Ground-Water Geology and Hydrology of Bunker Hill Air Force Base and Vicinity Peru, Indiana

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-B

Prepared on behalf of the Air Force, U.S. Department of Defense

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By F. A. WATKINS, JR., *and* J. S. ROSENSHEIN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GROUND-WATER GEOLOGY AND HYDROLOGY OF BUNKER HILL AIR FORCE BASE AND VICINITY, PERU, INDIANA

By F. A. Watkins, Jr., and J. S. Rosenshein

ABSTRACT

The report describes an area of about 35 square miles in the south-central part of northern Indiana, with special emphasis on the 16 square miles in the vicinity of the Bunker Hill Air Force Base. The land surface is flat to rolling in the vicinity of the airbase, except where Pipe Creek has eroded into the upland, and its topographic expression is that of a ground moraine whose land form has been influenced somewhat by the configuration of the underlying bedrock. This buried bedrock is covered by glacial material consisting chiefly of till. The uppermost till is a brown fissile silty clay with embedded sand and gravel and is underlain by a bluish-gray till that is a silty clay. Thin layers of sand and gravel are interbedded with the tills. Because of the type of material in them, the glacial deposits are considered a source of additional supply of water for the base only where the glacial cover is thickest over depressions in the bedrock surface.

Rocks of Middle Silurian age crop out along the northeast edge of the airbase. The Mississinewa shale, the oldest of these rocks penetrared by water wells on the airbase, is a bluish-gray argillaceous to highly argillaceous dolomitic limestone. This rock is overlain by the Liston Creek formation which is a light-gray to pale-yellowish-brown argillaceous dolomitic limestone with permeable zones throughout its thickness and is the chief bedrock aquifer in the area. Coefficients of transmissibility in this aquifer, as determined from tests on the base wells, range from about 13,000 to about 46,000 gpd per ft (gallons per day per foot). The long-term coefficient of transmissibility, as determined from piezometric-surface maps, is about 9,000 gpd per ft. Coefficients of storage range from 0.00001 to 0.002. The largest coefficients of transmissibility and storage are associated with a sinuous high in the bedrock surface which underlies the airbase.

Recharge to the rock aquifer occurs chiefly by slow percolation of precipitation through the overlying glacial material and is estimated to be about 2 million gpd in the 16 square miles in the vicinity of the airbase. The estimated flow is about 300,000 gpd through each mile-wide strip of the aquifer in the area. The estimated discharge in the area is about 700,000 gpd, of which the airbase currently (1959) is using about 650,000 gpd.

The natural slope of the piezometric surface is toward Pipe Creek. Pumping in the old well field has decreased the natural discharge to the creek but has not reversed this slope. Before the airbase was esatblished a ground-water divide existed along the south edge of the area. Pumping of wells in the old well field has caused this divide to move southward, and pumping of the well in the new

well field in the southeast corner of the airbase will cause the divide to move even further southward.

Ground water in the vicinity of the airbase is hard and has a high iron content. With some treatment, however, the water is made suitable for domestic, farm, public-supply, and many industrial uses.

INTRODUCTION

An investigation of the ground-water conditions at the Bunker Hill Air Force Base was begun in May 1959. This investigation was conducted by the U.S. Geological Survey at the request of the U.S. Air Force. The purpose was to determine the adequacy of the aquifers underlying the air base to meet the immediate needs for additional water supply, to determine the most feasible sites for additional wells in these aquifers or in other potential ground-water sources, and to provide adequate information to aid in sound development of the ground-water resources of the airbase with a minimum of interference between wells.

The investigation was made under the immediate supervision of C. M. Roberts, district geologist of the Ground Water Branch for Indiana.

LOCATION AND AREAL EXTENT

Bunker Hill Air Force Base is in parts of Cass and Miami Counties in the south part of north central Indiana (fig. 1) and is about 6 miles southwest of Peru, Ind. The area covered by this report is about 35 square miles; special emphasis is given to about 16 square miles.

PREVIOUS INVESTIGATIONS

Detailed information concerning the ground-water resources of the Bunker Hill Air Force Base and vicinity has not been published previously. Generalized information describing the ground-water resources of Cass and Miami Counties has been published in reports by Capps (1910), Harrell (1935), and Leverett (1899).

The geology of Cass and Miami Counties has been briefly described by Collett (1872), Elrod and Benedict (1894), Gorby (1889), and Leverett and Taylor (1915). The rocks of Silurian age in Cass and Miami Counties have been described in greater detail by Cumings and Shrock (1928), and the glacial deposits of Pleistocene age in Miami County have been described in greater detail by Thornbury and Deane (1955).

WELL-NUMBERING SYSTEM

A numbering system is used to locate and identify the wells in this report. Each well is assigned a designation that indicates its location according to the official rectangular public-land survey. For example, in the number for well 26/3–25A1, the numbers preceding the hyphen indicate that the well is in T. 26 N., R. 3 E. As all wells referred to

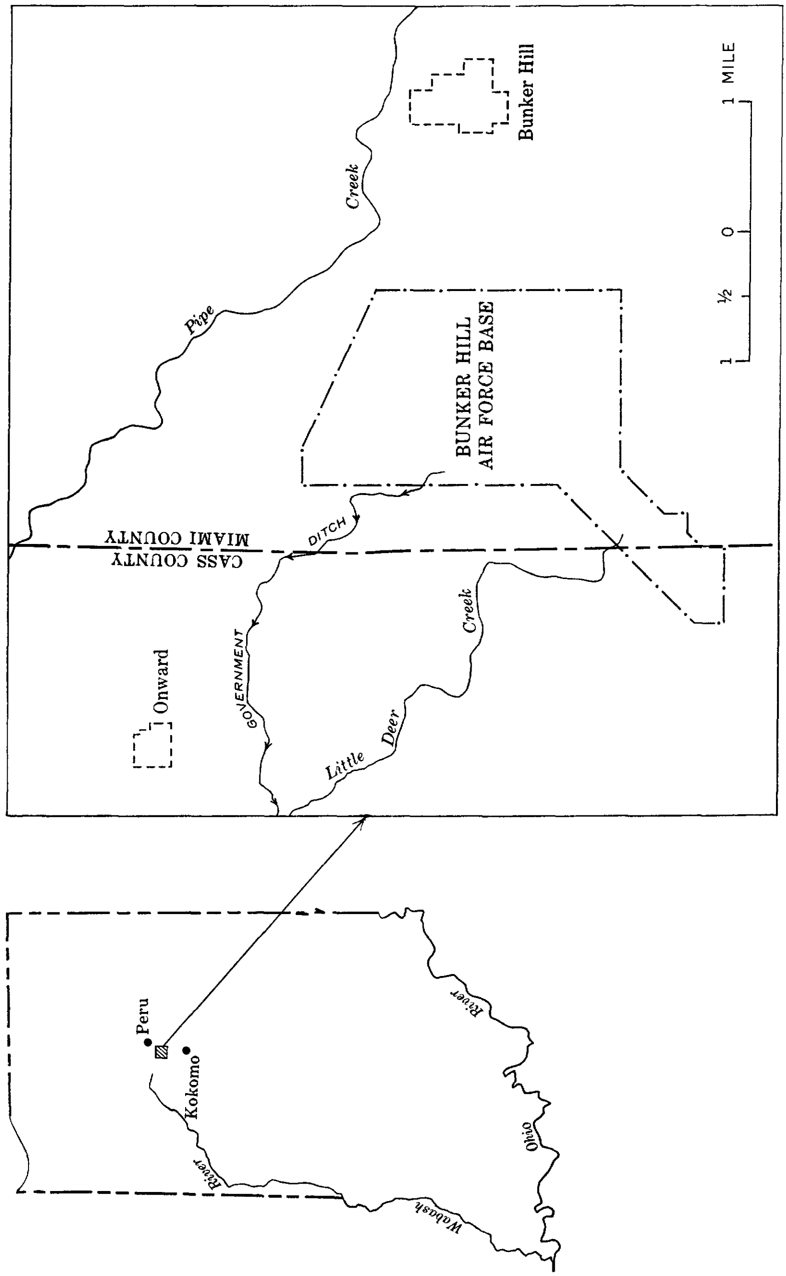

FIGURE 1.—Map of Indiana showing location of area described in this report.

in this report are east and north of the second principal meridian and base line, the letters indicating directions are omitted. The first number after the hyphen indicates the section in which the well is located. Each quarter-quarter section (40-acre tract) within a section is assigned a letter symbol, as shown in the figure 2. Within the quarter-quarter section the wells are numbered consecutively. For

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

FIGURE 2.—Diagram showing well-numbering system.

example, well 26/3–25A1 is the first well listed in NE¼NE¼ sec. 25, T. 26 N., R. 3 E. (See pl. 1.)

METHODS OF INVESTIGATION

Pertinent literature concerning the geology and ground-water resources was reviewed. Local well drillers were contacted and information concerning wells drilled in the area was collected. The locations of the wells were checked in the field, water levels were measured, and small samples of water were obtained for field chemical analyses wherever possible. Observation wells were established on the airbase, and a geologic and hydrologic reconnaissance was made of an area of about 145 square miles adjacent to the airbase. Data were collected concerning production tests on the existing airbase wells and on a pumping test of the new airbase well. In addition, a 48-hour pumping test was made in the new well field, and a shorter pumping test was made of the wells in the old well field. Earth-resistivity measurements were made at specific places, and electric and gamma-ray logs were obtained for selected wells. Samples from deep-structure borings and all available cuttings from water wells drilled on the airbase were collected for examination. These various data are used in the interpretations in the report.

ACKNOWLEDGMENTS

The authors wish to thank all persons who contributed information and assisted in the preparation of the report. Well drillers provided records of wells, related information, and rock cuttings from water wells on the airbase. The civilian and military personnel of the Air Force and the Navy were very cooperative in providing access to and information about the water supply of the airbase and about related matters. Mr. A. J. Franklin and Mr. D. Sheplar of the Base Installation Engineers Office were particularly helpful in coordinating efforts on the airbase before and during the pumping tests and in providing access to pertinent data concerning the airbase water supply.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The land surface in the vicinity of Bunker Hill Air Force Base is flat to slightly rolling and locally has a few small closed depressions (pl. 1). Its topography is that of a ground moraine influenced somewhat by configuration of the underlying bedrock surface. A topographic high extends along the south edge of the airbase, and slopes toward the north and the south.

The area is drained chiefly by Government Ditch and Little Deer Creek, which are tributaries of Pipe Creek. Along the northeast edge of the area, where Pipe Creek has eroded into the upland surface, the maximum relief is about 60 feet.

PRECIPITATION

The average annual precipitation is about 38 inches (fig. 3), according to the U.S. Weather Bureau station at nearby Kokomo, Ind. Yearly precipitation is rather evenly distributed, but, monthly precipitation is somewhat higher in April, May and September. Figure 4 shows the maximum, average, and minimum monthly precipitation and temperature at Kokomo, Ind., for the period 1893–1958.

The average annual temperature is about 54°F at Kokomo. January is the coldest month, having an average temperature of about 30°F, and July is the warmest month, having an average temperature of about 78°F.

GEOLOGY AND WATER-BEARING CHARACTERISTICS OF THE ROCK UNITS

A geologic reconnaissance was made to determine the characteristics and regional distribution of the consolidated and unconsolidated rocks.

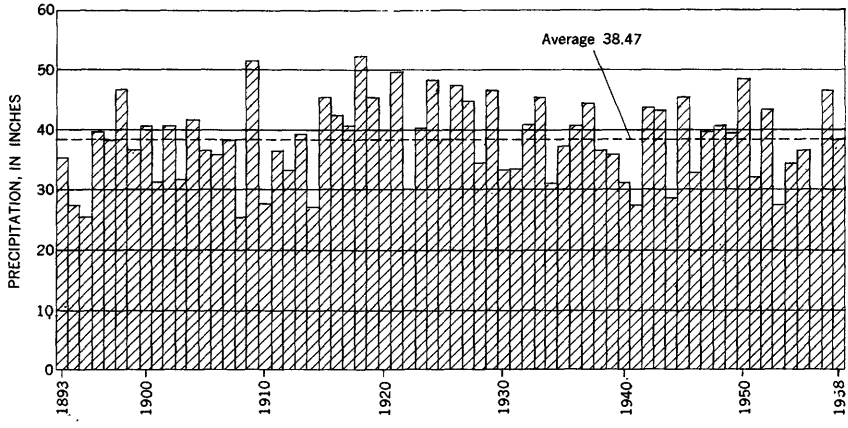

FIGURE 3.—Annual precipitation at Kokomo, Ind., 1893–1958.

Road cuts, ditches, and other outcrops were examined for information about the type of deposits, depositional characteristics, lithology, and other features that might affect the water-bearing properties and the recharge characteristics of the materials. The areal geologic map (pl. 2) was prepared chiefly from the data obtained during the reconnaissance and was modified somewhat as a result of interpretations of aerial photographs, foundation-test borings, published soils maps (Tharp and Kunkel, 1927; Rogers and others, 1955), and published geological reports (Cumings and Shrock, 1928; Thornbury and Deane, 1955).

SILURIAN SYSTEM

MIDDLE SILURIAN SERIES

The first detailed regional reconnaissance of rocks of Silurian age in northern Indiana was made by Cumings and Shrock (1927, 1928), who subdivided these rocks into five stratigraphic units on the basis of lithology, faunal characteristics, and formational contacts. The oldest of these stratigraphic units penetrated by wells on the airbase is the Mississinewa shale. Cumings and Shrock (1927, 1928) described this formation as a bluish-gray calcareous shale or argillaceous limestone (table 1), which has conchoidal fracture. The rock has pyrite along the joint planes and contains small mica flakes. Patton (1949) described the rock as a blue-gray argillaceous dolomitic silty massive limestone. The Mississinewa shale was penetrated by test wells drilled in the new well field in the SE¼SE¼NE¼ sec. 1, T. 25 N., R. 3 E. As determined by a study of rock samples from wells 25/3–1H3 and 25/3–1H4, the rock in the bottom 45 feet of these wells is tentatively referred to as the Mississinewa shale. The rock is fine-grained dolomitic limestone that is medium light gray to medium

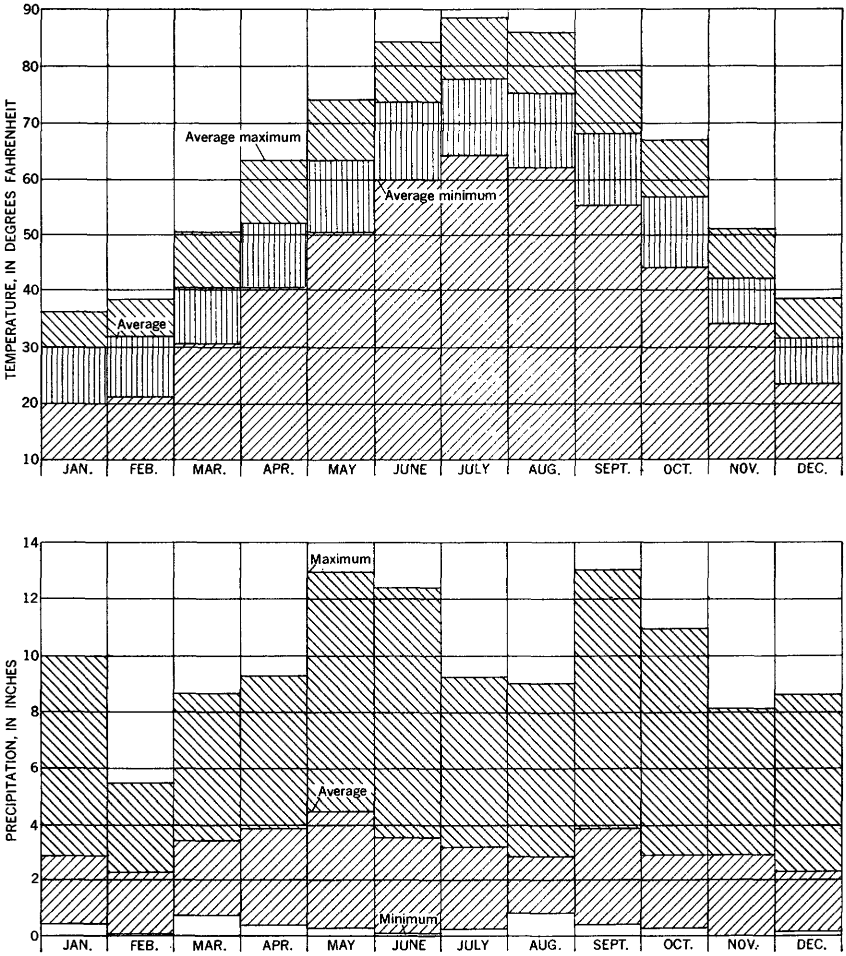

FIGURE 4.—Monthly temperature and precipitation at Kokomo, Ind., 1893–1958.

bluish gray and argillaceous to highly argillaceous. The argillaceous material, which is in the interstices between calcareous grains in the rock, has a marked effect upon the water-bearing characteristics of the formation. The rock contains much pyrite and many limonite spots. The formation is penetrated by all the deeper wells drilled on the airbase (pl. 2). The contact between the Mississinewa shale and the overlying rocks of Silurian age generally is distinctive in the well cuttings and in the gamma-ray logs of the deeper wells in the vicinity of the airbase. In well 26/3–25K1, however, the contact between the Mississinewa and the overlying rock is less distinctive and the rocks of the bottom 40 feet of the well are referred to the Mississinewa.

TABLE 1.—*Generalized stratigraphic section in the vicinity of Bunker Hill Air Force Base, Indiana*

System	Stratigraphic unit	Thickness	Character	Remarks
Quaternary	Undifferentiated	0-100+	Till, reddish- and tannish-brown to bluish-gray; chiefly silty clay; contains embedded sand and gravel; some thin glaciofluvial sand and gravel, locally moderately thick.	Overlain by recent thin organically rich deposits and alluvium.
	—Disconformity— Kokomo limestone.	0-50	Limestone and argillaceous limestone, interbedded, finely laminated, light- to dark-colored. Lower part of formation is more argillaceous than upper part.	May underlie area of report.
Silurian	—Disconformity— Liston Creek formation.	0-60	Limestone and nodular cherty limestone, containing alternate thin chert layers. Evenly jointed in weathered face.	Underlies area of report and is principal bedrock aquifer.
	Mississinewa shale.	0-130±	Shale, calcareous, or argillaceous fine-grained bluish-gray limestone; contains pyrite; conchoidal fracture.	Underlies area of report.

The youngest rock of definite Silurian age underlying the airbase is the Liston Creek formation. This rock crops out northeast of the airbase along Pipe Creek in sec. 24, T. 26 N., R. 3 E., and sec. 30, T. 26 N., R. 4 E. Cumings and Shrock (1927, 1928) described the Liston Creek formation as a thin slabby limestone with considerable chert. The lower part of the formation was subdivided by Cumings and Shrock into the Red Bridge limestone member, which represents a transition in lithology from the Mississinewa shale to the Liston Creek formation. Patton (1949) described the Liston Creek as a gray thin-bedded dolomitic, cherty limestone containing intercalated beds of chert. The rock overlying the Mississinewa shale in wells 25/3–1H3, 25/3–1H4, and 26/3–25K1 (pl. 2) is tentatively referred to the Liston Creek. As determined by an examination of the rock cuttings from the wells, the formation where it underlies the airbase ranges in thickness from about 50 feet in well 26/3–25K1 to about 80 feet in well 25/3–1H2. The rock is a light-gray to pale yellowish-brown argillaceous cherty, dolomitic limestone containing many limonite spots and local zones of thin medium-bluish-gray more highly argillaceous layers. The rock pores range in size from pinpoint to greater than 1 millimeter. The porosity is as much as 20 percent. The top 10 to 20 feet of the rock apparently is fractured and creviced. The electric logs of the wells confirm this interpretation and also indicate that fractured and creviced zones occur throughout the Liston Creek sequence to the top of the Mississinewa shale. The fractured condition of the rock is further shown by the driller's logs of wells 25/3–1H1 and 25/3–1H3. The rock is much less argillaceous than the underlying Mississinewa shale. The upper few feet of the

Liston Creek in these wells may belong to the Kokomo limestone of Cumings and Shrock (1927, 1928); however, no marked difference exists between the samples from this part of the section and those from the lower part of the Liston Creek section.

WATER-BEARING CHARACTERISTICS

The water-bearing characteristics of the rocks of Silurian age are dependent upon the physical characteristics of the rocks: the size, distribution, and number of openings; the chemical composition; and upon the topographic position of the rocks with respect to the pre-glacial bedrock surface. The rocks of Silurian age of Indiana are generally a source of only small to moderate supplies of water.

Cumings and Shrock (1928) noted that subterranean drainage tends to form in the Liston Creek formation. The Liston Creek and the overlying limestones have marked enlargements of secondary openings by weathering and solution along the joints and bedding planes. These secondary openings are best formed where the rocks occupy topographic highs on the buried bedrock surface. The Liston Creek formation has at least two definite joint systems. The sample studies indicate that the Liston Creek formation is more porous and much less argillaceous than the underlying Mississinewa shale. The electric logs of wells in the old and the new well fields show that most of the permeable zones penetrated lie within strata that have tentatively been referred to as the Liston Creek formation. These factors indicate that the water for the airbase is being derived from the Liston Creek formation and that this formation is the chief bedrock aquifer underlying the airbase. Further development by the airbase of the rocks of Silurian age as a source of water should be restricted chiefly to the Liston Creek formation.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

The youngest rocks in the vicinity of the Bunker Hill Air Force Base are unconsolidated glacial deposits of Pleistocene age and Recent alluvium (pl. 2). The glacial deposits consist chiefly of a till that is a calcareous silty clay containing sand, pebble gravel, and some cobble gravel. The lower part of the till is generally bluish gray and the upper part is tannish to reddish brown. The upper part, or brown till, ranges in thickness from about 3 feet to more than 20 feet. The till, which is exposed in the ditches and road cuts in the vicinity of the airbase, is fissile and consists of discontinuous platy or flaky layers of silty clay and embedded sand and gravel. This till forms the ground moraine that underlies the upland surface in the vicinity of the airbase.

The glacial deposits contain also some glaciofluvial material. A thin bed of sand and gravel separates the brown till and the gray till in many areas of the airbase. Locally, a thin bed of sand and gravel also lies between the till and the top of the bedrock (for example, at well 26/3–25D1). Some sand and gravel was deposited in a closed depression in the bedrock surface underlying sec. 25, T. 26 N., R. 3 E. (see well 26/3–25K1, pl. 2).

Recent deposits consist chiefly of alluvium along the flood plain of Pipe Creek and its tributaries. Locally, thin beds of organically rich silt and clay were deposited in the small closed depressions in the upland surface. Because of the small areal extent of these deposits, they are not shown on plate 2.

WATER-BEARING CHARACTERISTICS

The water-bearing characteristics of the unconsolidated rocks are dependent upon the grain size; grain-to-grain relationship; size, number, and distribution of the interconnected pores; and thickness of the deposit. Much of the glacial material in the vicinity of the base consists of clayey till, and clayey till is not a source of appreciable quantities of water because of the small size of the interconnected pores.

Deposits of glaciofluvial sand and gravel are generally sources of large quantities of water if they are of substantial areal extent and thickness and do not contain much fine material. The size of the pores and the number of interconnections are generally sufficient to enable the deposits to yield large quantities of water. Because the sand and gravel deposits are relatively thin, there are few areas from which possible additions to the airbase water supply can be obtained from these sources. Attempts to develop water supplies from sand and gravel deposits should be restricted to the areas of the thickest glacial cover over the bedrock and to areas underlain by depressions in the bedrock surface, such as in sec. 25, T. 26 N., R. 3 E. or in the southeast corner of sec. 3, T. 25 N., R. 3 E. As is shown by well 26/3–25K1, the depression in sec. 25, T. 26 N., R. 3 E., is a favorable potential area for obtaining additional water from the unconsolidated glacial material.

BEDROCK TOPOGRAPHY

Plate 1 shows the configuration of the bedrock surface underlying the airbase and vicinity. The pattern of preglacial streams was controlled to a large extent by the jointing in the rocks of Silurian age upon which the streams flowed. The bedrock surface is characterized by closed depressions (sinkholes) formed in the rock. One of these closed depressions underlies sec. 25, T. 26 N., R. 3 E. Well

26/3–25K1 is drilled on the east side of this depression, and the log of the well shows that the depression has some sand and gravel fill. The areal extent and the range in thickness of the fill is not known. This depression is apparently the result of the collapse of a subterranean drainage feature in the upper part of the Liston Creek formation.

The bedrock surface beneath the base forms a narrow sinuous ridge about a half to three-quarters of a mile wide that trends northwest-southeast. The rock composing the ridge has been weathered, and solution has enlarged openings along the joints and bedding planes. The water-supply test wells in the southeast corner of the airbase have been drilled into this ridge.

HYDRAULIC PROPERTIES OF THE ROCK UNITS

The hydraulic properties of a water-bearing formation or aquifer are expressed in terms of the coefficient of transmissibility, *T*, and the coefficient of storage, *S*. Data used to compute these coefficients are obtained from controlled aquifer tests or from long-term regional flow nets. These coefficients are used to make quantitative estimates of the future water-level decline with pumping and the amount of water available in the aquifer.

The coefficient of transmissibility, *T*, is defined as the number of gallons of water, at the prevailing temperature, that will move in 1 day through a vertical strip of the aquifer 1 foot wide, having a height equal to the full saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per foot, or 100 percent. The coefficient of storage, *S*, is defined as the volume of water that the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The nonequilibrium formula (Theis, 1935, p. 519–524) is used to calculate these coefficients, based on data from short-term pumping tests.

A 48-hour aquifer test was made, using wells in the southeast corner of the airbase (SE¼NE¼ sec. 1, T. 25 N., R. 3 E.). This test was conducted by the driller for the U.S. Navy, Department of Public Works Office, 9th Naval District, primarily to determine the pump size for the new supply well at this location. Additional data were collected by the Geological Survey in order to evaluate the hydraulic characteristics of the aquifer.

The test facilities consisted of a 12-inch well, 25/3–1H3, and three 6-inch wells, 25/3–1H1, 25/3–1H2, and 25/3–1H4. The 12-inch well was equipped with a 1,000-gpm pump, and an orifice plate was used to measure discharge. Water-level recorders were installed on the three 6-inch wells and on two 4-inch wells in the area, 25/3–1A1 and 25/3–10A1. Manual measurements of water levels were made in another

4-inch well, 25/4–6E1, and measurements were made in the pumped well with an electric tape. The results of this test are tabulated in table 2.

TABLE 2.—*Coefficients of transmissibility and storage in the new well field at Bunker Hill Air Force Base, Indiana*

Well	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Distance from pumped well (feet)
Drawdown, June 3–5, 1959			
25/3–1H3	[1] 46,000	----------	----------
1H1	[1] 43,000	[1] 0.0005	500
1H4	[1] 46,000	[1] .0005	500
1H2	[1] 41,000	.0002	1,000
25/4–6E1	43,000	.002	1,100
25/3–1A1	40,000	.00004	2,300
10A1	37,000	.0007	11,000
Recovery, June 5–7, 1959			
25/3–1H3	46,000	----------	----------
1H1	43,000	0.0005	500
1H4	46,000	.0005	500
1H2	41,000	.0002	1,000
25/4–6E1	43,000	.002	1,100
25/3–1A1	40,000	.00004	2,300

[1] Values used to compute distance-drawdown curves (fig. 5) and time-drawdown curves (fig. 6).

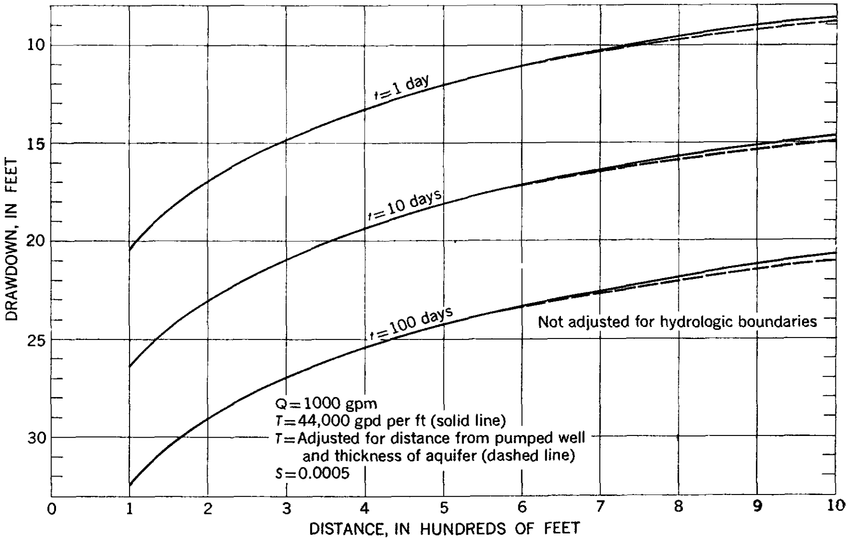

FIGURE 5.—Distance-drawdown curves for the limestone bedrock aquifer underlying the new well field at Bunker Hill Air Force Base.

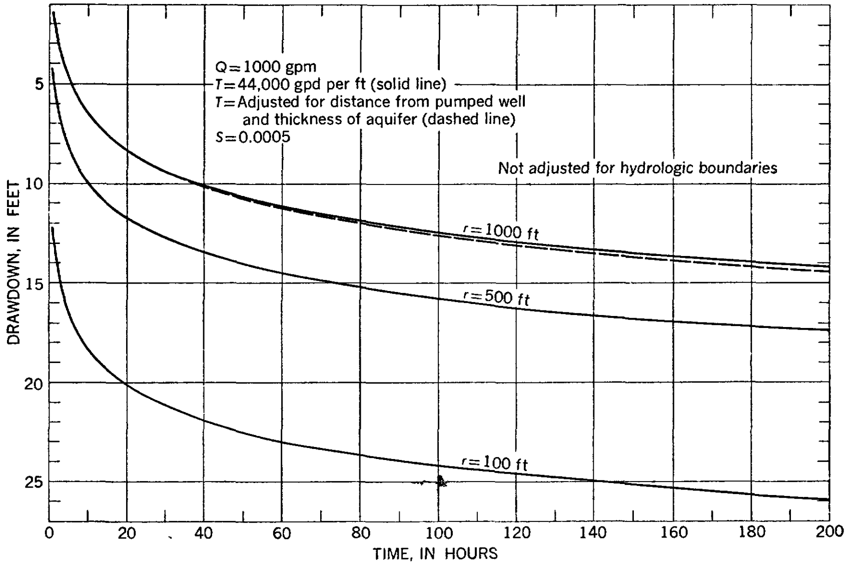

FIGURE 6.—Time-drawdown curves for the limestone bedrock aquifer underlying the new well field at Bunker Hill Air Force Base.

Data from table 2 were used to compute distance-drawdown (fig. 5) and time-drawdown curves (fig. 6) for the new well field. These curves are not adjusted for hydrologic boundaries but are adjusted for changes in the coefficient of transmissibility with distance from the well field and variations in aquifer thickness. From the curves the approximate drawdown can be determined for periods as long as 100 days and distances as far as 1,000 feet.

The hydraulic properties of the aquifer in the vicinity of the current well field and new well field were estimated from the driller's production tests on wells 26/3–25K1, 26/3–25N1, 26/3–26J1, 25/3–1H1, 25/3–1H2, and 25/3–1H4 and by running a short-term test in the current well field. The values computed from these tests are shown in table 3.

The hydraulic characteristics computed from pumping tests may be considerably different from those computed from regional flow nets. The values of the coefficients obtained from short-term tests are used in determining the results of pumping for short periods of time and over short distances. The values obtained from analysis of regional flow nets, represented by piezometric-surface maps, are more useful in calculating the long-term effects of changes in pumping in limestone aquifers.

A regional coefficient of transmissibility of about 9,000 gpd per ft was computed by the use of Darcy's law, $Q=TIL$ or $T=Q/IL$, in which

TABLE 3.—*Estimated values for coefficients of transmissibility and storage*

Well	Date	Estimated coefficient of transmissibility (gpd per ft)	Estimated coefficient of storage	Duration of test (hours)	Remarks
25/3-1H1	Feb. 24-25, 1959	45,000	0.0003	24	Recovery data.
1H4	do	44,000	.0004	24	Do.
1H2	do	44,000	.00008	24	Do.
26/3-25N1	July 2, 1942	17,000	.00001	9	Drawdown data.
26J1	do	13,000		9	Do.
26J1	June 18, 1959	16,000		2	Do.
25K1	Sept. 17, 1957	4,000		13	Do.
25K1	June 18, 1959	[1] 158,000		2	Do.

[1] Because of the short period of this test, the coefficient of transmissibility is abnormally high and its actual value is estimated to be 40,000 to 50,000.

Q is the pumping rate (in gallons per day), I is the hydraulic gradient (in feet per foot) whose values are determined from the piezometric-surface maps, and L is the length (in feet) of the cross section through which the water is moving in the cone of depression. This value of transmissibility differs considerably from the values determined by the pumping tests, because the data obtained from the piezometric maps reflect the effects of long-term pumping and indicate the hydraulic properties of a large part of the aquifer. Local variations in the physical properties of the aquifer and its associated beds may produce unusually large or unusually small values of the coefficient of transmissibility as determined by short-term tests. Because a larger part of the aquifer is sampled, the local variations are integrated in the value of the regional coefficient of transmissibility.

Table 3 shows that the hydraulic properties of the aquifer are better in the new well field than in the old well field, except perhaps at well 26/3–25K1. This well was drilled near the edge of a closed depression in the bedrock (pl. 1), which is apparently the result of the collapse of a subterranean-drainage feature. The driller's log shows that this well penetrated 16 feet of clayey sand and gravel at depths ranging from 60 to 76 feet and 8 feet of broken rock from 76 to 84 feet before entering solid rock. The well was originally cased into the solid rock. On June 18, 1957, a production test was run, and the well produced 90 gpm with 94 feet of drawdown. The well casing was pulled back; a 20-foot screen was set between 62 and 82 feet, and a gravel pack was placed. On September 17, 1957, another production test was run, and the well produced 351 gpm with 72 feet of drawdown. The well was accepted by the Air Force and connected to the water system. On June 18, 1959, during a 2-hour test, the well produced 430 gpm with 8.4 feet of drawdown. The large increase in specific capacity, gallons per minute per foot of drawdown (table 4), must have been the result of developing the aquifer in the screened interval by pumping and indicates the potential of this aquifer with proper well development. All wells in the old well field improved in specific capacity with pumping but to a much lesser degree than well 26/3-25K1.

TABLE 4.—*Specific capacity of the wells at Bunker Hill Air Force Base*

Well	Date of test	Duration of test (hours)	Specific capacity (gpm per ft of drawdown)
25/3- 1H3	6-5-59	48	31
26/3-25N1	5-29-42	9.5	10
	6-3-42	2	12
	7-2-42	5.5	12
	3-1-55	1	16
	3-3-55	1	16
	5-19-55	1	17
26J1	7-2-42	9	9
	3-3-55	1	10
	3-7-55	1	10
	5-25-55	1	10
	6-18-59	2	11
25K1	6-18-57		[1] 1
	9-17-57	13	[2] 5
	6-18-59	2	51

[1] Cased in rock.
[2] Screen was set from 62 to 82 ft and gravel pack was placed.

GROUND-WATER HYDROLOGY

RECHARGE

Water for recharge is derived from precipitation, and recharge takes place most readily where the bedrock is exposed at the land surface or is covered by permeable materials.

Bunker Hill Air Force Base area is covered by about 60 feet of glacial deposits consisting chiefly of till that is relatively impermeable. Recharge, however, must take place through these deposits or move into the area from the southeast. A piezometric-surface map (pl. 3*A*) shows that in 1941, before the airbase was established, this area was underlain by a ground-water high; the water surface sloped to the north and south. Since the start of pumping on the airbase, the ground-water divide has moved southward.

The topographic map (pl. 1) shows that the area has several small closed depressions where water is ponded after rain. Part of this water is available for recharge to the aquifer.

The estimated natural recharge to the bedrock aquifer in 16 square miles in the vicinity of the airbase is about 2 million gpd, as computed from Darcy's law by use of the regional coefficient of transmissibility (p. B13) and data obtained from plate 3*A* to determine the flow across each contour interval. From the difference in flow across each contour interval and the area represented by this interval, an average recharge factor was obtained for each square foot of surface area. This factor was applied to the area in the vicinity of the airbase to obtain the estimated rate of natural recharge.

The rocks of Silurian age are the chief source of water for the airbase. These rocks are exposed in Pipe Creek to the north and east (pl. 2). Under natural conditions the creek would not be a source of recharge to this aquifer, because the hydraulic gradient is toward the creek (pl. 3*A*). Under the conditions of pumping, however, some ground water is intercepted before it can be discharged into the creek (pl. 3*B*).

Recharge to the bedrock aquifer by precipitation can take place in two ways: (1) by slow percolation through the glacial materials, and (2) by lateral movement through the bedrock from some areas at a distance from the airbase. Figure 7 shows that rises in ground-water level lag behind precipitation by at least a month.

DISCHARGE

The natural discharge from the bedrock aquifer is into Pipe Creek and is estimated from the piezometric maps to be about 300,000 gpd for each mile-wide strip of the aquifer in the vicinity of the base. Ground water in the unconsolidated material in the area discharges chiefly into two large ditches which are tributary to Pipe Creek and also discharges directly into Pipe Creek.

The discharge from the bedrock aquifer by wells in the area is estimated to be about 700,000 gpd. Of this total, about 20,000 gpd is from rural farm wells, about 30,000 from other rural wells, and 650,000 from the airbase wells. During the irrigation season about 100,000 gpd is pumped from well 25/3–3C1 for about 15 days.

FLUCTUATIONS OF WATER LEVELS

The contour map of the piezometric surface for late spring in 1941 (pl. 3*A*) shows relatively undisturbed conditions in the aquifer and shows a ground-water divide trending northwest-southeast near the south edge of the airbase.

Plate 3B shows the piezometric surface on July 3, 1942, during the production test of wells 26/3–25N1 and 26/3–26J1. At this early date the ground-water divide was beginning to move southward due to the effect of pumping at the air base, as shown by the position of the 790-foot contour.

Plate 3C shows the piezometric surface on June 8, 1959, with the same wells pumping, the cone of depression created by pumping, and some residual effect of previous pumping in well 26/3–25K1. The cone of depression (pl. 3*C*) changes little, regardless of any combination of two wells in the field that may be pumping (pl. 3*D*). Plate 3*E* shows the piezometric surface at the end of the 48-hour aquifer test in the new well field, June 5, 1959, with well 25/3–1H3 pumping 1,000 gpm and wells 26/3–26J1 and 26/3–25K1, in the old well field, pumping a combined total of about 650 gpm. The major changes in the piezometric surface are a local cone of depression at well 25/3–1H3 and a movement of the 790-foot contour off the map area, showing that the ground-water divide is being shifted farther southward.

Fluctuations of water level are shown by hydrographs of all observation wells established for this study. Figure 7 is a hydrograph of well 25/3–25Q1 for the period from January 15, 1957, to July 31, 1959. The monthly precipitation and the monthly pumpage at the airbase,

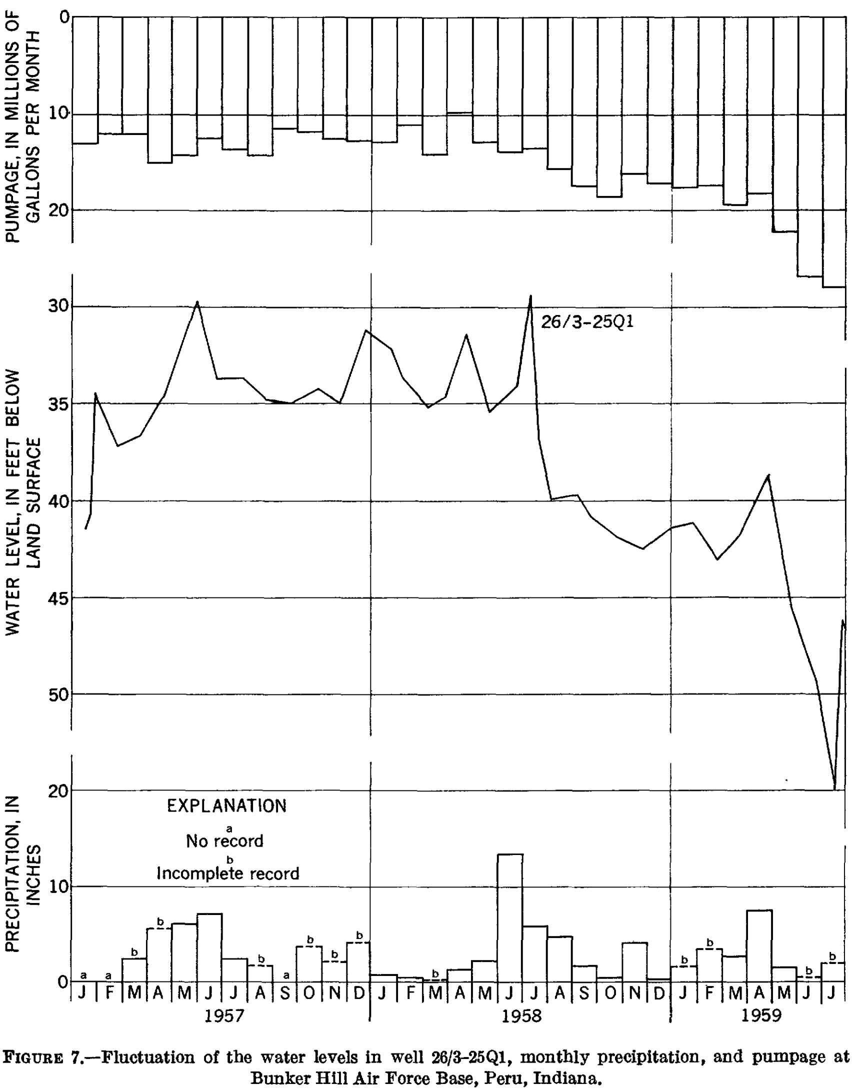

Figure 7.—Fluctuation of the water levels in well 26/3-25Q1, monthly precipitation, and pumpage at Bunker Hill Air Force Base, Peru, Indiana.

shown by bar diagrams on this figure, directly affect the fluctuation of the water levels. For example, the extreme low of July 1959 is due to the greater-than-normal pumpage and the deficiency of precipitation in May and June. The rise in water levels in July occurred after the airbase water department stopped all lawn watering, and the pumpage decreased from about 1 million gpd to about 650,000 gpd.

Figure 8 shows the hydrographs of three observation wells at various distances from the production wells in the old well field. The bar diagram at the bottom of the figure shows the length of each pumping period and identifies the wells pumping. Any combination of two wells will produce about 650 gpm. Table 5 gives the distances between wells.

Water levels in this well field are depressed somewhat because the periods of recovery are shorter than the periods of pumping. The water levels, therefore, do not return to a natural condition but are constantly adjusting to the pumping situation. The hydrographs are arranged so that distance of the observation wells from the center of pumping increases from the bottom to the top of the figure. In other words, well 26/3–25Q1 is nearest and well 26/3–26D1 is farthest from the center of pumping. The amount of change in water levels in the observation wells is controlled by their distance from the center of pumping. Pumping of wells 26/3–25N1 and 26/3–25K1 causes the greatest effect on water levels in the observation wells as shown by a marked decline; whereas the pumping of wells 26/3–25K1 and 26/3–26J1 causes the least effect, as shown by a flattening of the recovery curves, and—in time—a slight decline in water levels. The observation wells also record a noticeable lag in the time of arrival of highs and lows as distance from the center of pumping increases.

Figures 9 and 10 are hydrographs of all observation wells, except well 26/3–25Q1 (fig. 7). Wells 25/3–1A1, 26/3–1H1, 26/3–1H2, 26/3–1H4, and 25/3–10A1 are observation wells used during the 48-hour 1,000-gpm aquifer test in the new well field at the south edge of the base, and their hydrographs show the effect of this pumping. Distances of these wells from the pumping well are given in table 2. Wells 26/3–26D1 and 26/3–35C1 are near the old well field, and their hydrographs show the general seasonal trend of the water levels in the area and the effect of pumping at the airbase superimposed on this trend. The hydrograph of a dug well, 25/3–3Q1, shows fluctuations of water level in the shallow unconsolidated deposits near the southwest edge of the airbase.

QUALITY OF GROUND WATER

Table 6 shows comprehensive chemical analyses, made by the Geological Survey, of water from the wells on the airbase. In addition,

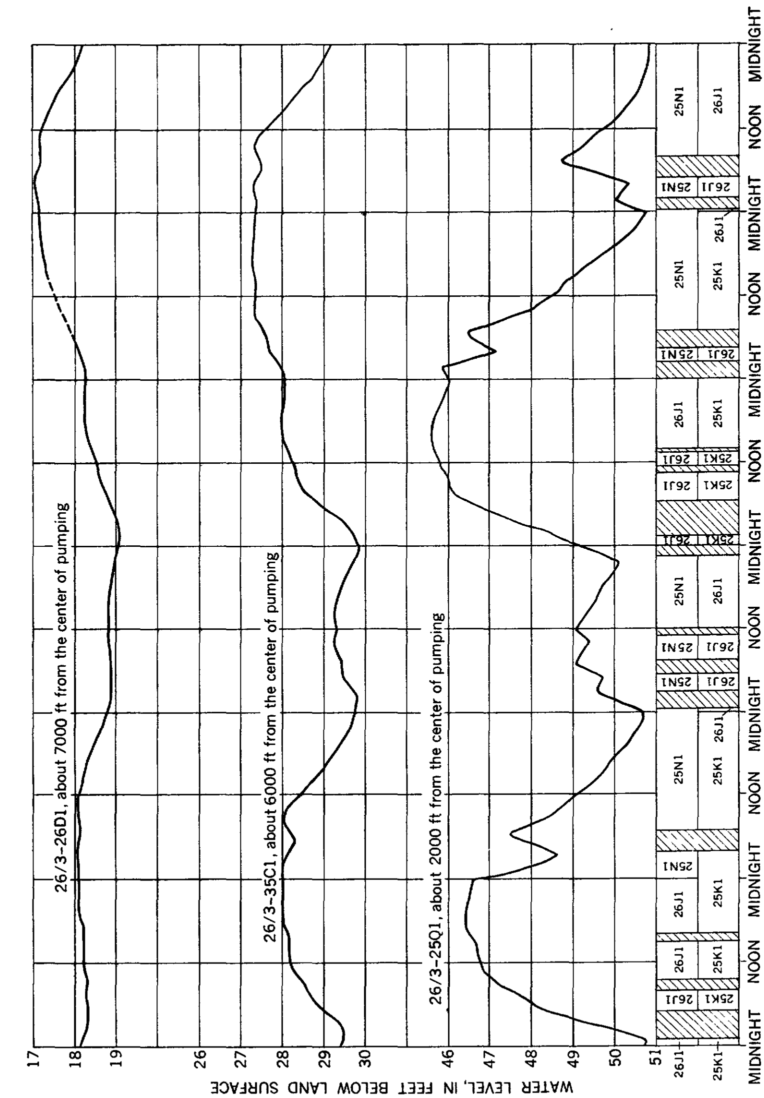

FIGURE 8.—Graphs showing fluctuation of the water levels in three observation wells at various distances from the center of pumping in the old well field and a bar diagram showing the length of the pumping periods and the wells pumped during each period.

TABLE 5.—*Distances, in feet, between the wells shown on figure 8*

25N1					
1650	26J1				
3100	3850	25K1			
1950	3350	1800	25Q1		
7100	5400	8450	8600	26D1	
4700	4000	7700	6650	5700	35C1

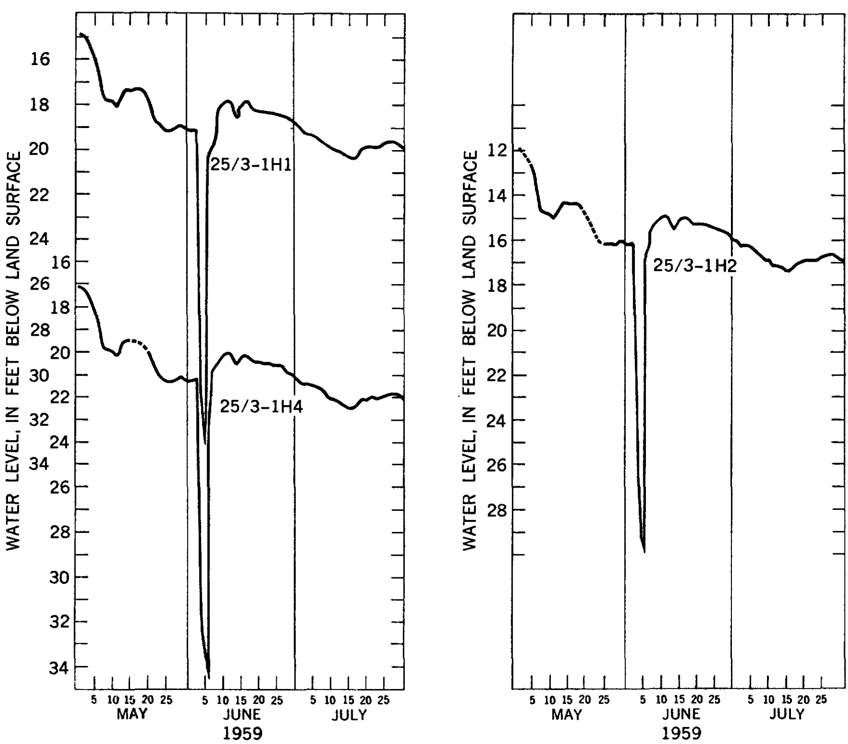

FIGURE 9.—Fluctuation of the water levels in observation wells 25/3-1H1, 25/3-1H4, and 25/3-1H2.

small samples of water were obtained wherever possible from wells in the vicinity of the airbase for field chemical analysis. The results of the field chemical analyses are shown in table 7 and are not as accurate or as comprehensive as laboratory analyses, but they show the general chemical character and hardness of the water.

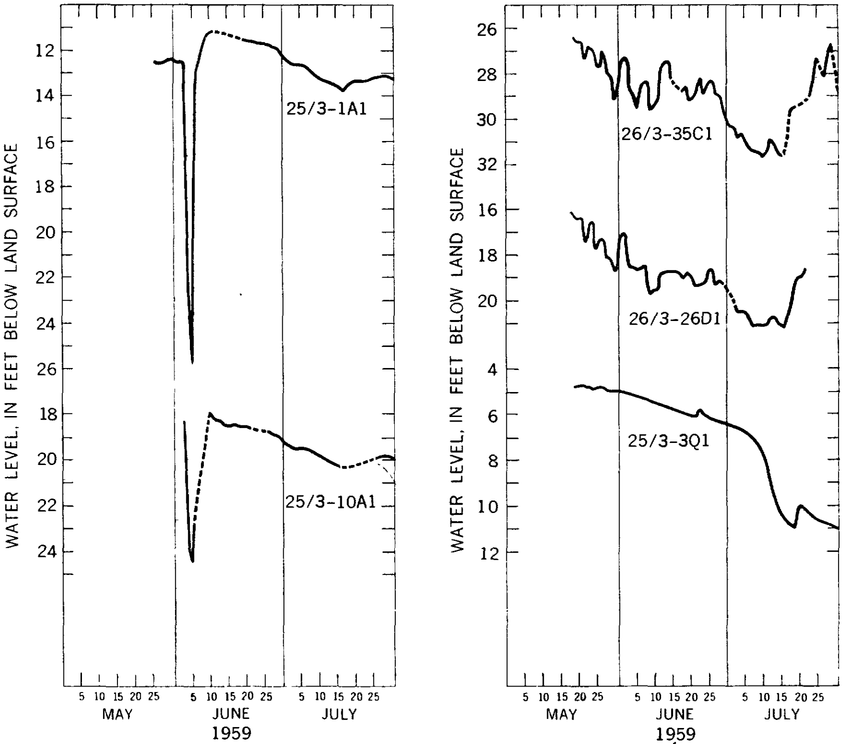

FIGURE 10.—Fluctuation of the water levels in observation wells 25/3-1A1, 25/3-10A1, 26/3-35C1, 26/3-26D1, and 25/3-3Q1.

The water from the consolidated and unconsolidated rocks is very hard, is high in calcium and magnesium bicarbonate, and is very uniform in composition. The water is generally acceptable for domestic and public-supply use, but scale will form in boilers and hot-water heaters if the water is not properly treated before use.

The iron content of water from the consolidated and unconsolidated rocks ranges from less than 0.1 ppm to 5 ppm (table 7). An iron and manganese content of more than 0.3 ppm is ordinarily objectionable in water for domestic, public-supply, and many industrial uses and tends to stain clothes, fixtures, cooking utensils, and to form scale in hot-water lines and boilers. Water containing iron in concentrations greater than 0.5 to 1.0 ppm has an objectionable taste.

TABLE 6.—*Chemical analyses of water from supply wells at Bunker Hill Air Force Base, Indiana*

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey. Aquifer: Ls, limestone; Sg, sand and gravel. Remarks: R, raw water; USGS, collected by U.S. Geological Survey]

Well	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	pH	Remarks
U.S. Public Health Service drinking-water standards.			----	----	[1] 0.3		----	[1] 125	----	------	------	[1] 250	[1] 250	[2] 1.5	------	[1] 500	------	----	------	
25/3- 1H3	Ls	6- 3-59	52	20	1.5	0.06	75	34	12	1.5	366	5.6	24	0.9	0.1	363	327	27	7.3	Taken after 30 minutes pumping. R, USGS.
	Ls	6- 4-59	52	18	.59	.01	74	34	13	1.4	410	5.0	1.	.9	.1	354	325	0	7.4	Taken after 22.5 hours pumping. R, USGS.
	Ls	6- 5-59	52	18	1.1	.01	75	32	13	1.5	408	5.2	2.0	.8	.1	351	319	0	7.3	Taken after 44.25 hours pumping. R, USGS.
26/3-25K1	Ls, Sg	4- 9-58	----	16	3.5	.36	73	27	18	1.3	400	0	0	1.6	.1	340	293	0	7.3	R.
	Ls, Sg	8-18-59	----	17	3.5	.03	78	27	16	1.5	394	2.6	2.0	1.2	6.4	369	306	0	7.2	R.
26/3-25N1	Ls	8-19-52	56	18	1.2	.19	71	32	14	1.9	386	4.3	1.4	1.2	3.2	331	302	0	7.3	R.
	Ls	3-29-54	----	16	.98	.08	73	27	16	1.6	399	2.1	1.4	1.8	3.9	332	296	0	7.5	Sample collected after coke filtration.
26/3-26J1	Ls	8- 1-55	----	18	1.3	0	74	28	17	1.3	398	1.3	1.2	1.5	0	332	298	0	7.8	R.
	Ls	8-13-56	----	18	1.1	.11	73	25	16	1.3	392	2.4	2.8	1.3	.1	319	285	0	7.1	R.
	Ls	8- 6-57	----	17	1.4	.21	74	27	16	1.3	391	2.8	2.0	1.2	1.0	328	296	0	7.5	R.
	Ls	4-17-58	----	17	1.6	.03	75	26	14	1.4	395	4.8	1.0	1.2	3.2	323	294	0	7.4	R.
	Ls	8-18-59	----	17	1.3	.03	76	27	16	1.6	390	5.6	1.0	1.2	3.2	357	301	0	7.0	R.
	Ls	8-19-52	56	17	1.5	.15	68	30	14	1.2	383	6.6	1.5	1.1	2.6	338	296	0	7.5	R.
	Ls	3-29-54	----	16	1.3	0	73	27	17	1.6	393	4.3	2.0	.5	3.4	328	295	0	7.3	R.
	Ls	8- 1-55	----	16	2.1	.04	72	30	15	.9	386	4.0	1.2	1.5	3.3	330	302	0	7.6	R.
	Ls	8-13-56	----	19	1.6	.04	73	27	16	1.4	390	3.3	2.8	1.3	.1	309	293	0	7.5	R.
	Ls	8- 6-57	----	18	2.5	.16	74	27	15	1.0	389	4.6	3.0	1.3	2.6	329	296	0	7.5	R.
	Ls	4-17-58	----	16	1.7	.03	75	27	14	1.3	395	6.0	1.0	1.2	3.1	324	298	0	7.3	R.
	Ls	8-18-59	----	17	1.3	.03	75	27	15	1.4	384	5.2	1.0	1.1	3.0	358	298	0	7.6	R.

[1] Concentrations which preferably should not be exceeded.
[2] Concentrations which must not be exceeded.

Except for fluoride, other constituents of the water from wells in the vicinity of the airbase are not present in sufficient concentration to make the water objectionable for general domestic, public-supply, and most industrial uses. The fluoride content of the water from the airbase supply wells, however, is at times greater than that recommended in standards of the U.S. Public Health Service for drinking water (table 6).

SUMMARY AND CONCLUSIONS

The chief bedrock aquifer underlying the Bunker Hill Air Force Base is the Liston Creek formation of Silurian age. The coefficients of transmissibility for this aquifer, as computed from tests, range from about 13,000 to 46,000 gpd per ft. The long-term coefficient of transmissibility, as computed from piezometric-surface maps, is about 9,000 gpd per ft. The coefficients of storage, as computed from aquifer tests, range from about 0.00001 to about 0.002. The largest values of the coefficients of transmissibility and storage are associated with a sinuous high in the bedrock surface that trends northwest-southeast across the airbase. The estimated flow through each 1-mile-wide strip of the aquifer is about 300,000 gpd in the 16-square-mile area in the vicinity of the base. In this area the natural recharge to the rock aquifer is about 2 million gpd. About 700,000 gpd is pumped from wells in the 16-square-mile area and of this amount, about 650,000 gpd is used by the base. The natural hydraulic gradient is toward Pipe Creek, and the cone of depression caused by pumping of the base wells has not reversed this slope. These factors show that additional supplies can be obtained from the bedrock aquifer. The most favorable well sites for additional water supply from this source are along the bedrock high.

The unconsolidated glacial material in the vicinity of the airbase consists chiefly of silty-clay till containing some thin beds of sand and gravel. These glacial deposits, therefore, offer few possibilities for large water supplies. Any attempt to obtain additional water from this source should be restricted to the areas of thickest glacial cover over the depressions in the bedrock. A short-term test of well 26/3–25K1, which was drilled near the edge of such a depression and was screened in the unconsolidated material, indicated the largest coefficient of transmissibility for any well site on the airbase. This well has shown a marked improvement in specific capacity with continued use. These factors show that a properly developed well in the unconsolidated fill in this bedrock depression may have the best potential of any well site on the airbase.

Under natural conditions there is a divide on the piezometric surface along the south edge of the airbase. Pumping in the old well field has moved this divide southward, and the pumping during the test of the new well field had moved it even further southward. Pumping in the old well field and the new well field affects wells beyond the base. Additional wells drilled for large water supplies will markedly affect the water levels in domestic and farm wells in the area. These conditions warrant a continuation of the observation-well program in the area and the running of aquifer tests on new large supply wells.

RECORDS OF WELLS

The data in this report are summarized in tables 7 and 8. Information on 59 wells and 1 spring is given in table 7. Of these wells,

TABLE 7.—*Record of wells by township, Bunker*

Well: See text for description of well-numbering system.
Type of well: Dr, drilled; Du, dug.
Character: Gr, gravel; Ls, limestone; Sd, sand; T, till.
Geologic age: P, Pleistocene; S, Silurian.
Water level: In feet below land surface on date of completion of well, except where plus sign (+) indicates level is above land surface.

Well	Owner	Driller	Date completed	Altitude above mean sea level (feet)	Type of well	Depth of well (feet)	Diameter (inches)	Finish	Water-bearing zone	
									Depth to top (feet)	Thickness (feet)
										T. 25 N.,
25/3-1A1	U.S. Government.	J. B. Ortman and Sons.	12-15-24	803	Dr	124	4	Oph	62	58
1H1	do	Layne-Northern Co., Inc.	1-21-59	808	Dr	182	6	Oph	69	113
1H2	do	do	1-30-59	806	Dr	183	6	Oph	63	120
1H3	do	do	2-15-59	812	Dr	180	12	Oph	70	110
1H4	do	do	2-17-59	809	Dr	182	6	Oph	67	115
2M1	do	J. B. Ortman and Sons.	12-15-24	806	Dr	137	4	Oph	101	36
3C1	R. H. Bevington.	W. E. Zehring	1954	795	Dr	250	10	Oph	100	150
3C2	do	do	7- 1-55	798	Dr	------	4	Oph	73	------
3E1	R. E. Bevington.	do	2-24-44	799	Dr	112	4	Oph	97	15
3E2	do	do	5- 2-45	802	Dr	118	4	Oph	95	23
3J1	U.S. Government.			804	Dr	------	4			
3Q1	do			806	Du	17.9	36			
3R1	J. Weaver	J. Snyder	4-18-48	806	Dr	126	4	Oph	104	22
4H1	C. Carey	W. E. Zehring	1-21-44	801	Dr	199	4	Oph	97	102
4Q1	M. Bevington	do	10-16-41	804	Dr	132	4	Oph	94	38
10A1	U.S. Government.			808	Dr	130	4	Oph		
12A1	G. Childers	W. E. Zehring	5-21-35	808	Dr	139	4	Oph	64	75
										T. 25 N.,
25/4-6E1	R. Comerford	W. E. Zehring	6-21-44	806	Dr	108	4	Oph	77	31
9D1	O. Sullivan	J. W. Mills	6- 7-47	822	Dr	127	4	Oph	76	51

24 are domestic or stock wells, 8 are public-supply wells, 12 are observation wells, 1 is an irrigation well, 1 is an industrial well, and 13 are unused or their use is unknown. Table 7 gives the locations, owners, and drillers and, in addition, gives pertinent information about wells, water-bearing materials, water levels, results of field chemical analysis, and other available data.

Table 8 consists of unpublished logs of selected wells. The logs give information about the subsurface geologic material underlying the airbase and an interpretation of their stratigraphic sequence. Of these logs, four were prepared from an examination of rock cuttings.

Hill Air Force Base and vicinity, Indiana

Finish: Op, open end; Oph, open hole.
Use or condition: D, domestic; Des, destroyed; I, industrial; Ir, irrigation; N, not used; O, observation; P, public supply; S, stock; T, water-well test hole.
Remarks: El, electric log available for inspection; Grl, gamma-ray log available for inspection; H, hydrograph included in report; L, log of well included in report; lsd, land surface datum.

Water-bearing zone		Water level (feet)	Use or condition	Field chemical analysis							Remarks
				Date of collection of sample	Temperature (°F)	Parts per million					
Character	Geologic age					Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$	
R. 3 E.											
Ls	S	20	O	------	------	------	------	------	------	------	Water level measured 10.66 ft below lsd, 5-7-59. El, Grl, H.
Ls	S	18.5	O	------	------	------	------	------	------	------	El, Grl, H, L.
Ls	S	18.3	O	------	------	------	------	------	------	------	Do.
Ls	S	18.3	P, O	------	------	------	------	------	------	------	Do.
Ls	S	19.7	O	------	------	------	------	------	------	------	Do.
Ls	S	13	------	------	------	------	------	------	------	------	
Ls	------	8	Ir	6-18-59	54	1.0	415	15	2	352	
Ls	------	12	D	7- 9-59	------	5	371	25	4	264	
Ls	S	15	D	6-18-59	------	.5	415	50	8	340	
Ls	S	14	D, S	6-18-59	------	3	425	25	8	340	
Ls(?)	S	------	P	------	------	------	------	------	------	------	
T(?)	P	------	O	5-19-59	48	<.1	249	40	8	232	Water level measured 3.07 ft below lsd, 5-6-59. H.
Ls	S	------	Des	------	------	------	------	------	------	------	
Ls	S	17	D	------	------	------	------	------	------	------	
Ls	S	24	D, S	6-18-59	------	5	420	25	10	348	
Ls	S	------	O	------	------	------	------	------	------	------	Water level measured 18.13 ft below lsd, 6-2-59. El, Grl, H.
Ls	S	14	D, S	6-19-59	54	1.5	444	10	8	332	
R. 4 E.											
Ls	S	22	S, O	------	------	------	------	------	------	------	Water level measured 13.38 ft below lsd, 6-3-59.
Ls	S	22	D	6-19-59	62	3	449	5	10	336	

TABLE 7.—*Record of wells by township, Bunker Hill*

Well	Owner	Driller	Date completed	Altitude above mean sea level (feet)	Type of well	Depth of well (feet)	Diameter (inches)	Finish	Water-bearing zone: Depth to top (feet)	Water-bearing zone: Thickness (feet)
T. 26 N.,										
26/3-12P1	P. Kunkle	W. E. Zehring	12-14-55	744	Dr	67	4	Oph	46	21
16P1	W. Morris	J. Snyder	1-10-49	768	Dr	89	4	Oph	71	18
16P2	Onward Lumber Co.	do	1953	768	Dr	96	4	Oph	----	----
16P3	E. Hall	do	1954	768	Dr	86	4	Oph	74	12
16P4	L. Wilson	do	1954	768	Dr	84	4	Oph	74	10
16Q1	F. Wouster	do	2-1-49	768	Dr	99	4	Oph	70	29
16Q2	E. Grant	do	1950	768	Dr	84	4	Oph	68	16
16Q3	R. Perkins	do	1949	768	Dr	83	4	Oph	70	13
16Q4	P. Mays	do	1950	768	Dr	84	4	Oph	66	18
16Q5	H. Wilson	do	5-17-54	768	Dr	96	4	Oph	72	24
22J1	M. Puterbaugh	do	1951	778	Dr	83	4	Oph	78	5
22R1	A. Armstrong	do	1950	780	Dr	92	4	Oph	69	23
24A1	G. W. Carson	B. Harmon	1958	782	Dr	99	4	Oph	83	16
25A1	State of Indiana	W. E. Zehring	5-21-41	740	Dr	141	4	Oph	9	132
25D1	Indiana Bell Telephone Co.	B. Harmon	6-30-59	787	Dr	65	4	Op(?)	52	12
25K1	U.S. Government.	Layne-Northern Co., Inc.	7-18-57	788	Dr	165	16	----	----	----
25N1	do	R. Stewart	5-29-42	795	Dr	157	12	Oph	65	92
25Q1	do	J. W. Mills	1942	795	Dr	165	4	Oph	65	100
26D1	do	----	----	782	Dr	77	4	Oph	64	13
26D2	Centex Construction Co., Inc.	O. Willis	5-13-59	784	Dr	100	4	Oph	66	34
26J1	U.S. Government.	H. Ness	6-19-42	790	Dr	150	12	Oph	65	85
27A1	M. and E. Stoner.	W. E. Zehring	7-15-44	782	Dr	110	4	Oph	84	26
27H1	A. Mays	do	7-24-44	783	Dr	200	4	Oph	83	117
28F1	R. Erbaugh	do	4- 7-45	768	Dr	103	4	Op	----	----
28N1	O. J. Lees	do	5-10-45	779	Dr	90	4	Oph	65	25
33K1	G. Thompson	J. B. Ortman and Sons.	11-27-23	790	Dr	150	4	Oph	55	95
33M1	C. Deisch	W. E. Zehring	2-13-42	785	Dr	106	4	Op	----	----
34E1	----	----	----	783	----	----	----	----	----	----
34M1	H. Preiser	W. E. Zehring	4-28-45	793	Dr	200	4	Oph	72	128
35C1	U.S. Government.	----	----	794	Dr	143	6	Oph	----	----
35C2	do	J. B. Ortman and Sons.	8-18-36	794	Dr	84	4	----	52	32
T. 26 N.,										
26/4- 7N1	A. Kuehl	W. E. Zehring	10-16-44	772	Dr	140	4	Oph	90	50
7Q1	R. Lees	O. Willis	7-24-58	782	Dr	170	4	Oph	95	75
7Q2	F. E. Lees	do	3- 3-59	774	Dr	194	4	Oph	112	82
19D1	B. Marine	B. Harmon	1958	792	Dr	68	4	Oph	64	4
19E1	C. Murry	W. E. Zehring	6-14-39	782	Dr	95	4	Oph	72	23
29F1	H. Golding	J. Zehring	2- 7-58	790	Dr	94	4	Oph	65	29
30M1	Siranoff Vegetable Oil Corp.	J. B. Ortman and Sons.	7-14-44	795	Dr	140	6	Oph	60	80
30N1	C. E. Hutchcroft	W. E. Zehring	7 -3-42	793	Dr	99	4	Oph	58	41
31D1	Milligan and Dunn.	J. B. Ortman	1 -6-56	782	Dr	175	6	Oph	58	117
32F1	C. McConnelly	----	----	----	Dr	815	4	Oph	----	----

Air Force Base and vicinity, Indiana—Continued

Water-bearing zone: Character	Water-bearing zone: Geologic age	Water level (feet)	Use or condition	Field chemical analysis: Date of collection of sample	Temperature (°F)	Parts per million: Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$	Remarks
R. 3 E.											
Ls	S	------	D, S	7-8-59	------	1.0	302	15	2	240	
Ls	S	------	D	------	------	------	------	----	----	------	
Ls	S	6	P	6-18-59	58	2	400	20	16	348	
Ls	S	------	D	------	------	------	------	----	----	------	
Ls	S	------	D	------	------	------	------	----	----	------	
Ls	S	------	D	6-18-59	66	5	439	20	8	332	
Ls	S	------	D	------	------	------	------	----	----	------	
Ls	S	------	D	------	------	------	------	----	----	------	
Ls	S	------	D	6-18-59	------	1	459	30	12	376	
Ls	S	------	D	6-18-59	53	3	439	15	8	312	
Ls	S	------	D	6-18-59	54	.5	434	10	8	300	
Ls	S	------	D, S	6-18-59	------	3	415	10	8	304	
Ls	S	54	D	6-19-59	------	3	488	30	10	368	
Ls(?)	S	+6	P	5-5-59	53	0.1	395	20	8	284	Water level measured 7.16 ft above lsd, 5-5-59.
Gr	P	22	D	7-6-59	58	3	400	5	2	304	Limestone at 64 ft. L.
Sd, Gr, Ls	P, S	30	P	------	------	------	------	----	----	------	Well is screened in sand and gravel from 62 to 82 ft and is open hole in limestone from 90 to 165 feet. L.
Ls	S	15	P	------	------	------	------	----	----	------	L.
Ls	S	------	O	------	------	------	------	----	----	------	El, Grl, H, L.
Ls	S	------	O	------	------	------	------	----	----	------	Water level measured 16.06 ft below lsd, 5-18-59. El, Grl, H.
Ls	S	24	P	------	------	------	------	----	----	------	Water level measured 16.44 ft below lsd, 6-59. L.
Ls	S	12	P	7-3-42	52	------	------	----	----	------	L.
Ls	S	17	D, S	6-19-59	54	2.5	425	10	8	316	
Ls	S	17	D	------	------	------	------	----	----	------	
Gr	P	------	S	------	------	------	------	----	----	------	Flows.
Ls	S	8	D	7-7-59	51.5	1.5	434	5	4	340	
Ls	S	21	------	------	------	------	------	----	----	------	
Gr	P	7.5	D, S	6-18-59	53	.5	449	10	6	360	
T	P	------	N	5-28-59	53	1.5	360	95	18	364	Spring issuing at contact of brown fissile till with underlying bluish-gray till in ditch bank.
Ls	S	8	------	------	------	------	------	----	----	------	
Ls	S	------	O	------	------	------	------	----	----	------	Water level measured 26.60 ft below lsd, 5-19-59. El, Gr l, H.
Ls	S	24	Des	------	------	------	------	----	----	------	
R. 4 E.											
Ls	S	45	D	7-8-59	------	2.0	434	15	2	352	
Ls	S	52	D	5-25-59	------	0.3	327	15	8	216	
Ls (?)	S	------	D	5-25-59	59	1	239	18	10	192	Water level measured 35.97 ft below lsd, 5-25-59.
Ls	S	44	N	------	------	------	------	----	----	------	Water level measured 47.33 ft below lsd, 7-6-59.
Ls	S	25	D	------	------	------	------	----	----	------	
Ls	S	36	D	7-6-59	53.5	1	420	20	4	364	
Ls	S	43	I	------	------	------	------	----	----	------	Yielded 40 gpm with 12 ft drawdown.
Ls	S	17	------	------	------	------	------	----	----	------	
Ls	S	25	P	7-6-59	63	.5	390	10	2	308	Yielded 155 gpm with 10 ft drawdown.
Ls(?)	S	------	O	------	------	------	------	----	----	------	Water level measured 43.24 ft below lsd, 6-3-48. Use as observation well discontinued 7-18-50.

TABLE 8.—*Logs of wells and test holes in the vicinity of Bunker Hill Air Force Base, Indiana*

	Thickness (feet)	Depth (feet)	Remarks
Well 25/3-1H1			
[Altitude: 808 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Clay	4	4	
Clay and gravel (till?)	6	10	
Clay	4	14	
Clay and gravel (till?)	16	30	
Clay	18	48	
Clay and streaks of gravel	12	60	
Gravel, dirty	9	69	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limerock, broken	1	70	
Limerock, hard, gray	22	92	
Limerock, brown	43	135	
Lime, porous, creviced	5	140	
Mississinewa shale:			
Limerock, gray	42	182	
Well 25/3-1H2			
[Altitude: 806 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Topsoil and yellow clay	10	10	
Clay (till?), sandy, gray, and gravel	44	54	
Sand and gravel, muddy	5	59	
Gravel, muddy	4	63	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Lime rock	79	142	
Mississinewa shale:			
Lime rock	41	183	
Well 25/3-1H3			
[Altitude: 812 feet above mean sea level. Type of record: Sample log of water well (samples collected by driller, examined by J. S. Rosenshein)]			
Quaternary system:			
Recent and Pleistocene series:			
Soil and clay (till)	5	5	
Clay (till), silty, calcareous, brown to gray-brown; contains fine to coarse sand and subrounded pebble gravel.	49	54	Color changes to gray brown at about 35 ft. No gravel in sample from 25 to 30 ft.
Clay (till), silty, calcareous, gray-brown; rounded to subrounded sand; fine to medium subangular to subrounded pebble gravel.	12	66	Driller reports clay with streaks of gravel and boulders. Sample from 60 to 65 ft is chiefly broken fragments of dolomitic limestone. Sample probably taken from bottom of hole.
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, dolomitic, argillaceous, yellowish-gray, fine-grained, creviced(?); small pores.	19	85	Samples have large amount of unconsolidated glacial fragments.
Limestone, dolomitic, argillaceous, pale-yellowish-brown to light-olive-gray, fine-grained; pinpoint-size and larger pores; contains faintly banded limonite.	5	90	Very porous.
Limestone, dolomitic, argillaceous, pale-yellowish-brown to bluish-gray, banded, fine-grained; pinpoint-size pores; contains pyrite masses, limonite spots, and chert inclusions.	5	95	Bluish-gray layers are more argillaceous.

TABLE 8.—*Logs of wells and test holes in the vicinity of Bunker Hill Air Force Base, Indiana*—Continued

	Thickness (feet)	Depth (feet)	Remarks
Well 25/3-1H3—Continued			
Silurian system—Continued			
Middle Silurian series—Continued			
Liston Creek formation—Continued			
Limestone, dolomitic, argillaceous, pale-yellowish-brown, fine-grained; sparse pinpoint-size pores; some bands chert inclusions.	15	110	Has some dark calcareous-shale partings.
Limestone, dolomitic, argillaceous, pale-yellowish-brown and light-olive-gray; bands with limonite spots.	5	115	Not as shaly as above rock.
Limestone, dolomitic, argillaceous, pale-yellowish-brown, fine-grained; small pores; dark-bluish-gray bands; some limonite spots.	5	120	Very porous. Banded chips have thin shale partings.
Limestone, dolomitic, argillaceous, pale-yellowish-brown and medium-bluish-gray; bands with limonite spots.	15	135	Not as argillaceous as above rock. Has clastic unconsolidated rock fragments, from crevices(?).
Sample missing	10	145	
Mississinewa shale:			
Limestone, dolomitic, argillaceous, light-gray, fine-grained; sparse pinpoint-size pores; contains much pyrite, some limonite spots, and chert.	5	150	
Sample missing	5	155	
Limestone, dolomitic, highly argillaceous, medium-light-gray; contains much pyrite, many limonite spots, and some bands.	30	180	Clay constitutes as much as 40 percent of the rock and is deposited in interstitial space between grains.

Well 25/3-1H4

[Altitude: 809 feet above mean sea level. Type of record: Sample log of test hole (samples collected by driller, examined by J. S. Rosenshein)]

	Thickness (feet)	Depth (feet)	Remarks
Quaternary system:			
Recent and Pleistocene series:			
Soil, clay, silty, noncalcareous	2	2	
Clay (till), silty, noncalcareous, mottled tan and brown; subrounded, coarse sand, and few small pebble gravel.	7	9	Probably taken from top of sampled interval.
Clay (till), silty, calcareous, brown; fine to coarse subrounded sand and fine to medium subrounded to subangular pebble gravel.	16	25	Becomes grayish brown near base of bed.
Sand and pebble gravel, very clayey, calcareous, grayish-brown.	30	55	Driller's log records gray sandy clay and gravel.
Clay (till?), silty, calcareous, grayish-brown; fine to medium subrounded sand; some small pebble-gravel.	12	67	Driller's log records boulders.
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, dolomitic, argillaceous, yellowish-gray, fine- to medium-grained; some chert chips, limonite spots, and some pyrite.	8	75	Upper 3 ft had many unconsolidated glacial fragments.
Limestone, dolomitic, argillaceous, yellowish-gray to medium-bluish-gray, fine-grained; sparse pinpoint-size pores; contains limonite spots and pyrite.	5	80	Medium bluish-gray rock is more argillaceous.
Limestone, dolomitic, argillaceous, light-olive-gray, fine-grained; medium bluish-gray bands; contains limonite spots, pyrite, and a little chert.	50	130	Almost sandy in lower part. Rock is fractured from 120 to 125 ft.
Limestone, dolomitic, argillaceous, dark-yellowish-brown, fine-grained; thin grayish-black shale bands.	5	135	More argillaceous than overlying rock. A few chips are very porous.
Mississinewa shale:			
Limestone, dolomitic, highly argillaceous, bluish-gray to light-gray, fine-grained; abundant pyrite masses and limonite spots.	45	180	Almost sandy in lower part.

TABLE 8.—*Logs of wells and test holes in the vicinity of Bunker Hill Air Force Base, Indiana*—Continued

	Thickness (feet)	Depth (feet)	Remarks
Well 26/3-25D1			
[Altitude: 787 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Clay, brown	2	2	
Clay, (till?), red	18	20	
Clay (till?), sandy, red	5	25	
Mud, soft, gray	7	32	
Sand, fine, gray	7	39	
Clay, gray, with sand	13	52	
Gravel, medium	12	64	
Silurian system:			
Limestone	--------	64	
Well 26/3-25K1			
[Altitude: 788 feet above mean sea level. Type of record: Sample log of water well (samples collected by driller, examined by J. S. Rosenshein)]			
Quaternary system:			
Recent and Pleistocene series:			
Soil, silt, clayey, noncalcareous, yellowish-brown.	4	4	
Clay (till), silty, calcareous, brown grading downward to grayish-brown; fine to coarse sand and fine subrounded to subangular pebble gravel.	56	60	Color becomes brownish black in lower 20 ft.
Sand and gravel, subrounded to subangular, clayey; many limestone fragments.	16	76	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, dolomitic, argillaceous, yellowish-gray to pale-yellowish-brown, fine-grained, porous (pores range from sparse pinpoint size to more than 1 mm); some bands, limonite spots, and chert.	44	120	Many stylolites. Some calcite veins from 115 to 120 ft.
Limestone, dolomitic, argillaceous, banded, pale-yellowish-brown and gray-black, fine- to medium-grained, vuggy.	5	125	Some chips show brecciation and recementation.
Mississinewa shale:			
Limestone, dolomitic, argillaceous to highly argillaceous, pale-yellowish-brown grading downward to medium-bluish-gray, fine-grained, banded; limonite spots.	30	155	
Shale, calcareous, or highly argillaceous limestone that is dolomitic, medium bluish gray, and fissile.	5	160	
Limestone, dolomitic, highly argillaceous, medium-bluish-gray, fine-grained; thin calcareous-shale bands.	5	165	
Well 26/3-25N1			
[Altitude: 795 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Topsoil and yellow clay (till)	8	8	
Clay, gray, gravelly (till?)	51	59	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, gray	19	78	
Limestone, white	10	88	
Limestone, gray	2	90	
Limestone, white	38	128	
Mississinewa shale:			
Limestone, dark-gray	10	138	
Limestone, gray	8	146	
Limestone, dark-gray	10	156	

TABLE 8.—*Logs of wells and test holes in the vicinity of Bunker Hill Air Force Base, Indiana*—Continued

	Thickness (feet)	Depth (feet)	Remarks
Well 26/3-25Q1			
[Altitude: 795 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Loam and clay	13	13	
Gravel	5	18	
Hardpan (clay till?)	42	60	
Mud, blue	5	65	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone	20	85	
Limestone, fissured	49	134	Formation break is indicated by gamma-ray log of well.
Mississinewa shale:			
Limestone, fissured (?)	31	165	
Well 26/3-26D2			
[Altitude: 784 feet above mean sea level. Type of record: Sample log of water well (samples collected by driller, examined by J. S. Rosenshein)]			
Quaternary system:			
Recent and Pleistocene series:			
Clay, sand, and some small gravel	66	66	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, dolomitic, argillaceous, pale-yellowish-brown	34	100	
Well 26/3-26J1			
[Altitude: 795 feet above mean sea level. Type of record: Driller's log]			
Quaternary system:			
Recent and Pleistocene series:			
Topsoil and clay mixed, (till)	34	34	
Clay, gravelly	25	59	
Silurian system:			
Middle Silurian series:			
Liston Creek formation:			
Limestone, brown	26	85	
Limestone, gray	50	135	
Mississinewa shale:			
Limestone, brown	15	150	

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