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Ground-Water Hydrology and Geology of the Lower Great Miami River Valley Ohio

By ANDREW M. SPIEKER

GROUND WATER IN THE LOWER GREAT MIAMI RIVER VALLEY, OHIO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 605-A

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probably under conditions similar to those now prevailing on the Continental Shelf. The total thickness of the Cincinnatian Series is about 800 feet. These shales and limestones have a low permeability; the small amount of water that does occur in them is in joints and cracks, whose distribution is erratic. Although the permeability of these rocks may be too low to sustain large water yields from wells, the large area of shale in contact with sand and gravel aquifers possibly contributes a significant quantity of water to the aquifers.

Several times during the Pleistocene Epoch, which comprised the last 2½–3 million years before the Holocene (Recent) Epoch, Ohio was in large part covered by continental ice sheets. Of the four recognized major glaciations, three, possibly four (Ray, 1966), invaded the lower Great Miami River valley. Each ice sheet blanketed the area with glacial till, which is a tough, poorly-sorted aggregate with a predominantly clay matrix containing pebbles, cobbles, and boulders that, in the lower Great Miami River valley, are largely limestone. This glacial till, like the shale bedrock, is nearly impermeable although water is locally present in pockets and lenses of sand and gravel within the till.

As a result of the Pleistocene glaciations, impermeable bedrock was blanketed by equally impermeable till. In the valleys, however, glacial outwash deposits of the last glaciation of Wisconsin age, and perhaps those of the next older glaciation of Illinoian age, form the most potentially productive water-bearing deposits in the Midwest. During one or more of the interglacial ages the valley that is in general followed by the present Great Miami, became entrenched in bedrock to depths of 200 feet or more. The filling of glacial outwash, consisting mainly of well-sorted sand and gravel, was deposited in the entrenched valley by the torrential meltwaters of the younger ice sheets. Till, interstratified with the permeable outwash sand and gravel in the valleys, has produced confining layers of lower permeability.

GROUND WATER IN THE HYDROLOGIC SYSTEM

The Great Miami River valley has an abundant supply of water owing to both the high storage capacity of the valley-train aquifers and the high average annual rainfall of about 40 inches. Because of such plentiful recharge and storage, the sustained dry-weather flow of the Great Miami River is one of the highest in Ohio. The mean discharge of the river at Hamilton is 3,323 cfs (cubic feet per second), and the discharge equaled or exceeded 90 percent of the time is 490 cfs (Cross and Hedges, 1959, p. 147). The latter figure is considered by many hydrologists to be a good index of a stream's sustained dry-weather flow. The Great Miami River's high dry-weather flow, or base flow, is due largely to the high permeability and storage capacity of the sand and gravel deposits which underlie much of the streambed. Ground water in these deposits is hydraulically connected with the river. Under natural conditions the gradient is from the aquifer to the river; therefore, ground water discharges into the river. In periods of little or no precipitation, streamflow results almost entirely from ground-water discharge. (See Cross and Hedges, 1959, p. 5–13.)

Man has influenced the hydrologic cycle in the lower Great Miami River valley. The most readily apparent effect of man's activity on the relationship of ground water and surface water is the reversal of the natural hydraulic gradient caused by pumping ground water from the sand and gravel aquifers. Where and when the rate of pumping is great enough for the cone of depression to intersect the river, the hydraulic gradient is reversed, and water is induced to infiltrate from the river into the aquifer. About 110 million gallons of water are pumped from the aquifer each day in the report area. Most of this pumping is concentrated around the cities of Middletown, Hamilton, and Franklin, where the hydraulic gradient has been reversed. Though man has altered the hydrologic cycle, he does not permanently remove water from the system. He has merely changed the path that water takes through the system.[2]

Although the hydrologic system of the lower Great Miami River valley has here been described in very general terms, the hydrologic regimen of this area—in its present state as well as its possible future trends—requires a more detailed analysis of its complexities to be fully understood. Therefore, the environments in which ground water occurs in the lower Great Miami River valley are described next.

HYDROGEOLOGIC ENVIRONMENTS

The characteristics of the sand and gravel aquifers are far from uniform throughout the lower Great Miami River valley. By geologic mapping it is possible to differentiate aquifer units, each with its distinctive physical properties. The occurrence of ground water is further complicated by differences in aquifers' potential for recharge by induced infiltration, which are usually not considered in conventional geologic mapping. A somewhat broader concept is needed to define these important areal variations in the occurrence of ground water.

[2] These remarks refer to the hydrologic system in the lower Great Miami River valley as a whole, and not to any specific locality. The aquifers have been overdrawn locally; the extent and the consequences of this local overdraft are discussed in Professional Paper 605 D (Spieker, 1968b).

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The concept of "hydrogeologic environment" was introduced in the present investigation to broaden the usual scope of geologic mapping. A hydrogeologic environment is here defined as a mappable area whose underlying aquifer materials possess distinct hydrologic and geologic properties that differ significantly from the properties of aquifers in the adjacent areas. In other words, ground water occurs under essentially uniform hydrologic and geologic conditions within any given hydrogeologic environment. The term "hydrogeologic environment" owes its origin to the relatively new interdisciplinary science of hydrogeology, which deals with the geology and hydrology of ground water. Hydrogeologic mapping—or the mapping of hydrogeologic environments—thus somewhat broadens the scope of conventional geologic mapping.

The lower Great Miami River valley has been classified into 11 different hydrogeologic environments, which are as follows:

Valley-train deposits

I. Sand and gravel aquifer; recharge by induced stream infiltration potentially available.
  A. No interstratified clay layers present.
    1. Aquifer 150–200 feet or more thick.
    2. Aquifer less than 150 feet thick.
  B. Interstratified clay layers possibly present.
    1. Aquifer 150–200 feet or more thick.
    2. Aquifer less than 150 feet thick.

II. Sand and gravel aquifer; no recharge by induced stream infiltration available.
  A. No interstratified clay layers present.
    1. Aquifer 150–200 feet or more thick.
    2. Aquifer less than 150 feet thick.
  B. Interstratified clay layers possibly present.
    1. Aquifer 150–200 feet or more thick.
    2. Aquifer less than 150 feet thick.

III. Sand and gravel aquifer overlain by clay; stream recharge generally not available.

IV. Valleys filled largely or entirely with clay; large water supplies generally not available.

Upland areas

V. Shale bedrock overlain by glacial till; large water supplies generally not available.

The four principal criteria on which this classification is based are nature of the aquifer, availability of recharge by induced stream infiltration, presence or absence of interstratified clay layers, and thickness of the aquifer unit. The above outline is arranged in order of generally decreasing potential for the development of large ground-water supplies. Should more detailed work in the future make possible a more detailed classification, the expanded classification can easily be fitted into the framework in the outline just given.

The following discussion of hydrogeologic environments in the lower Great Miami River valley is based on the hydrogeologic map of the area and a series of geologic sections (pls. 1, 2). The sections are consecutively designated by letters (*A–A'*, *B–B'*, and so on) beginning in the northern part of the area, but are discussed in the order given in the above outline. The boundaries between the environments (pls. 1, 2) are generalized, as is implied by the dashed lines. The contacts, as shown on maps in this report, represent the best generalizations which can be made on the basis of available data. Further investigations may reveal information that will permit some refinement of this map.

ENVIRONMENT I–A–1

[Sand and gravel aquifer 150–200 feet or more thick; no interstratified clay layers present; stream recharge available]

The most favorable environment for the development of large ground-water supplies in the lower Great Miami River valley is in those areas where 150 feet or more of sand and gravel with no retarding clay layers are sufficiently close to the river to permit induced recharge by stream infiltration. This hydrogeologic environment, designated I–A–1, occurs in three parts of the report area (pls. 1, 2): the vicinity of Trenton, immediately southwest of Middletown; that part of the valley from a point north of New Miami, through Hamilton and Fairfield, to a point west of Ross; and the lower Whitewater River valley, southeast of Harrison. Several of the largest ground-water supplies in the lower Great Miami River valley are in this environment—at New Miami, Hamilton, Fairfield, and Ross—but the aquifer in much of this highly favorable territory remains untapped.

The coefficient of transmissibility (T) of the aquifer in evironment I–A–1 ranges generally from 300,000 to 500,000 gpd per ft (gallons per day per foot). The coefficient of storage (S) is about 0.2, indicating that the water is unconfined. Properly constructed individual wells can yield 3,000 gpm (gallons per minute) or more and have specific capacities of as much as 300 gpm per foot of drawdown.

The geologic sections on plate 2 show the significant characteristics of hydrogeologic environment I–A–1. Section *E–E'* (pl. 2) is in the western part of the Hamilton South well field, about 1 mile east of the site of a new well field proposed by the city of Cincinnati. Here the buried valley of the ancestral Great Miami River is about 2 miles wide. Its floor is nearly flat and its bedrock walls are steep. Although no areally extensive clay layers appear to be present, a distinct layer of fine-grained materials, consisting of sand and silt, can be identified in the lower part of the valley fill.

Section *G–G'* (pl. 2) is representative of conditions in the lower Whitewater River valley. As yet, data from

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wells are rather scarce in this area for little development of the ground-water resource has been done. Control on the bedrock surface for this cross section is based on results of a seismic refraction survey. The lenses of clay shown are diagrammatic and indicate that widely scattered lenses and stringers of fine-grained material may be present anywhere in the valley fill. These lenses are not, however, of sufficient thickness or areal extent to act as semiconfining layers or to otherwise affect the general movement of the ground water in the area.

The bedrock floor of the buried Whitewater River valley is flat and the walls are steep, just as they are in the Fairfield area (pl. 2). The Whitewater River valley ranges in width from 1 to 1½ miles in the reach between Harrison and Elizabethtown; the valley in this reach is somewhat narrower than Great Miami River valley at Fairfield. The Whitewater River valley in the study area has undergone only little ground-water development and, indeed, has all the characteristics favorable to such development; therefore, it is one of the most promising parts of the lower Great Miami River valley for future development of ground-water supplies.

RECHARGE BY INDUCED STREAM INFILTRATION

The key factor in sustaining the large ground-water supplies in hydrogeologic environment I–A–1 is the availability of recharge by induced stream infiltration. The rate of such recharge varies widely with respect to both place and time and depends on many factors, such as stream discharge, stream velocity, condition of the streambed, temperature of the stream water, and the hydraulic gradient in the aquifer. Induced infiltration, despite its major role in the hydrologic system, is, nonetheless, one of the least understood phenomena. That it is not more clearly understood can be partly attributed to the fact that meaningful results are obtainable only with fairly large expenditures of time and funds. Induced infiltration in the lower Great Miami River valley certainly should receive future study.

Probably the most comprehensive study of stream infiltration induced by pumping of ground water was made by Rorabaugh (1956) in the alluvial deposits of the Ohio River valley in northeastern Louisville, Ky. Rorabaugh (p. 117–125) derived several equations for the determination of infiltration characteristics, and these equations have become the basis of most subsequent infiltration studies.

Most induced recharge occurs during periods of high streamflow. This phenomenon can be attributed to three causes:

1. The higher stream velocities associated with high streamflow tend to keep the fine-grained particles (such as clay and silt) in suspension, and the resultant streambed is composed mainly of sand and gravel and is conducive to infiltration.
2. The head differential between water in the stream and water in the underlying aquifer is greater at high streamflow than at low flow, and leads to increased infiltration.
3. The wetted area of the streambed is generally larger at high streamflow.

No independent analysis of these three factors has been made to ascertain their relative importance.

Although most induced recharge occurs at high streamflow, a large amount is also known to occur during periods of sustained low streamflow. It is the amount of recharge during periods of low streamflow that is critical in sustaining large ground-water supplies during prolonged drought periods; therefore, most stream-infiltration studies have emphasized these periods.

Dove (1961, p. 62–66) determined the rate of induced infiltration at the well field of the Southwestern Ohio Water Co. near Ross—in hydrogeologic environment I–A–1—by use of a flow-net analysis based on water-level measurements made on August 31, 1956. The company's two horizontal collectors (wells 73 and 77) were being pumped at a combined rate of 16.9 mgd (million gallons per day). The average discharge of Great Miami River at Hamilton on that day was 587 cfs, a rate exceeded about 85 percent of the time and considered to be representative of low streamflow. The average infiltration rate for the affected reach of the river was calculated to be 240,000 gpd (gallons per day) per acre of streambed. The maximum infiltration rate, however, was considerably higher. On the basis of the determined rate of 115,000 gpd per acre per foot of head loss, the infiltration rate at the point where the maximum of 6.37 feet of head loss was measured was 735,000 gpd per acre of streambed.

Another determination of the average infiltration rate in the lower Great Miami River valley was made during a pumping test conducted by the city of Cincinnati on June 26–29, 1962, at a site in Fairfield township of Butler County, about half way between the Southwestern Ohio Water Co. well and the Hamilton South well field. The test site is near the location of Cincinnati's proposed well field. R. C. Smith (written commun. to the city of Cincinnati, 1962) calculated an average infiltration rate of 492,000 gpd per acre for a reach of about 1,800 feet of streambed at the site of the test, during which well 63 was pumped at 3,000 gpm for 3 days. The results of this test are discussed in chapter C of the present series (Spieker, 1968a, p. C5–C9). Discharge of Great Miami River at Hamilton ranged from 676 to 624 cfs, a range exceeded over 75 percent of the time (Cross and Hedges, 1959, p. 147).

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Although the two estimates of stream infiltration rate are of the same order of magnitude, this does not indicate that the phenomenon of stream infiltration in the Great Miami River valley is adequately understood. Both determinations were made in hydrogeologically similar terrains and under similar streamflow conditions. The hydrologic regimen in the lower Great Miami River valley presents such a wide range of conditions that two determinations, alone, are not representative of it.

Temperature is one of the variables that affect infiltration rates. Both the above determinations were made during the summer, when temperature of the river water was about 80°F. During the winter the river temperature is as low as 33°F. Inasmuch as the viscosity of water varies inversely with temperature, the permeability of a medium varies inversely with viscosity of the water it contains. A decrease in the temperature of the river water reduces the effective permeability of the streambed materials and thus inhibits recharge. A decrease of river temperature of 1°F would decrease the infiltration rate by about 1.5 percent. Therefore, the infiltration rate for river water at 40°F would be reduced by 60 percent from its value of 80°F. However, the reduction of the infiltration rate caused by lowered temperature is at least partly offset by the generally higher streamflow that occurs during the colder months of the year. Much additional research on the temperature–infiltration-rate relationship is needed.

EVIDENCE OF INDUCED STREAM INFILTRATION

Although recharge by induced stream infiltration is generally acknowledged by hydrologists, some scientists have expressed the opinion that much of the recharge attributed to induced infiltration is actually the result of ground-water runoff that is diverted from its normal path toward a stream. Indeed, diversion of ground-water runoff can produce the same effect as induced recharge from a stream; however, two examples in the lower Great Miami River valley can be cited as evidence that water actually has been induced to flow from the stream into the aquifer. Evidence of the first example is based on changes in the ground-water temperature during an aquifer test, and of the second, on a progressive change in the quality of water over a period of years.

During the previously mentioned aquifer test, conducted by the city of Cincinnati in June 1962, temperature-depth logs of several observation wells were made by using a thermister-type thermometer. The temperature logging technique has been discussed in detail by Norris and Spieker (1962).

Figure 2 is a temperature-depth log of well 62 made after well 63 had been pumped at 3,000 gpm for 2 days. The temperature of ground water in this area ranges from 53° to 56° F. The river temperature was about 80° F. when the test was made. Well 63 is 200 feet from the river, and well 62, the observation well, is 70 feet from the river and in line with well 63. No temperature log of well 62 was made before pumping of well 63 started; however, temperature logs of other wells not affected by stream recharge in this vicinity show a uniform temperature distribution with depth. The presence of a distinct layer of warmer water above the

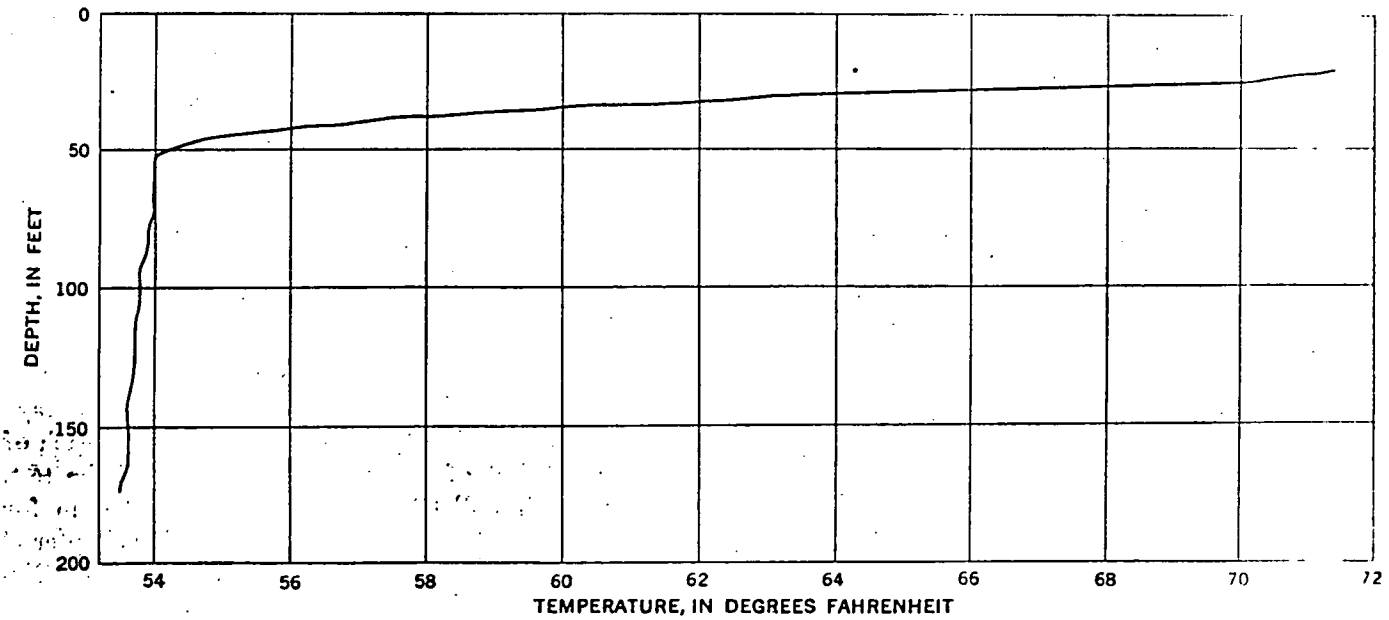


FIGURE 2.—Temperature-depth log of well 62 after well 63 had been pumped at 3,000 gpm for 2 days. Warm water above the 50-foot depth indicates that river water has entered the aquifer.

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50-foot depth in well 62 indicates that river water has infiltrated the aquifer.

The second example of induced stream infiltration is a progressive change in the chemical quality of the water from Southwestern Ohio Water Co. collector 1 (well 77 in present report) near Ross. Table 4 gives selected results from seven chemical analyses of samples taken at the collector near Ross over a 13-year period, and results of similar analyses of water from Great Miami River at Hamilton. The first sample from collector 1 was taken July 11, 1952, shortly after the collector was placed in operation; the most recent sample included in the present analysis was collected February 16, 1965. These analyses show that a distinct and progressive increase in the concentration of sulfate, from 38 mg/l (milligrams per liter) in 1952 to 121 mg/l in 1965, occurred during this 13-year period, during which the collector was pumped at rates of 5–10 mgd. Equally notable increases in the concentrations of chloride, hardness, and dissolved solids occurred. The temperature of water in the collector increased from 54° F in 1952 to 63° F in 1965. A comparison of these analyses from the collector with three selected analyses from Great Miami River at Hamilton also given in table 4, indicates that the quality of the ground water pumped from the collector was gradually approaching that of the water from the river during this 13-year period. Thus, it is concluded that water induced from the river mixed with the ground water as a result of induced stream infiltration.

TABLE 4.—*Chemical analyses of water from horizontal collector near Ross and from Great Miami River at Hamilton, showing progressive effect of induced stream infiltration*

[Data are in milligrams perliter except as indicated]

Date of analysis	Sulfate (SO_4)	Chloride (Cl)	Hardness ($CaCO_3$)	Dissolved solids	Temperature (°F)	Discharge at Hamilton (cfs)
Southwestern Ohio Water Co. collector 1 well, near Ross [Well 77 of present report]						
7-11-52	38	5.5	288	335	54	857
1-29-54	64	12	340	383	56	2,490
11- 7-56	72	16	340	401	56	638
3-27-57	75	21	360	420	56.5	1,670
6- 4-58	79	16	339	410	56	1,240
6- 4-63	82	24	354	423	59	1,370
2-16-65	121	38	380	486	73	4,130
Great Miami River at Hamilton [Mean discharge, 10-30-30 to 9-30-60, 3,214 cfs]						
5-13-46	78	11	331	390	.....	3,460
9-19-46	141	31	378	517	.....	496
10-11-49	102	18	360	438	.....	1,060

EFFECTS OF INDUCED RECHARGE ON STREAMFLOW

Induced stream recharge and captured ground-water runoff not only affect the sustained yield of wells, as previously discussed, but also affect streamflow. Generally, the withdrawal of a given amount of water from an aquifer that is hydraulically connected with a stream will eventually reduce the flow of the stream between the point of withdrawal and the point of return by an amount approximately equal to the amount withdrawn. However, this reduction in flow will generally occur whether the water entering the well comes from induced stream recharge or from captured ground-water runoff.

This relationship between withdrawals from wells and reduction in streamflow is generally obscured or overlooked for three reasons:

1. The point of return is usually so close to the point of withdrawal that the effect cannot be readily detected.
2. Ground water in storage acts as a "buffer," sometimes delaying the effect of pumping on streamflow.
3. For a stream with as high a sustained flow as the Great Miami River, the rate of ground-water withdrawal at any single locality is usually very small in comparison with the rate of streamflow; also, most streamflow losses to induced infiltration occur during periods of high flow, when they are difficult to detect.

To measure losses in streamflow caused by ground-water withdrawal in the area of investigation would be difficult for the above reasons. Studies have been made, however, in the Dayton area, immediately north of the study area. Conditions for measuring streamflow losses are more favorable in the Dayton area because much of the ground-water withdrawal is concentrated in the northeastern and central parts of the city; the flow of the Great Miami River is not as great in this area as it is farther downstream; and the principal sewage plant, which returns used water to the river, is in southwest Dayton, downstream from several of the principal pumping centers.

Cross and Hedges (1959, p. 52) mentioned that, on the basis of long-term averages, there is a loss in streamflow in the Great Miami River through Dayton approximately equal to the quantity of effluent discharged from the Dayton sewage-treatment plant. All water supply for Dayton comes from a ground-water source, and one can thus assume that the ground-water withdrawals cause the reduction in streamflow.

A detailed analysis of the effects of ground-water withdrawal on streamflow in the Dayton area during a period of low flow was described by Norris and Spieker (1966, p. 88–92). On October 4, 1960, discharge measurements were made at eight sites on the Great Miami and Mad Rivers. A net loss of 105.4 cfs, or 68 mgd, occurred between Mad River at Huffman Dam and the Great Miami River 1 mile north of Holes Creek (Norris

and Spieker, 1966, table 4). The average daily groundwater pumpage in the Dayton area at that time (Norris and Spieker, 1966, table 6) was about 110 mgd. These figures indicate that 48 mgd (the difference between the stream loss and the total pumpage) was being pumped from storage.

Because most of the ground water withdrawn from the valley-fill aquifers is eventually returned to the river, the net depletion of streamflow for the report area as a whole is slight. The principal effect of this cycling is on the quality of water; the water returned to the river is generally of lower quality and of higher temperature than naturally occurring ground water.

ENVIRONMENT I–A–2

[Sand and gravel aquifer less than 150 feet thick; no interstratified clay layers present; stream recharge available]

The second most favorable hydrogeologic environment in the lower Great Miami River valley consists of those areas where the sand and gravel aquifer is 150 feet or less thick, has no areally extensive clay layers, and is sufficiently close to a major stream to be recharged by induced infiltration. This environment is present chiefly along two reaches of the Great Miami River (pls 1, 2); one, between Trenton and New Miami, and the other, between New Baltimore and Cleves. Hydrogeologic environment I–A–2 also occurs adjacent to environment I–A–1 along the edges of the buried valley; for example, along the walls of the Great Miami River valley southwest of Hamilton, between Fairfield and Ross.

Section *H–H′* (pl. 2) displays the main characteristics of hydrogeologic environment I–A–2. This section is at the Gulf Oil Co. refinery near Cleves. Here the sand and gravel aquifer is about 100 feet thick. The buried valley is slightly less than a mile wide but has virtually the same configuration (flat floor and steep walls) as does the wider, and deeper valley in the Hamilton area. (Compare with sections *E–E′* and *G–G′*, pl. 2.) The valley fill consists mainly of sand and gravel, with a thin clay layer (probably weathered bedrock) immediately overlying the bedrock.

The transmissibility of the aquifer in hydrogeologic environment I–A–2 ranges from 100,000 to 300,000 gpd per ft. The storage coefficient is about 0.2. Individual wells drilled in this environment can yield as much as 2,000 gpm and have specific capacities ranging from 75 to 150 gpm per foot of drawdown. At the Gulf Oil Co. refinery near Cleves, where the only large groundwater supply in this hydrogeologic environment was found, most production wells were originally tested at 1,500 gpm and had drawdowns ranging from 10 to 28 feet. The main factor limiting well capacities in this environment is the relatively limited thickness of the aquifer, which restricts the available drawdown. Where the buried valleys are narrow, as at the Gulf Oil Co. refinery, the proximity of the valley walls tends to result in increase of drawdowns. This tendency for greater drawdowns, combined with the limited available drawdown, dictates that wells be spaced farther apart than in the more favorable hydrogeologic environment I–A–1.

ENVIRONMENT I–B–1

[Sand and gravel aquifer 150 to 200 feet or more thick; clay layers possibly present; stream recharge available]

Much of the Great Miami River valley between the central part of Middletown and the north edge of the study area (pl. 1) is underlain by sand and gravel with one or more interstratified layers of clay. Those parts of the valley where the sand and gravel aquifer is more than 150 feet thick and where recharge by induced stream infiltration is potentially available are designated as hydrogeologic environment I–B–1. This environment is also characteristic of much of the Dayton area, to the north. The characteristics of the valley-fill aquifer in the Dayton area have been described in detail by Norris and Spieker (1966, p. 33).

The best example of hydrogeologic environment I–B–1 is in the central part of Middletown, near the Middletown Water Works. Section *B–B′* (pl. 1) shows the generalized geology of this area. Here the valley-train deposits are separated into two distinct aquifers by a layer of clay 50 feet or more thick. Other clay layers are scattered through the section. The upper aquifer is typically about 50 feet thick but ranges in thickness from 30 to 70 feet. The lower aquifer is typically about 100 feet thick. The slope of the bedrock valley walls is less steep and the floor is less flat than in the Hamilton area. (Compare section *B–B′*, pl. 1, with section *E–E′*, pl. 2.) The deepest part of the buried valley, below an altitude of 400 feet, is inferred from seismic refraction surveys. The deepest known well in the Middletown area is a test well at the Armco East Works which reached bedrock at an altitude of 408 feet.

The coefficients of transmissibility and storage in environment I–B–1 were not determined during the present investigation. Norris (1959, p. 7), however, determined that the transmissibility of the lower aquifer at the Rohrers Island well field of the city of Dayton, situated in a similar environment, is 125,000 gpd per ft. At that site the lower aquifer is 50–75 feet thick; therefore, at sites such as the Middletown well field, where it is about 100 feet thick, the transmissibility is probably 200,000–250,000 gpd per ft. The transmissibility of the upper aquifer is probably less than 100,000 gpd per ft. The storage coefficient in the upper aquifer is probably

about 0.2, a characteristic value reflecting unconfined conditions. In the lower aquifer the storage coefficient probably ranges from 0.02 to 0.0002 and thus reflects varying degrees of confinement by the clay layer.

Most large ground-water supplies in this environment are developed in the lower aquifer, for the upper aquifer generally does not supply enough allowable drawdown to permit high yields. One notable exception is the Middletown Water Works, which has 16 wells in the upper aquifer pumped by suction pumps from a central pumping station (number 20 in present report). This group of wells provides 1–2 mgd of Middletown's total supply of 8 mgd. By thus pumping the supply from a large number of wells, it is possible to reduce the drawdown. Generally, though, an individual well in the upper aquifer should not be expected to yield more than 200 gpm. Specific capacities in the upper aquifer range from 25 to 50 gpm per foot of drawdown.

Wells screened in the lower aquifer can yield as much as 3,000 gpm. Well 2 of the Middletown Water Works, a typical well screened in the lower aquifer, yielded 2,100 gpm with 18 feet of drawdown for a specific capacity of 117 gpm per foot of drawdown.

Separation of the valley fill into two aquifers is distinct in the downtown Middletown area, but it is not necessarily so distinct throughout hydrogeologic environment I–B–1. Clay is generally present in wells drilled in this environment, but it is not always present in a single well-defined layer. Because of the irregular distribution of clay in the section, adequate test drilling is needed prior to development of any large water supplies. Particular care should be taken in both the selection of the proper screen size and the development of production wells.

The clay shown in section *B–B′* (pl. 1) has not been differentiated as to origin; it is believed to be a combination of originally deposited till, till reworked by melt waters, and lacustrine deposits. Generally these different types of clay are impossible to distinguish on the basis of a typical driller's log. The hydrologic significance of clay as a retarding layer, however, remains virtually the same, regardless of its origin.

ENVIRONMENT I–B–2

[Sand and gravel aquifer less than 150 feet thick; clay layers possibly present; stream recharge available]

In most of the Great Miami River valley between Miamisburg and Franklin, and along the valley's east side between Franklin and Middletown, the valley-train aquifer is generally less than 150 feet thick and contains interstratified clay layers. Recharge by induced stream infiltration is available. This hydrogeologic environment is designated I–B–2 (pl. 1) and bears the same relation to environment I–B–1 as environment I–A–2 does to environment I–A–1.

Section *A–A′* (pl. 1), at the O. H. Hutchings station of the Dayton Power & Light Co., shows the distinctive characteristics of this environment. The effective thickness of the aquifer is generally 100 feet or less, although a deep narrow channel just east of the Hutchings station has been identified, and another deep channel west of the power plant has been inferred from seismic refraction surveys. Several clay layers appear to be present, although no single layer is as well defined as the major clay layer which separates the valley fill into two aquifers in the Middletown area.

The coefficient of transmissibility probably ranges from 100,000 to 200,000 gpd per ft in hydrogeologic environment I–B–2. The storage coefficient probably ranges from 0.2 to 0.02, depending on the degree to which the clay layers confine the aquifer. In areas where the lower part of the aquifer is confined by an extensive clay layer, the storage coefficient might be as low as 0.0002.

The range of specific capacities in this environment is great, indicating that the rock materials are not homogeneous. Table 5 shows the results of specific-capacity tests made on the six production wells (wells 7–12) at the O. H. Hutchings station of the Dayton Power & Light Co. The specific capacities range from 59 to 550 gpm per foot of drawdown and average 232 gpm per ft.

TABLE 5.—*Static water level, drawdown, and specific capacity of production wells at the O. H. Hutchings station of the Dayton Power & Light Co., September 29, 1964*

[Discharge of Great Miami River, 292 cfs; river temperature, 66° F]

Well	Static water level		Pumping rate (gpm)	Drawdown (ft)	Specific capacity (gpm per ft)	Water temperature (° F)
	Below measuring point (ft)	Elevation above sea level (ft)				
7	30.4	673.4	1,025	17.4	59	60
8	31.4	671.9	1,045	1.9	550	58
9	30.6	672.7	980	9.4	104	58
10	33.2	669.6	925	4.0	232	61
11	30.1	672.7	1,120	3.2	350	63
12	31.1	671.7	1,145	8.4	135	60

All six wells are within 3,000 feet of each other. The water-temperature range, 58° to 63°F, is somewhat higher than normal for ground water in this area and indicates that induced infiltration from the river has been taking place over a prolonged period of time. Individual wells at the more favorable sites in hydrogeologic environment I–B–2 could probably yield as much as 2,000 gpm with 6–12 feet of drawdown. As in environment I–B–1, production-well sites should be selected only after adequate test drilling, and care must be taken in the development of wells.

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ENVIRONMENTS II–A–1 AND II–A–2

[Sand and gravel aquifer; stream recharge not available; no interstratified clay layers present]

Hydrogeologic environment II–A occurs principally in a wide trough, which is the abandoned course of the ancestral Great Miami River, between Trenton and New Miami (pls. 1, 2). This environment consists of a sand and gravel aquifer that contains no areally extensive clay layers. It is too far from the Great Miami River to receive recharge by induced infiltration. It is geologically similar to environment I–A, the only significant difference being its lack of available stream recharge.

The major part of the area in the center of this trough (pls. 1, 2), where the aquifer is more than 150 feet thick, is designated as hydrogeologic environment II–A–1. Areas along the edges of this trough, where the aquifer is less than 150 feet thick, are designated as hydrogeologic environment II–A–2. Environment II–A–2 also occurs along the edges of the Great Miami River valley in the Hamilton-Fairfield area and on the east side of the Whitewater River valley, where the aquifer is less than 150 feet thick and is too far from the river for recharge by induced infiltration to be effective.

The transmissibility and storage coefficients in environment II–A are probably similar to those of environments I–A–1 and I–A–2. No large ground-water supplies have been developed in environment II–A. The hydrologic system in environment II–A–1, however, can probably sustain supplies of 500 gpm, and some wells possibly can yield as much as 1,000 gpm. These areas may thus be considered suitable for light industry or small municipal supplies. Because environment II–A–2 is near the bedrock valley walls, it is not a favorable environment for the development of large ground-water supplies.

ENVIRONMENTS II–B–1 AND II–B–2

[Sand-and-gravel aquifer; stream recharge not available; interstratified clay layers possibly present]

Hydrogeologic environment II–B is not especially significant in the regimen of the lower Great Miami River valley. The environment II–B areas, where the sand and gravel aquifer with interstratified clay layers is too far from a stream to permit induced recharge, occur only as small patches in contact with environment II–A. One such area (pl. 1) is about 2 miles west of West Carrollton, and another is at and around the town of Carlisle. The aquifer is more than 150 feet thick in these two areas, which are designated as hydrogeologic environment II–B–1. A third such area, along the east side of the Great Miami River valley in Middletown, is designated as hydrogeologic environment II–B–2, as the aquifer is less than 150 feet thick.

Individual wells drilled in hydrogeologic environment II–B can be expected to yield 100–500 gpm, so that the areas in which it occurs should provide water supplies suitable for development of light industry.

ENVIRONMENT III

[Sand and gravel aquifer overlain by clay; stream recharge generally not available]

In four areas of the lower Great Miami River valley the sand and gravel aquifer is overlain by 50 feet or more of clay. These four areas (pls. 1, 2) are (1) the abandoned trough of the ancestral Great Miami River north of Carlisle, (2) an area southeast of Middletown at the mouth of the ancestral Todds Fork valley, (3) an area southeast of Hamilton where the valley of the ancestral Ohio River enters the Great Miami River valley, and (4) the abondoned trough of the ancestral Ohio River between Ross and Harrison. The last area is known as the New Haven Trough (Fenneman, 1916, p. 33–34). Although the characteristics of the overlying clay layer and its relation to the sand and gravel aquifer are not the same in all these areas, the clay layer inhibits recharge to the aquifer. Because these terranes are hydrologically similar, they are classified together as hydrogeologic environment III.

Three geologic sections illustrate the various features of hydrogeologic environment III. Section *C–C′* (pl. 1) shows the occurrence of this environment in the southern part of Middletown. The East Works of the American Rolling Mill Co. (Armco) is in the eastern part of this section. In this highly generalized section, the principal sand and gravel aquifer is shown to be overlain by 100 feet or more of clay, believed to be largely of lacustrine origin. The aquifer thins as the clay thickens to the east. The deepest part of the trough, as shown on section *C–C′* (pl. 1), is inferred from seismic surveys. The present valley of the Great Miami River is separated from the buried ancestral valley by a bedrock high; the river flows over bedrock covered only by a veneer of alluvium. The Armco East Works area is therefore in an unfavorable location for receiving recharge by induced stream infiltration.

A distinctive variation of hydrogeologic environment III is shown on section *D–D′* (pl. 2) along Gilmore Road, southeast of Hamilton. Here, the sand and gravel aquifer is 100–150 feet thick and is overlain by a clay layer about 100 feet thick. Till units are differentiated at both top and bottom of the clay leyer, most of which is considered to be of lacustrine origin. This area differs from the area southeast of Middletown in that its units are more uniform in thickness, its bedrock valley walls are steeper and the floor flatter, and no bedrock high separates it from the Great Miami River. (See pl. 2.)

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The upper sketch of section *D–D'* (pl. 2) shows the section drawn to true vertical scale. Considerable vertical exaggeration is used in the other sections to better illustrate the features of the valley-train aquifers. Such exaggeration, however, distorts the true configuration of the buried valleys, so the upper sketch is intended to show their true order of magnitude.

A third variation of hydrogeologic environment III is shown by section *F'–F''* near Ross, through the well fields of the Southwestern Ohio Water Co. and the U.S. Atomic Energy Commission (pl. 2). This section shows the relationship of hydrogeologic environment III, on the northwest, to hydrogeologic environment I.A.1, on the southeast. Here a high terrace, composed mostly of till and clay, overlies the aquifer in the western part of the valley. This semiconfining layer continues west and south through the New Haven Trough and terminates southeast of Harrison (pl. 2).

The large area of hydrogeologic environment III north of Carlisle (pl. 1) is not too well known, for no industrial or municipal water supplies are situated there. The area is believed to be similar to the area southeast of Hamilton (section *D–D'*, pl. 2), except that it contains more interstratified clay layers in the aquifer.

The transmissibility and storage coefficients in hydrogeologic environment III differ greatly from place to place. The transmissibility ranges from 35,000 to 300,000 gpd per ft.; the storage coefficient, though never accurately determined, probably ranges from 0.1 to 0.002. Norris and Spieker conducted an aquifer test at the Feed Materials Production Center of the U.S. Atomic Energy Commission near Fernald in the summer of 1962. The hydrogeologic setting of this area is shown on section *F–F'* (pl. 2). In addition to the thick clay layer which overlies the valley-train aquifer, there is another clay layer about 10 feet thick which divides the aquifer into two parts at that site. The test indicated that the transmissibility of the lower half of the aquifer is 150,000 gpd per ft.; therefore, the transmissibility of the entire aquifer is estimated to be about 300,000 gpd per ft.

The transmissibility of the aquifer in the vicinity of the Armco East Works, southeast of Middletown, can be determined by flow-net analysis, as described by Bennett (in Ferris and others, 1962, p. 139–144). Where a well-defined cone of depression around a well or pumping center can be mapped, a flow net can be constructed in which the area between water-level contours is divided into approximate squares. This was done for the area between the 540- and 560-foot contours at the Armco field (pl. 1). The average pumping rate at Armco is 10 mgd. The flow-net equation, as stated by Bennett, is:

$$Q=\frac{n_f}{n_d}Th,$$

where

Q=discharge, in gallons per day,
n_f=number of flow paths,
n_d=number of potential drops,
T=coefficient of transmissibility, in gallons per day per foot, and
h=total potential drop, in feet.

This equation can be rearranged into the form

$$T=Q\frac{n_d}{n_f h}.$$

In the present example, Q=10,000,000 gpd; n_f=22; n_d=1; and h=10 feet. Substitution of these values in the equation and solution for T yields a coefficient of transmissibility of 45,454 gpd per ft, which should be rounded to 45,000 gpd per ft.

In the small area of hydrogeologic environment III southeast of Hamilton, the transmissibility is an estimated 200,000 gpd per ft, based on the specific capacity of two wells. The transmissibility in the area north of Carlisle is probably in the same general range.

Individual wells in hydrogeologic environment III can be expected generally to yield 100–500 gpm, though yields of as much as 1,000 gpm are not uncommon. Wells in this environment that are close to the boundary with hydrogeologic environment I may have considerably higher yields owing to the possibility of induced recharge and to the aquifer's vast storage capacity. The need for test drilling and care in the development of wells is nowhere more important than in this environment because of the common presence but irregular distribution of clay layers.

ENVIRONMENT IV

[Valleys filled largely or entirely with clay; large water supplies generally not available]

At least two buried valleys that are tributary to the main buried valley of the ancestral Great Miami River are filled largely or entirely with clay; hence, they are not suitable for the development of large water supplies. These areas are designated as hydrogeologic environment IV. One such area is in a tributary valley south of the Armco East Works in Middletown (pl. 1), and the other is in the northwestern part of Hamilton (pl. 2).

ENVIRONMENT V

[Shale bedrock overlain by glacial till; large water supplies generally not available]

Hydrogeologic environment V includes most of the upland areas and all areas filled with sand and gravel except the buried valleys. In general, the shale bedrock of the Cincinnatian Series of Late Ordovician age is overlain by 50 feet or less of clay-rich till. Neither the

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till nor the bedrock is capable of yielding large quantities of water to wells. Many wells drilled in this environment are failures; others yield about 5–10 gpm, which is adequate for domestic supplies. Widely scattered lenses and stringers of sand and gravel interbedded in the till are capable of yielding as much as 50 gpm to wells. The distribution of these bodies is erratic.

SURFACE-WATER REGIMEN

The early settlement and industrialization of the Great Miami River valley was largely due to the river's high sustained flow. The river thus provided a dependable source of water for the Miami and Erie Canal and for the paper mills, which were the valley's earliest industries. The base flow, or sustained dry-weather flow, of a river is largely due to effluent seepage of ground water from the aquifer. Thus, streams hydraulically connected with highly permeable aquifers are likely to have a high base flow. During prolonged periods of dry weather, most of the Great Miami River's flow consists of ground-water seepage.

Many hydrologists (Cross and Hedges, 1959, p. 5–13) consider that the discharge equaled or exceeded 90 percent of the time is a good index of a stream's dry-weather flow. An even better means of comparing the base flow at various gaging stations is to divide the 90-percent discharge by the size of the drainage area above the station. This approach equalizes the results of all gaging stations with respect to drainage area, so that the record of one station can be compared with the record of any other station. Cross and Hedges (1959, p. 5–13), summarized the flow-duration data for all primary gaging stations in Ohio.

Table 6 shows the flow-duration data for the two gaging stations, whose locations are shown on plates 1 and 2, on the Great Miami River in the report area. Both stations have a high base flow. The discharge equalled or exceeded 90 percent of the time for Great Miami

TABLE 6.—*Flow-duration data for Great Miami River at Miamisburg and Great Miami River at Hamilton*

[Data from Cross and Hedges, 1959]

Period	Discharge equaled or exceeded for indicated percentage of time (upper line, cubic feet per second; lower line, cubic feet per second per square mile)														
	5	10	15	20	25	30	40	50	60	70	75	80	85	90	95
361. Great Miami River at Miamisburg															
1917–20, 1925–35, 1953–55.	8,100	4,750	3,400	2,680	2,220	1,880	1,410	1,080	825	665	592	525	455	385	310
	2.98	1.75	1.25	0.986	0.817	0.692	0.519	0.397	0.304	0.245	0.218	0.193	0.167	0.142	0.114
Adj. to 1921–45	8,800	5,050	3,750	2,920	2,380	2,000	1,460	1,110	855	650	575	505	442	380	310
	3.24	1.86	1.38	1.07	0.876	0.735	0.537	0.408	0.315	0.239	0.212	0.186	0.163	0.140	0.114
1926–30	11,180	7,450	4,900	3,950	3,290	2,810	2,220	1,800	1,400	1,030	860	730	643	572	510
	4.34	2.74	1.80	1.45	1.21	1.03	0.816	0.662	0.515	0.379	0.316	0.268	0.236	0.210	0.188
1931–35	6,190	3,550	2,500	2,020	1,630	1,350	1,000	780	625	505	458	410	358	304	260
	2.28	1.31	0.919	0.743	0.599	0.497	0.368	0.287	0.230	0.186	0.168	0.151	0.132	0.112	0.096
366. Great Miami River at Hamilton															
1931–55	11,700	6,900	4,970	3,840	3,000	2,530	1,800	1,320	990	755	668	589	520	450	378
	3.22	1.90	1.37	1.06	0.819	0.695	0.495	0.363	0.272	0.207	0.184	0.162	0.143	0.124	0.104
Adj. to 1921–45	12,400	7,150	5,100	4,000	3,310	2,790	2,000	1,460	1,070	830	738	655	572	490	398
	3.41	1.96	1.40	1.10	0.910	0.767	0.550	0.401	0.294	0.228	0.203	0.180	0.157	0.135	0.109
1931–35	8,700	5,380	3,800	2,900	2,300	1,900	1,400	1,100	860	700	620	550	475	390	310
	2.39	1.48	1.04	0.797	0.632	0.522	0.385	0.302	0.236	0.192	0.170	0.151	0.131	0.107	0.085
1936–40	14,100	7,600	5,500	4,400	3,600	3,050	2,200	1,650	1,250	940	800	700	610	520	402
	3.87	2.09	1.51	1.21	0.989	0.838	0.605	0.453	0.344	0.258	0.220	0.192	0.168	0.143	0.110
1941–45	9,500	5,400	3,700	2,850	2,300	1,910	1,430	1,050	760	590	540	500	460	420	370
	2.61	1.48	1.02	0.783	0.632	0.525	0.393	0.289	0.209	0.162	0.148	0.137	0.126	0.115	0.102
1946–50	15,300	9,200	6,700	5,380	4,500	3,750	2,590	1,830	1,450	1,180	1,050	936	800	650	551
	4.20	2.53	1.84	1.48	1.24	1.03	0.172	0.501	0.398	0.324	0.289	0.257	0.220	0.181	0.151
1951–55	11,300	7,200	5,180	4,110	3,250	2,690	1,700	1,150	860	680	600	531	469	409	350
	3.11	1.98	1.42	1.13	0.893	0.739	0.467	0.316	0.236	0.187	0.165	0.146	0.129	0.112	0.096

STATION DATA

361. *GREAT MIAMI RIVER AT MIAMISBURG*

Location: Lat 39°38'45", long 84°17'20", 600 ft downstream from bridge on State Highway 725 at Miamisburg, Montgomery County, and 0.3 mile downstream from Bear Creek. Prior to 1924 at site 6.7 miles downstream and 1924 to 1935, at site 2.2 miles downstream.
Drainage area: 2,718 sq. mi. At site used 1916–20, 2,780 sq. mi.; 1924–35, 2,719 sq. mi.
Period of record: March 1916 to Sept. 1920, Aug. 1924 to Sept. 1935, Oct. 1952 to Sept. 1955.
Maximum daily discharge: 50,800 cfs, Feb. 27, 1929.
Minimum daily discharge: 148 cfs, Sept. 7, 1925.
Mean discharge: 18 years, 1917–20, 1925–35, 1953–55: 2,217 cfs, 0.816 cfs per sq. mi., 11.08 in.
Adjusted mean discharge: 1921–45: 2,427 cfs, .893 cfs per sq. mi., 12.12 in.
Maximum recorded discharge: 55,000 cfs, Feb. 27, 1929.
Minimum recorded discharge: 69 cfs, Sept. 9, 1934.
Remarks: Diurnal fluctuation caused by powerplant above station. Flood flow regulated by four retarding basins above station.

366. *GREAT MIAMI RIVER AT HAMILTON*

Location: Lat 39°23'28", long 84°34'20", 1,000 ft downstream from Columbia Bridge at Hamilton, Butler County, and 3 miles downstream from Talawanda Creek.
Drainage area: 3,639 sq. mi.
Period of record: Jan. 1907 to June 1909 (fragmentary), Jan. 1910 to Sept. 1918, Apr. 1927 to Sept. 1955.
Maximum daily discharge: 71,500 cfs, Jan. 22, 1937.
Minimum daily discharge: 155 cfs, Sept. 27, 1941.
Mean discharge: 36 years, 1910–18, 1927–55: 3,323 cfs, 0.913 cfs per sq. mi., 12.40 in.
Adjusted mean discharge: 1921–45: 3,323 cfs, 0.913 cfs per sq. mi., 12.40 in.
Maximum recorded discharge: 78,800 cfs, Mar. 19, 1943.
Minimum recorded discharge: 100 cfs, Sept. 26, 27, 1941.
Remarks: Low flow regulated by powerplant at Hamilton. Flood flow regulated by five retarding basins above station beginning in 1920. Records prior to 1931 affected by diversion by Miami and Erie Canal; amount of diversion uncertain.

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I-A-2
III



EXPLANATION

HYDROGEOLOGIC ENVIRONMENTS

I-A-1

Sand and gravel aquifer 150-200 feet or more thick; no areally extensive interstratified clay layers present; recharge by induced stream infiltration available. Transmissibility generally ranges from 300,000 to 500,000 gpd per foot. Storage coefficient about 0.2. Individual wells can yield as much as 3,000 gpm

I-A-2

Sand and gravel aquifer less than 150 feet thick; no areally extensive interstratified clay layers present; recharge by induced stream infiltration available. Transmissibility generally ranges from 100,000 to 300,000 gpd per foot. Storage coefficient about 0.2. Individual wells can yield as much as 2,000 gpm

I-B-1

Sand and gravel aquifer 150-200 feet or more thick; areally extensive interstratified clay layers may be present; recharge by induced stream infiltration available. Transmissibility of entire aquifer generally ranges from about 250,000 to 450,000 gpd per foot; transmissibility of individual component units is lower. Storage coefficient is about 0.2 in upper, unconfined unit and ranges from 0.02 to 0.0002 in lower, semiconfined or confined units. Properly located and developed individual wells in lower units can yield as much as 3,000 gpm. Yields in upper unit generally do not exceed 500 gpm owing to lack of available drawdown

I-B-2

Sand and gravel aquifer less than 150 feet thick; areally extensive interstratified clay layers may be present; recharge by induced stream infiltration available. Transmissibility generally ranges from 100,000 to 200,000 gpd per foot. Storage coefficient ranges from 0.2 to 0.0002, depending on degree of confinement. Individual wells can yield as much as 2,000 gpm

II-A-1

Sand and gravel aquifer 150-200 feet or more thick; no areally extensive interstratified clay layers present; recharge by induced stream infiltration not available. Transmissibility generally ranges from 300,000 to 500,000 gpd per foot. Storage coefficient about 0.2. Individual wells can yield 500 gpm, with some favorably located wells yielding as much as 1,000 gpm

II-A-2

Sand and gravel aquifer less than 150 feet thick; no areally extensive interstratified clay layers present; recharge by induced stream infiltration not available. Large ground-water supplies generally cannot be developed in this environment owing to its insufficient areal extent or proximity to bedrock valley walls

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II-B-1

Sand and gravel aquifer 150-200 feet or more thick, areally extensive interstratified clay layers may be present; recharge by induced stream infiltration not available. Transmissibility generally ranges from 250,000 to 450,000 gpd per foot. Storage coefficient ranges from 0.2 to 0.0002, depending on degree of confinement. Individual



cannot be developed in this environment owing to its insufficient areal extent or proximity to bedrock valley walls

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Sand and gravel aquifer 150-200 feet or more thick, areally extensive interstratified clay layers may be present; recharge by induced stream infiltration not available. Transmissibility generally ranges from 250,000 to 450,000 gpd per foot. Storage coefficient ranges from 0.2 to 0.0002, depending on degree of confinement. Individual wells can yield 100-500 gpm

Sand and gravel aquifer less than 150 feet thick; areally extensive interstratified clay layers may be present; recharge by induced stream infiltration not available. Large ground-water supplies generally cannot be developed in this environment owing to its insufficient areal extent and proximity to the bedrock valley wall

Sand and gravel aquifer overlain by clay; stream recharge generally not available. Transmissibility ranges from 35,000 to 300,000 gpd per foot. Storage coefficient ranges from about 0.1 to 0.002. Individual wells can generally be expected to yield 100-500 gpm; yields as high as 1,000 gpm are not uncommon. The transmission and storage properties of this environment are highly variable

Valley filled largely or entirely with clay; large ground-water supplies generally not available

V

Shale bedrock overlain by 50 feet or less of relatively impermeable glacial till; large ground-water supplies generally not available

550

Piezometric contour

Shows altitude of piezometic surface in October 1964. Contour interval, 10 feet with supplemental 5-foot contours. Datum is mean sea level. Dashed where inferred

WELLS

39 — Number of well
544 — Measured altitude of water surface, in feet above mean sea level

60 — Number of well
(491) — Projected altitude of water surface, in feet above mean sea level

31

Well sampled for chemical analysis

1

Stream-sampling station and number (See table 9)

Stream-gaging station

Boundary of buried valley

Arbitrary limit of area of investigation

Ground-water divide

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