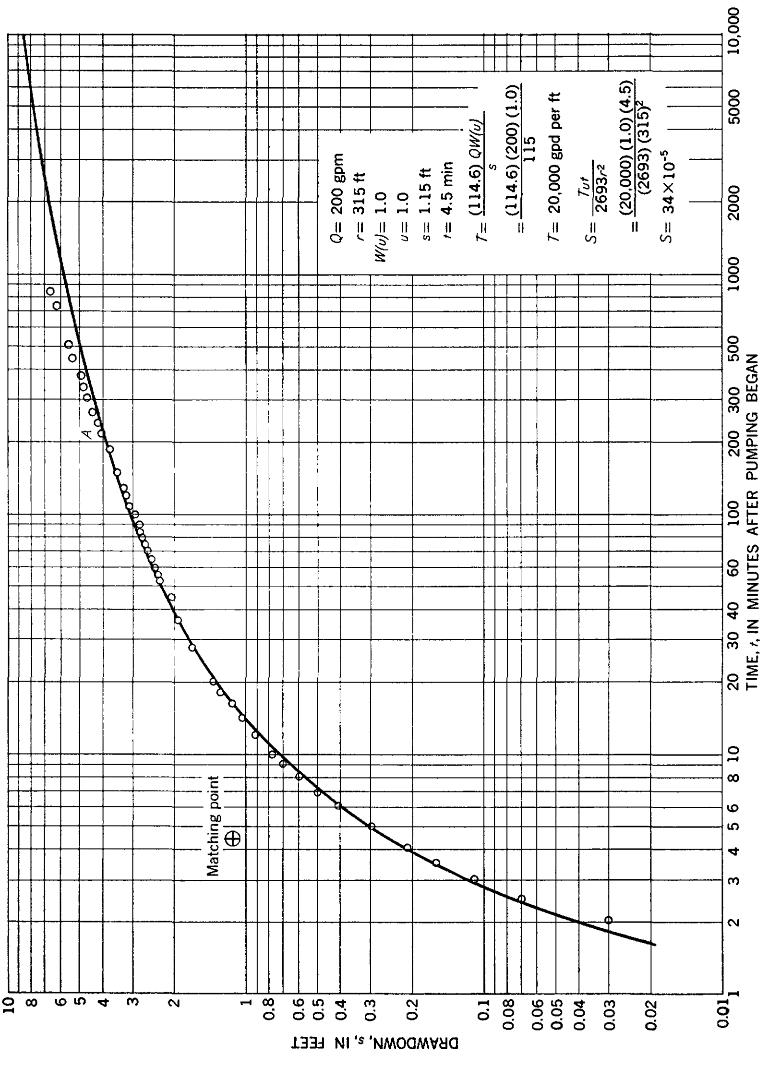

FIGURE 13.—Logarithmic graph of drawdown in well Da–83. Pumping test, drawdown cycle; data plot, drawdown of observation well Da–83; location, main base (eastern area); discharging well, Da–81; observation wells, Da–80, 82, and 83; date of test, Feb. 2, 1959.

Figures 11, 12, and 13 show drawdown curves of observation wells Da-80, 82, and 83. At the point on each curve the line steepened in slope, indicating an impermeable boundary. The effect of the impermeable boundary appeared in wells Da-80 and Da-83 about 200 minutes after pumping started. It appeared in well Da-82 after 400 minutes of pumping. The exact nature of the impermeable boundary is not known.

Pumping rates of wells in the central area range from 130 to 750 gpm. The specific capacity of well Da-89 (AFB-10) is reported to be 2.3 gpm per foot of drawdown. (See table 1.)

One pumping test was made in this area. Well Da-92 (AFB-13) was pumped at 575 gpm for 195 minutes and well Da-87 (AFB-8) was used as an observation well. The water level in the observation well declined 5.5 feet during the test, indicating hydraulic connection with the pumped well. The water-level drawdown in the pumped well was more than 90 feet. The coefficients of transmissibility and storage obtained from figure 14 are believed to be greater than the correct values, because well Da-87 taps only the upper part of the stratigraphic section penetrated in well Da-92, and well Da-87 probably does not tap the strata that yield much of the water to well Da-92. Figure 14 shows the effects of a recharge boundary at point A. The effect became apparent 15 minutes after pumping started. The recharge-boundary effect is probably caused by induced recharge from the Susquehanna River, which is 2,200 feet from well Da-87. It is not known definitely whether the river is recharging the aquifer directly or recharging the overlying alluvium, which in turn recharges the aquifer. In either case, however, the pumping of well Da-92 results in diversion of river water to the artesian aquifer at the Air Force Base.

Wells in the western area are pumped at rates ranging from 265 gpm to 758 gpm, and the specific capacities of wells range from a reported 1.4 gpm per foot of drawdown to a reported 18 gpm per foot of drawdown. (See table 1.) The coefficient of transmissibility of the aquifer penetrated by well Da-91 (AFB-12) was calculated to be 55,000 gpd per foot, but this figure may be too high. The storage coefficient is calculated to be 10×10^{-5}.

A test was made in this area by pumping well Da-90 (AFB-11) at 700 gpm for 315 minutes and observing the drawdown of water level in wells Da-88 (AFB-9) and Da-91 (AFB-12). The water levels in the observation wells declined during the test, indicating hydraulic connection with the pumped well. The maximum drawdowns observed were 45 feet in well Da-90, 0.7 foot in well Da-88, and 4.6 feet in well Da-91. As shown in figure 15, the upper strata penetrated by the pumped well are also penetrated by well Da-91, whereas only the

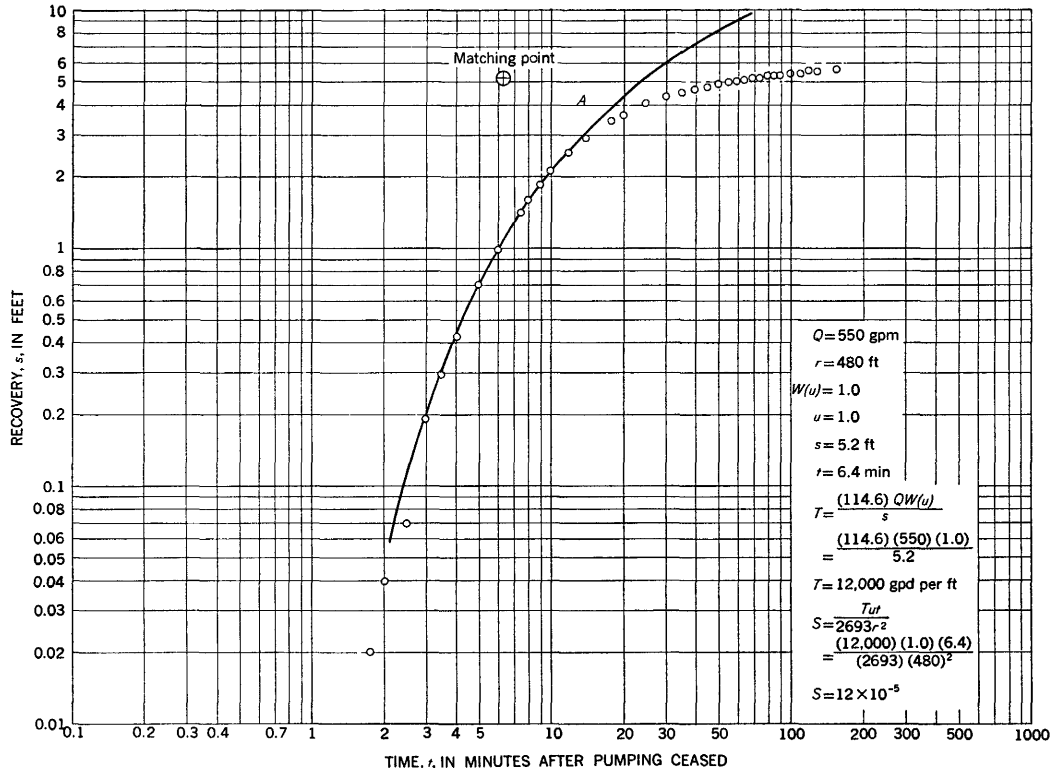

FIGURE 14.—Logarithmic graph of recovery in well Da–87. Pumping test, recovery cycle; data plot, recovery of observation well Da–87; location, main base (central area); discharging well, Da–92; observation well, Da–87; date of test, Jan. 30, 1959.

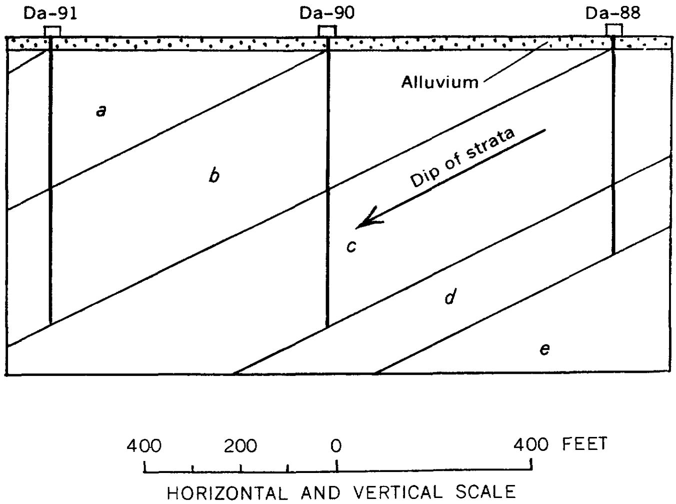

FIGURE 15.—Cross section showing relation of strata penetrated by wells in western part of Olmsted Air Force Base.

a. Strata penetrated only by Da–91.
b. Strata penetrated only by Da–90 and 91.
c. Strata penetrated only by Da–88 and 90.
d. Strata penetrated only by Da–88.
e. Strata not penetrated.

lower strata are penetrated in well Da–88. Because much greater drawdown occurred at well Da–91, it is probable that the important water-bearing strata in well Da–90 occur in the upper half of the well. Further evidence of this probability will be discussed subsequently.

Figures 16, 17, and 18 show recovery curves for wells Da–88, 90, and 91. Point A on the curves shows the effect of a recharge boundary, which occurred half a minute after pumping ceased in well Da–90, 7 minutes after pumping ceased in well Da–91, and 60 minutes after pumping ceased in well Da–88. The effect of the recharge boundary on water levels occurred very early in the test, which indicates that the recharging source is nearby. The ultimate source is clearly the Susquehanna River. The recharging source is not necessarily the river proper but may be the alluvium, which in turn is recharged by river water. The wide difference between arrival times of the effects of the recharge boundary in the observation wells indicates that Da–88 is not as closely connected hydrologically to the pumped well as is Da–91. This is further evidence that the water-bearing strata are largely in the upper half of the pumped well.

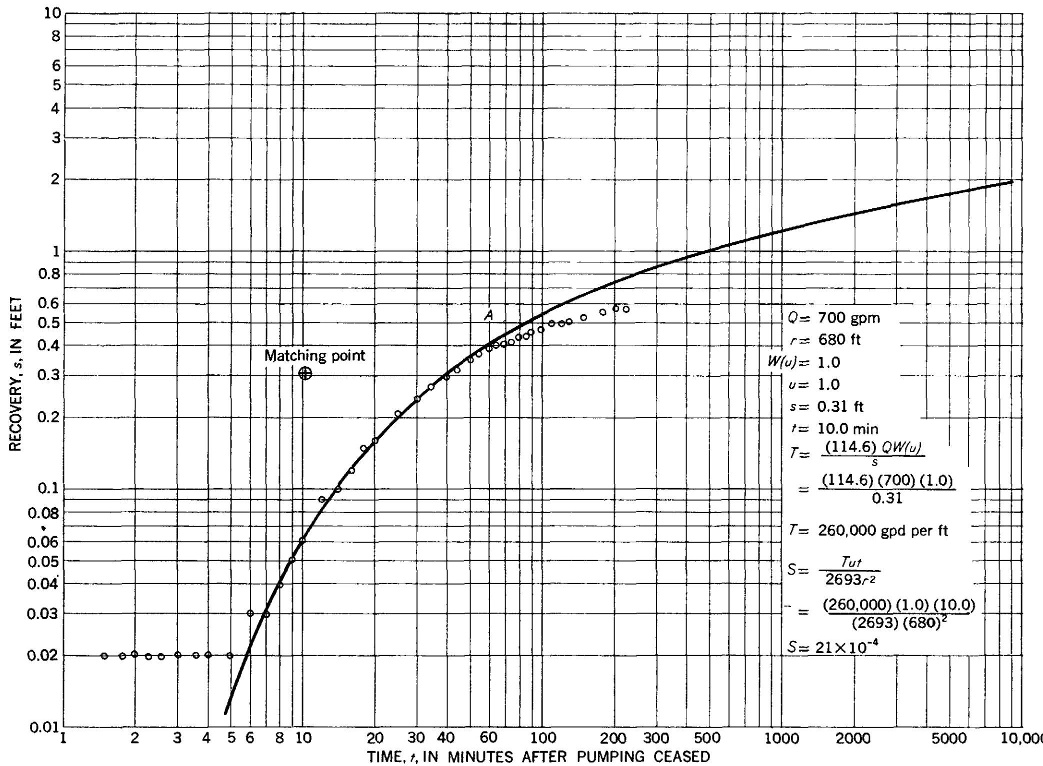

FIGURE 16.—Logarithmic graph of recovery in well Da–88. Pumping test recovery cycle; data plot, recovery of observation well Da–88; location, main base (western area); discharging well, Da–90; observation wells, Da–88 and 91; date of test, Jan. 26, 1959.

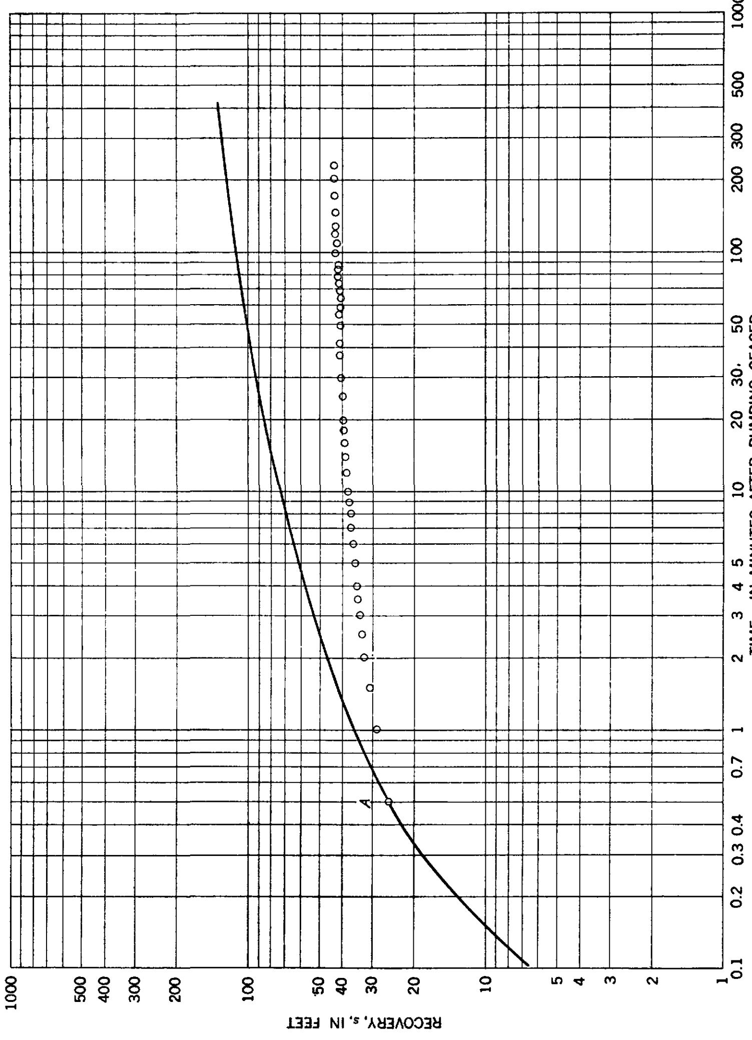

FIGURE 17.—Logarithmic graph of recovery in well Da–90. Pumping test, recovery cycle; data plot, recovery of discharge well Da–90; location, main base (western area); discharging well, Da–90; observation wells; Da–88 and 91; date of test, Jan. 26, 1959. It is not possible to compute the aquifer coefficient from these data.

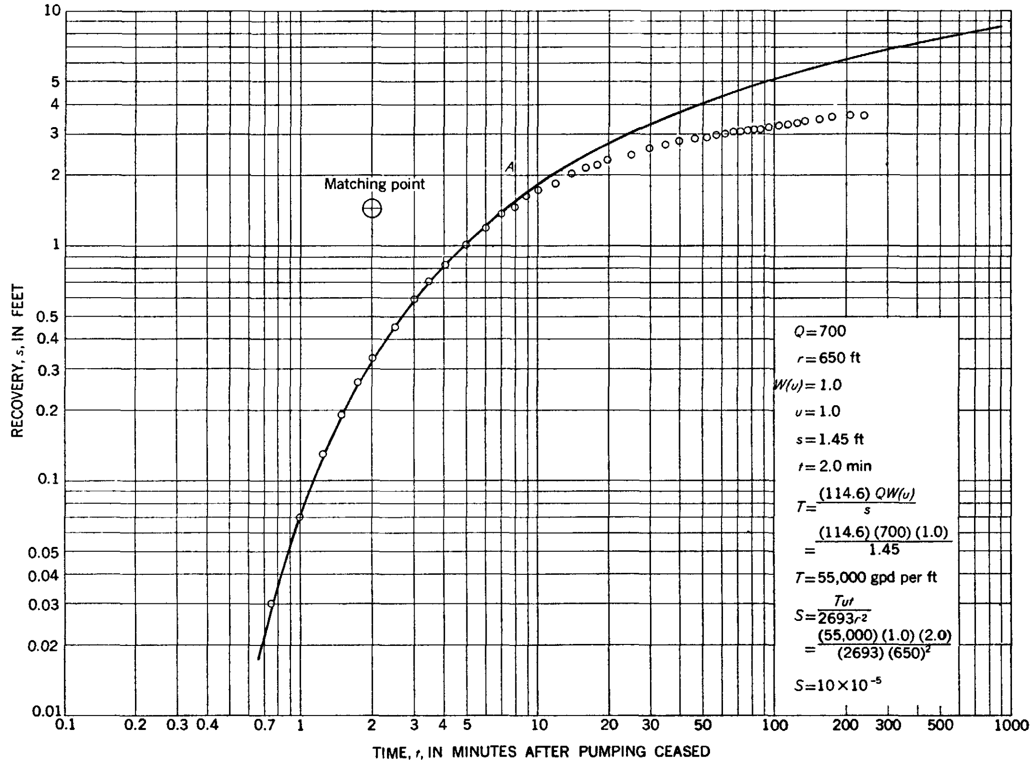

FIGURE 18.—Logarithmic graph of recovery in well Da–91. Pumping test, recovery cycle; data plot, recovery of observation well Da–91; location, main base (western area); discharging well, Da–90; observation wells, Da–88 and 91; date of test, Jan. 26, 1959.

GEOCHEMISTRY

Ground water in the main part of Olmsted Air Force Base is high in calcium and low in sodium and potassium. The chemical composition of the water differs from well to well, and in any given well it varies with time. Hardness as $CaCO_3$ ranges from 137 to 826 ppm (parts per million). Dissolved solids range from 200 to 1,340 ppm. Analyses of water from wells Da–80 to Da–93 (AFB 1–14) on the main base are given in table 2.

TABLE 2.—*Chemical analyses of water from*

[In parts per million

USGS Well No.	Owner and owner's well No.	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
	Olmsted Air Force Base:							
Da–80	Well 1	6–5–53	78	0.01	103	18	14	1.5
80	do	5–7–56	26	.09	85	32	[1]6.4	
80	do	6–11–57	31	.07	85	16	[1]14	
80	do	7–23–58	29	.08	82	18	15	--------
Da–81	Well 2	6–5–53	87	.08	75	16	10	1.5
81	do	5–7–56	26	.03	75	21	[1]2.5	
81	do	6–11–57	30	.05	71	15	[1]9.9	
81	do	7–22–58	26	.03	76	17	7.6	--------
Da–82	Well 3	6–5–53	81	.04	86	9.7	10	1.3
82	do	5–7–56	28	.00	92	15	[1]7.1	
82	do	6–11–57	30	.08	69	7.5	[1]9.0	
82	do	7–27–58	26	.08	80	7.9	8.5	--------
Da–83	Well 4	6–5–53	94	.04	90	24	11	1.6
83	do	5–7–56	23	.02	84	25	[1]5.1	
83	do	6–11–57	28	.10	56	15	[1]10	
83	do	7–23–58	24	.07	69	17	4.8	--------
Da–84	Well 5	6–5–53	74	.05	270	37	47	1.9
84	do	5–10–56	28	.03	176	45	[1]1.4	
84	do	6–18–57	31	.07	79	11	[1]14	
84	do	7–25–58	29	.26	154	18	27	--------
Da–85	Well 6	6–5–53	98	.08	68	22	--------	1.5
85	do	5–9–56	21	.00	61	14	[1]4.7	
85	do	6–12–57	18	.08	71	4.0	[1]25	
85	do	7–25–58	15	.22	118	17	16	--------
Da–87	Well 8	6–5–53	95	.59	66	10	10	1.6
87	do	5–11–56	18	2.4	62	14	[1]8.3	
87	do	6–20–57	23	5.9	58	11	[1]9.7	
87	do	7–24–58	21	1.6	53	12	7.8	--------
Da–88	Well 9	5–9–56	17	.06	81	18	[1]12	
88	do	6–12–57	22	.15	98	22	[1]15	
88	do	7–22–58	20	.08	154	31	23	--------
Da–89	Well 10	5–11–56	25	.20	45	9.9	[1]8.6	
89	do	6–20–57	28	--------	54	8.5	[1]7.8	
89	do	7–24–58	25	.23	53	11	5.3	--------
Da–90	Well 11	6–13–57	24	.12	71	14	[1]10	
90	do	7–22–58	21	.07	86	21	7.6	--------
Da–91	Well 12	6–13–57	20	.31	71	11	[1]13	
91	do	7–23–58	16	.06	66	13	10	--------
Da–92	Well 13	6–13–57	26	1.2	40	9.0	[1]5.8	
92	do	7–28–58	26	1.4	44	11	9.7	--------
Da–93	Well 14	6–18–57	24	.38	101	15	[1]9.7	
93	do	7–25–58	22	.16	162	27	33	--------

[1] Sodium and potassium, calculated as sodium.

Field determinations of hardness and specific conductance of ground water from the warehouse area are available for comparison with data from the main base. The hardness as $CaCO_3$ and specific conductance of water from well Da–78 are 120 ppm and 280 micromhos per cm. A specific conductance of 280 micromhos per cm is approximately equivalent to 190 ppm of dissolved solids. Water samples from wells Da–94, 95, and 96 (Pennsylvania Turnpike, Gulf Oil Co. service station), adjacent to the warehouse area, had a hardness of

wells on Olmstead Air Force Base

except as indicated]

Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness	Specific conductance (micromhos at 25° C.	pH
188	0	165	16	0.0	16	510	331	177	669	7.8
188	0	162	14	.0	19	450	344	190	675	7.9
177	0	125	12	.1	19	398	278	133	578	7.0
188	0	120	12	.0	18	394	279	125	577	7.2
188	0	89	10	.2	19	410	253	99	526	7.9
189	0	88	11	.0	21	351	274	117	529	8.2
180	0	80	9.8	.1	18	344	239	91	495	7.3
182	0	95	9.0	.0	19	349	260	111	520	7.6
192	0	83	13	.0	22	410	254	97	539	7.5
195	0	101	14	.0	27	395	291	131	586	7.7
173	0	43	8.8	.1	28	290	203	61	429	7.2
185	0	63	10	.0	24	333	232	81	495	7.3
172	0	177	9	.0	16	520	323	182	654	7.9
166	2	156	6.7	.0	15	413	312	176	599	8.3
144	0	80	5.8	.1	16	296	201	83	437	7.2
154	0	103	6.2	.1	13	372	242	116	497	6.6
140	0	708	36	.1	31	1,340	826	711	1,550	7.9
164	0	434	16	.1	22	820	624	490	1,170	8.0
177	0	104	7.7	.1	20	347	242	106	510	7.3
166	0	337	8.8	.3	20	676	458	322	901	7.6
172	0	129	8.5	.0	14	430	260	119	560	7.9
148	0	73	9.0	.1	12	278	210	88	430	7.9
148	0	101	8.4	.1	11	314	194	72	475	7.7
115	0	274	10	.1	6.5	554	365	271	720	7.2
196	0	50	10	.0	5.2	350	206	45	431	7.6
164	0	75	7.3	.1	9.4	297	213	78	431	8.1
180	0	45	5.6	.1	9.1	266	190	42	403	7.8
172	--------	41	5.5	.1	8.1	268	182	41	380	7.8
204	0	115	7.0	.0	7.5	368	276	109	556	8.0
210	0	172	7.5	.1	7.7	462	335	163	652	7.1
218	--------	345	9.5	.1	11	727	512	333	980	8.0
146	0	26	7.0	.0	19	216	153	33	317	7.9
163	0	24	11	.1	15	237	170	36	370	6.9
170	0	22	11	.1	13	240	177	38	378	7.5
189	0	75	9.8	.1	11	320	235	80	477	7.2
181	0	135	12	.0	14	468	301	153	595	7.6
158	0	95	9.2	.0	11	318	222	93	476	6.8
126	0	111	12	.0	5.7	317	218	115	463	7.7
118	0	31	4.6	.1	17	200	137	41	295	7.3
128	0	46	4.8	.0	20	224	155	50	338	7.4
196	0	156	5.8	.1	3.5	425	314	153	604	7.8
201	0	396	6.5	.1	1.0	792	516	351	1,000	8.0

137 ppm and a specific conductance of 360 micromhos per cm (approximately 240 ppm of dissolved solids). Hence, judging from these data, ground water in the warehouse area is much softer and contains less dissolved solids than water on the main base. (See table 2.)

Fluid-resistivity logs revealed a highly mineralized water at depths below 300 feet in wells Da-77 and Da-79. Lack of sufficient data prevents a satisfactory explanation of this mineralization, but because the water occurs at the same depth in two wells which are approximately along the strike of the strata, it is believed that this water may be confined to a particular bed or group of beds.

Tests for specific conductance and hardness were made on samples of ground water taken during pumping tests. Hardness as $CaCO_3$ and specific conductance increased during the early stages of three of the tests but remained constant as pumping continued. Table 3 shows the changes that occurred during pumping. The changes in chemical composition of the water that took place during the early stages of pumping may have been caused by the changes in the amounts of water supplied by individual aquifers tapped by the pumped well, or they may have been caused by movement of more highly mineralized water from downdip in one or more aquifers.

Ground water in the main base falls into three geochemical groups that coincide with the three distinct areas on the Air Force Base. Each of these areas has a different pumping history. Table 4 summarizes certain characteristics of water in each group.

TABLE 3.—*Change of hardness and specific conductance during pumping of wells*

Well No.	Time (minutes)	Hardness as $CaCO_3$ (ppm)	Specific conductance (micromhos per cm at 25° C.)
Da-81 (AFB-2)	38	154	425
	105	205	475
	210	205	480
	316	222	500
	480	222	500
	780	222	500
Da-92 (AFB-13)	5	171	285
	75	205	450
	130	222	465
	180	222	475
Da-90 (AFB-11)	30	290	
	60	290	
	70		675
	135	308	
	150		675
	215		675
	300	308	

TABLE 4.—*Comparison of the chemical character of ground water in the three areas of the main base*

Geochemical group	Year	Average sulfate content (ppm)	Percentage equivalents per million of $SO_4+Cl+NO_3$	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C.)
Eastern area	1953	244	59	397	788
Wells Da-80, 81, 82,	1956	188	57	369	712
83, 84 (AFB 1-5).	1957	86	46	233	490
	1958	144	52	294	598
Central area	1953	50	31	206	431
Wells Da-87, 89, 92	1956	51	36	183	374
(AFB 8, 10, 13).	1957	33	31	166	356
	1958	36	32	171	365
Western area					
Wells Da-85, 88, 90,	1956	94	45	243	493
91, 93 (AFB 6, 9, 11,	1957	120	49	260	537
12, 14).	1958	252	65	382	752

One geochemical group coincides with the eastern area, which includes wells Da-80, 81, 82, 83, and 84 (AFB-1, 2, 3, 4, and 5). This area has been yielding ground water since 1941. The water is moderately to very hard and is fairly high in sulfate and dissolved solids. Sulfate content, hardness, and specific conductance decreased from 1953 to 1958.

Another geochemical group coincides with the central area, which includes wells Da-87, 89, and 92 (AFB-8, 10, 13). Water from this area is relatively low in sulfate content, contains less dissolved solids, and, though hard, is much softer than water in the eastern area. Much less water has been pumped from this area than has been pumped from the eastern area, and little or no change in the chemical character of the ground water took place between 1956 and 1958. Wells Da-87 and Da-92 have been contaminated by petroleum products since 1957. The contamination was caused by leakage of petroleum products (used in Air Force Bace operations) through the alluvium into the aquifer.

The third geochemical group coincides with the western area which includes wells Da-85, 88, 90, 91, and 93 (AFB-6, 9, 11, 12, and 14). In general, this area except for Da-85 has been yielding water since 1953. The water here has been characterized by a rapid change in chemical character from moderate sulfate content (94 ppm in 1956) to high sulfate content (252 ppm in 1958). Specific conductance and hardness as $CaCO_3$ also have risen sharply.

Figure 19 shows the percentages of equivalents per million of important constituents or groups of constituents in the various types of

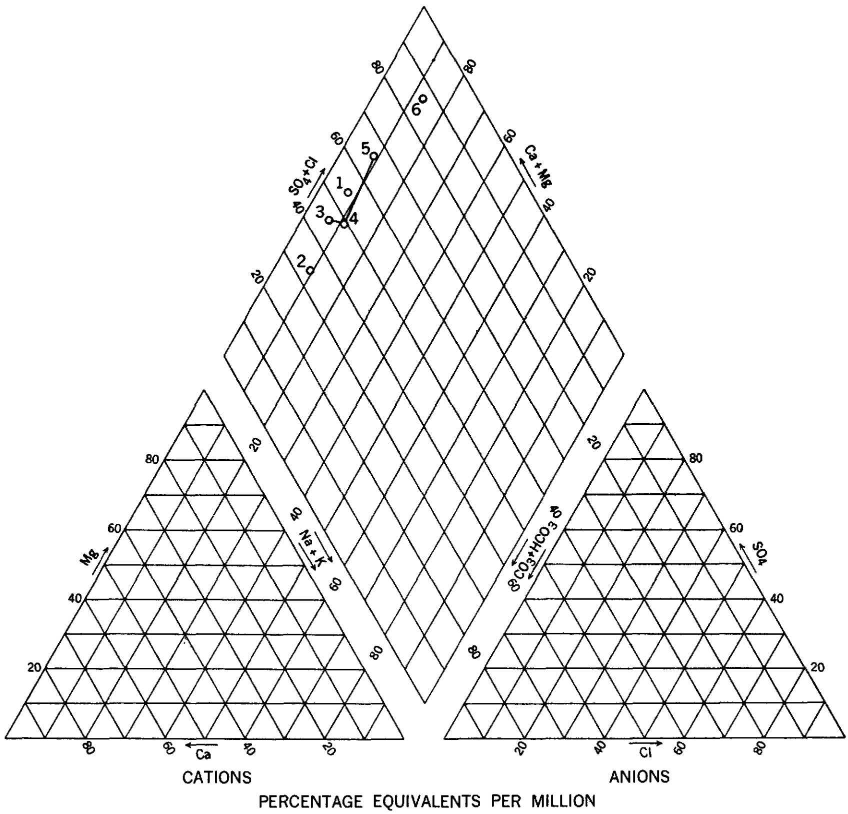

FIGURE 19.—Trilinear diagram showing chemical character of ground water at Olmsted Air Force Base.

1. Eastern area, wells Da–80 to Da–84.
2. Central area, wells Da–87, 89, and 92.
3. Western area, wells Da–85, 88, 90, 91, and 93; 1956.
4. Western area, wells Da–85, 88, 90, 91, and 93; 1957.
5. Western area, wells Da–85, 88, 90, 91, and 93; 1958.
6. Susquehanna River, east channel at Harrisburg.

water at Olmsted Air Force Base. Sulfate and chloride are plotted against carbonate and bicarbonate on one axis and calcium and magnesum are plotted against sodium and potassium on another axis. The graph shows the general chemical character of ground water in the three geochemical groups. The graph shows also the progressive change in water character toward the calcium sulfate type in the western area.

Ground water in the main part of Olmsted Air Force Base appears to be a mixture of two chemical types: (a) the calcium bicarbonate type, as exemplified by water from the central area and by the early analyses of water from the western area, and (b) the calcium sulfate type, as exemplified by water from the eastern area and by the 1958 analyses from the western area. Water from a newly pumped or little-pumped area falls within the calcium bicarbonate type and is low in dissolved solids. As heavy pumping continues, the water changes to the calcium sulfate type and becomes harder, and the dissolved solids increase. The first type probably represents water that is being recharged by precipitation at the outcrop area under the alluvium. The second type represents water that has been in storage in the aquifer, probably downdip from the pumped well.

CONCLUSIONS

The warehouse area does not appear to be a potential source for large supplies of ground water. The coefficient of transmissibility of the aquifers tested is very low, and no aquifers of higher potential appear to be present. Specific capacities of the existing wells also are very low, and the presence of nearby impermeable boundaries means that water levels will continue to decline rapidly in the area if large withdrawals are made. In addition, the electric logs of wells Da–77 and 78 revealed the presence of some highly mineralized water in the area.

However, if it is absolutely necessary for a ground-water supply to be developed in the warehouse area, the following procedures should afford the greatest possibility of success. It is probable that 10 to 15 wells would be needed to obtain a total yield of 700 gpm. As the specific capacities of the wells are low, the wells should be located so as to penetrate the greatest possible section of potential water-bearing strata. Wells should be spaced sufficiently far apart (stratigraphically) to insure that no two nearby wells will penetrate the same strata; this will afford minimum interference between wells. Wells drilled along a line perpendicular to the strike of the strata (in the direction of dip) will permit minimum spacing between wells. Wells drilled according to some other plan should be spaced farther apart. The average dip of the strata in the area is 26° to the northwest, and the tangent of this angle is approximately 0.5; therefore, the lowest strata in a 300-foot well (for example) will crop out 600 feet to the southeast of the well. Wells drilled 300 feet deep should, therefore, be spaced at least 600 feet apart along a line perpendicular to the strike.

If any exceptionally good aquifer is penetrated, it may be advisable to drill additional wells along the strike of the strata in order to tap the same aquifer, but care should be taken to space the wells far enough apart to minimize interference between wells.

Available data are insufficient to determine optimum depths of wells. However, the range in depth of wells probably should be from 300 to 600 feet.

Large supplies of ground water are available on the main base. The eastern area contains greater supplies of water than the warehouse area, but extensive further development in the vicinity of the existing wells would cause excessive interference because a relatively impermeable boundary exists in this area.

The central and western areas are capable of yielding large supplies of water. A recharge boundary representing induced recharge from the Susquehanna River exists in both these areas. The central area, however, has yielded ground water of poor quality due largely to surface contamination.

The western area appears to offer the greatest potentiality for future ground-water development. The specific capacities of wells and the transmissibilities of the aquifers in this area are the highest on the entire base. The existing wells in the western area are capable of yielding sufficient additional water to supply the demands of the warehouse area. Wells in this area, especially wells Da–90, 91, and 93 (AFB–11, 12, and 14), can be pumped for considerably longer periods of time each day than they are now being pumped, without danger of excessive lowering of water levels.

A supplemental supply of water may be required in case of breakdowns or other emergencies. To provide for such an occurrence, one new well in the western area may be needed.

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