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

Prepared in cooperation with the
Miami Conservancy District and the
Ohio Department of Natural Resources,
Division of Water, Columbus, Ohio

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

GROUND WATER IN THE LOWER GREAT MIAMI RIVER VALLEY, OHIO

GROUND-WATER HYDROLOGY AND GEOLOGY OF THE LOWER GREAT MIAMI RIVER VALLEY, OHIO

By Andrew M. Spieker

ABSTRACT

The valley of the lower Great Miami River, extending from Dayton to the Ohio River about 15 miles west of Cincinnati, is one of the most productive sources of ground water in the Midwestern United States. A major buried valley averaging 2 miles in width and 150–200 feet in depth, formed during interglacial intervals of the Pleistocene Epoch and subsequently filled with highly permeable sand and gravel outwash, follows essentially the course of the present Great Miami River.

The valley can be divided into 11 hydrogeologic environments on the basis of the nature and thickness of the aquifer materials, the availability of recharge by induced stream infiltration, and the presence or absence of semiconfining clay layers. The most favorable areas for the development of large ground-water supplies are in those environments where 150 feet or more of sand and gravel with no clay layers are close enough to a major stream to permit recharge by induced infiltration. These most favorable areas are near Trenton, the reach of the Great Miami River between Hamilton and Ross, and the lower Whitewater River valley south of Harrison, where individual wells can yield as much as 3,000 gpm. Only slightly less favorable are the areas similarly situated near streams but where the aquifer is less than 150 feet thick or where the aquifer contains areally extensive layers of clay. Most of the valley north of Middletown is in the last category.

Pumping from an aquifer hydraulically connected with a stream will generally reduce the streamflow between the point of withdrawal and the point of sewage return. Little net depletion of streamflow is evident in the report area, however, for the sewage returns are generally close to the points of withdrawal. The returned used water is thus available again for induced recharge to the aquifers. Such recycling of water would theoretically make possible pumping of ground water in the area at a virtually unlimited rate. The limit of such pumping from wells whose water supplies are recharged with used water would be imposed by deterioration of the water quality or by the cost of adequate treatment of the used water.

In the parts of the valley where the aquifer is either too far from a major stream for induced infiltration or overlain by a semiconfining clay layer, individual wells can be expected to yield 500 gallons per minute, although yields as high as 1,000 gallons per minute are not uncommon. Such environments are present in abandoned segments of the ancestral Great Miami River valley between West Carrollton and Carlisle, between Trenton and New Miami, and between Ross and Harrison. Smaller areas with this environment are present southeast of Hamilton and southeast of Middletown. The least favorable hydrogeologic environments are in tributary buried valleys filled largely or entirely with clay and in the upland areas where shale bedrock is overlain by relatively impermeable glacial till. Large ground-water supplies generally cannot be developed in these last two environments.

The discharge of Great Miami River at Hamilton equals or exceeds 490 cubic feet per second 90 percent of the time. The base flow of this stream is among the highest in Ohio, and ample water is available for recharge to the aquifer by induced steam infiltration. The recharge rate by induced infiltration in warm weather under conditions of low streamflow has been determined to be about 400,000 gallons per day per acre of streambed, with considerably higher rates under conditions of higher streamflow.

Pumpage of ground water, which is mostly concentrated around the area's larger cities, totaled 110 million gallons per day in 1964. The ground-water resources of much of the area remain untapped. The gradient of the water surface trends generally toward the southwest at 5–10 feet per mile, about the same as the gradient of the Great Miami River. Small cones of depression have formed around the pumping centers at Miamisburg, Chautauqua, Franklin, Middletown, New Miami, Hamilton, Fairfield, Ross, and Cleves. The only major cone of depression, about 70 feet deep, is around the Armco East Works in southeast Middletown.

The ground-water surface in most of the valley stands about 30–50 feet beneath the land surface; it fluctuates about 5–15 feet annually, generally rising during the winter and spring and falling during the summer and autumn. The fluctuation is greatest in the areas where ground water is being pumped or where the aquifer is semiconfined. The only area of chronic overdraft of the aquifer, indicated by a persistent decline of the water level, is the vicinity of the Armco East Works, where the water level was 132 feet below land surface at the end of 1964.

Water in the lower Great Miami River valley is generally hard, containing high concentrations of calcium and bicarbonates. The total dissolved solids content of both ground water and surface water is typically 400–450 milligrams per liter. The Great Miami River is generally contaminated by organic and industrial wastes in most of the area of investigation. Concentrations of the contaminants are highest during prolonged periods of low streamflow. Water from some wells where the aquifer is being recharged by induced infiltration from the Great Miami River has become slightly contaminated, as indicated by the presence of minute quantities of phenols and higher than normal concentrations of nitrate. Such contamination of ground water has not yet become a serious problem.

INTRODUCTION

Investigation of the occurrence of ground water in the lower Great Miami River valley was made during 1961–65; the present series of reports on the area's ground-water resources is a result of that investigation. Water is the key to the industrial prominence of the Great Miami River valley, which was originally settled more than 150 years ago owing to its ease of access by way of the Great Miami River, and later by way of the Miami and Erie Canal. The earliest industries—the paper mills—settled along the river. More recently the availability of ground water has been an important factor in the area's industrial growth.

All the cities in the Great Miami River valley depend entirely on ground water for their public supplies, and many of the larger industries have their own wells. Ground water is so much more abundant in this area than it is in the Cincinnati metropolitan area immediately adjacent that on three separate occasions industrial and municipal interests in Cincinnati have sought relief from water shortages by using ground water in the Great Miami River valley to supplement their own supplies.

Purpose of the investigation was to make available the facts needed to solve or control four significant water problems that exist in the report area; they are as follows:

1. *Variable availability of water in place and time.*—Identification of the distribution in place of the major aquifers and their relation to sources of recharge. Consideration of changes in ground-water storage with respect to time.
2. *Local overdraft and declining ground-water levels resulting from increased water use.*—Identification of areas of present and potential overdraft based on analysis of water-level trends. Predicted effect of future ground-water development on water levels.
3. *Ground-water contamination.*—Identification of present contamination, possible sources of contamination, and future dangers of contamination.
4. *Water-rights law.*—Summary of Ohio's water law and its relation to ground-water development and management problems.

PURPOSE AND SCOPE OF REPORT

The purpose of this chapter is to define quantitatively, so far as possible, the ground-water resource in the lower Great Miami River Valley, including its magnitude, distribution, movement, and withdrawal, and changes in its storage, and chemical quality. The report is intended to provide the facts necessary for those responsible for managing this resource so that they can adequately handle the four previously stated problems and achieve the most efficient and beneficial use of the resource. Emphasis is placed on the relation between the ground-water resource and the physical environment in which it occurs. This interrelation is termed the "hydrogeologic environment" in this report. The availability of induced stream recharge, the areal distribution of sources of recharge to the principal aquifers, and the maintenance of adequate water quality in the streams that are sources of recharge are considered to be the key factors in this interrelation.

PREVIOUS INVESTIGATIONS

The lower Great Miami River valley has been the subject of several water-resources and geologic investigations. Fuller and Clapp (1912) conducted the first reconnaissance of the area's ground-water resources. Klaer and Thompson (1948) described the occurrence of ground water in Butler and Hamilton Counties, which include most of the present study area. Norris, Cross, and Goldthwait (1948) described the geology and water resources of Montgomery County, which includes the northernmost part of the present area. Walker (1960a, b, c) prepared generalized water-availability maps of the area. These maps are part of the Ohio Division of Water series of such maps of the entire State, which show the occurrence of ground water by drainage basins. Spieker (1961) summarized the occurrence of ground water in the lower Great Miami River valley and the adjacent areas of Dayton and the Mill Creek valley. Klaer and Kazmann (1943) and Dove (1961) presented detailed quantitative appraisals of ground water in the Fairfield and Venice (Ross in the present report) areas, respectively. Bernhagen and Schaefer (1947) provided up-to-date information for Butler and Hamilton Counties. Fenneman (1916) described the geology of the southern part of the area. Caster, Dalve, and Pope (1955) summarized the paleontology and stratigraphy. Goldthwait, White, and Forsyth (1961) mapped the Pleistocene deposits of the area.

ACKNOWLEDGMENTS

The investigation on which this report is based was conducted by the U.S. Geological Survey in cooperation with the Miami Conservancy District, Max L. Mitchell, chief engineer, and the Ohio Department of Natural Resources, Division of Water, C. V. Youngquist, chief. The author conducted the investigation under the general supervision of the Ohio Water Resources Division Council and under the direct supervision of Stanley E. Norris, district geologist, Ground Water Branch.

An electric analog model of the Fairfield–New Baltimore area was built and analyzed by the Geological Sur-

vey's Analog Model Unit at Phoenix, Ariz., under the direction of Eugene P. Patten. Seismic refraction surveys to determine depths to bedrock were conducted during 1962–63 under the direction of Joel S. Watkins of the Branch of Regional Geophysics. Chemical analyses of water samples were performed at the Columbus laboratory of the Quality of Water Branch, under the direction of George W. Whetstone, district chemist. Material pertaining to water-rights law was researched by George D. Dove. Norman G. Bailey, formerly of the Ohio Division of Water, augered several test holes in the Fairfield–New Baltimore area. Richard E. Fidler, Edward O'Donnell, Ralph Wharton, and Ronald J. Wolf assisted the author in the collection and compilation of basic data.

The author thanks the many representatives of industry and municipalities, too numerous to mention, for their wholehearted cooperation in making basic records available. Particular thanks are extended to Mr. Harold W. Augenstein, superintendent of the Hamilton Water Works; Mr. Charles M. Bolton, superintendent of the Cincinnati Water Works; Mr. R. L. Bookwalter of Armco Steel; Mr. Arthur Hansen of the Dayton Power & Light Co.; and Mr. Robert C. Lewis, general manager of the Southwestern Ohio Water Co. for their splendid cooperation.

WELL-NUMBERING SYSTEM

All wells included in the present report except observation wells maintained by the Ohio Division of Water are numbered sequentially, from the northeastern part of the study area to the southwestern part, beginning with 1 and ending with 104. The Ohio Division of Water observation wells are identified by their assigned numbers, which consist of a prefix denoting the county followed by a number. All such observation wells used in the present report are described in Bulletin 41 of the Ohio Division of Water (Kaser and Harstine, 1965). Prefixes for well designations are "Bu" for Butler County, "H" for Hamilton County, and "Mt" for Montgomery County. The location of all wells is shown on plates 1 and 2. Table 10 (p. A34) is a summary of records of the wells pertinent to this report.

The present report is not intended to be a comprehensive inventory of wells in the lower Great Miami River valley. Only those wells specifically discussed in the report are included in table 10. Records of several hundred wells collected during the investigation are on file with the Columbus, Ohio, district of the U.S. Geological Survey. Thousands of additional well records are on file with the Ohio Division of Water in Columbus, for drillers in Ohio have been required by law to file logs of all wells drilled since 1948.

GEOGRAPHY

LOCATION, TOPOGRAPHY, AND DRAINAGE

The report area consists of the lower part of the Great Miami River valley; it extends from West Carrollton to the Ohio River near the southwest corner of Ohio (fig. 1). This area is in the Till Plains section of the Central Lowland physiographic province (Fenneman, 1938, p. 499–518). The south edge of the area is at the north margin of the Bluegrass section of the Interior Low Plateau (Fenneman, 1938, p. 427–431), and its topography resembles the unglaciated Bluegrass region more than it does the glaciated Till Plains. Characteristic topography in the study area consists of flat to rolling uplands at altitudes ranging generally from 850 to 1,000 feet. South of the boundary of the Wisconsin Glaciation, which extended to just south of Fairfield, the terrain is considerably more rugged and is deeply dissected. The largest stream in the study area is the Great Miami River, which flows in a flat valley about 2 miles wide at an altitude of 200–350 feet below the till plain of the upland. Major tributaries to the river in the area are Twin Creek, Fourmile Creek, Dicks Creek, Elk Creek, Sevenmile Creek, Indian Creek, and the Whitewater River.

CLIMATE

The occurrence and the distribution of precipitation govern the regimens of both surface water and ground water. Hence, an understanding the area's climate is fundamental.

Southwestern Ohio has a climate which is generally classified as humid temperate. Table 1 gives a summary of normal monthly precipitation in the area, and table 2 summarizes monthly normal temperatures. The Cincinnati and Dayton stations are not in the area of investigation but are included because they are the only nearby first-order weather stations. The Cincinnati and Dayton stations are in the uplands, whereas the Hamilton and Middletown stations are in the Great Miami River valley.

Annual precipitation averages 36–40 inches and is evenly distributed throughout the year. Much of the summer precipitation, however, is in the form of scattered thundershowers. Areal variation in precipitation may therefore be large. Distribution of these local storms tends to average out over a long period of record, as shown by the consistent records for the four stations given in table 1. Precipitation in the spring and summer (March–August) slightly exceeds precipitation in the autumn and winter (September–February). Average monthly precipitation for the four listed stations is 3.64

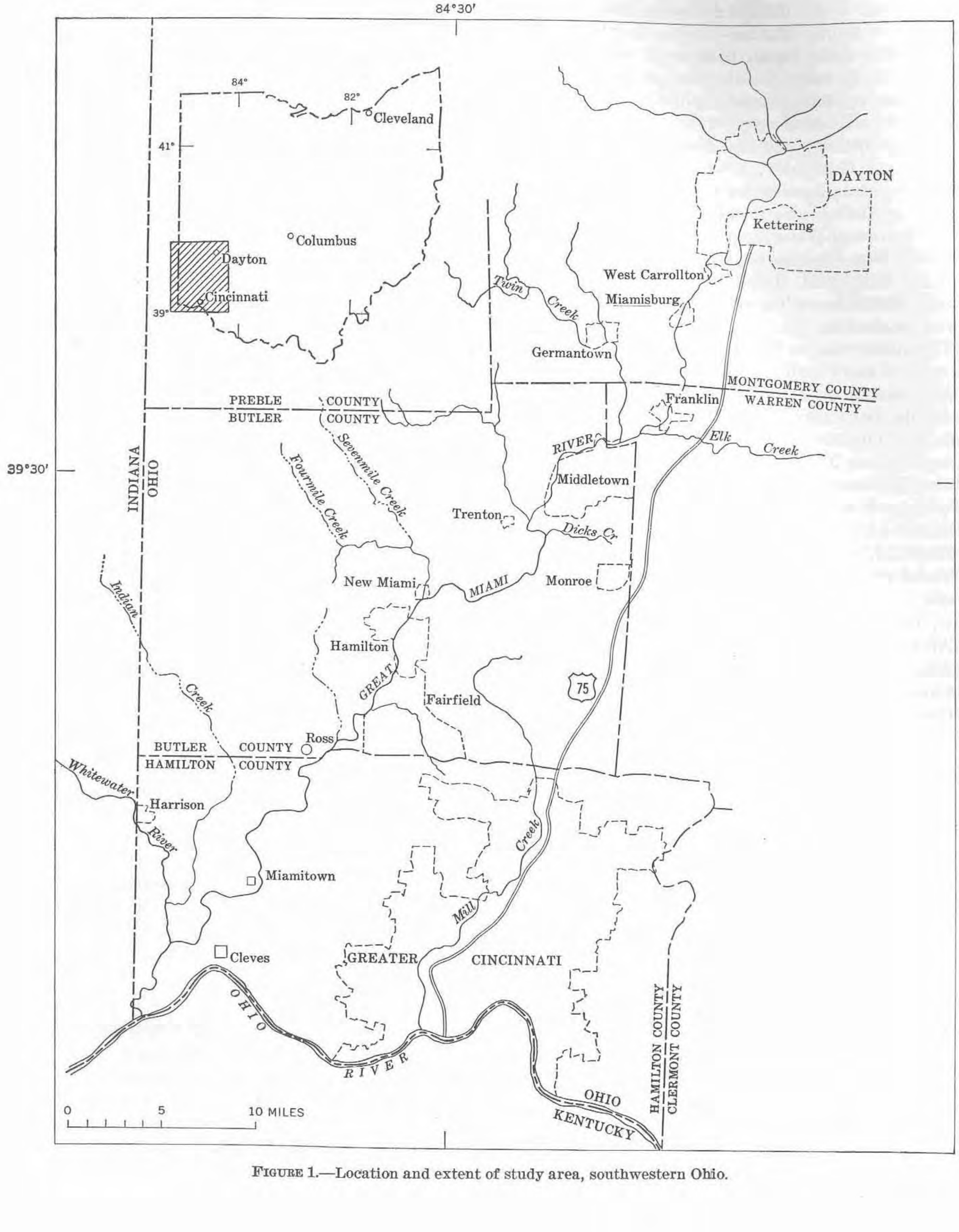


FIGURE 1.—Location and extent of study area, southwestern Ohio.

inches for March–August, and 2.80 inches for September through February. Of the total annual precipitation, 57 percent occurs during spring and summer.

TABLE 1.—*Normal monthly precipitation, based on 1931–60 period of record, for four weather stations in southwestern Ohio*

[Precipitation given in inches]

	Cincinnati Abbe Observatory	Hamilton Water Works	Middletown Water Works	Dayton airport
January	3.67	3.63	3.73	3.18
February	2.80	2.64	2.80	2.32
March	3.89	3.65	3.68	3.12
April	3.63	3.61	3.63	3.32
May	3.80	3.72	4.16	3.73
June	4.18	4.06	4.27	4.10
July	3.59	3.82	3.95	3.53
August	3.28	2.68	2.96	2.88
September	2.71	3.37	3.12	2.59
October	2.24	2.22	2.28	2.23
November	2.95	2.76	2.90	2.67
December	2.77	2.65	2.76	2.37
Annual	39.51	38.81	40.24	36.04

TABLE 2.—*Normal monthly maximum, average, and minimum temperatures, based on 1931–60 period of record, for three weather stations in southwestern Ohio*

[Data in °F]

	Cincinnati Abbe Observatory			Dayton airport			Hamilton Water Works (Avg)
	Max	Avg	Min	Max	Avg	Min	
January	41.3	33.7	26.1	36.9	29.6	22.2	33.1
February	43.4	35.1	26.7	38.8	30.9	22.9	34.7
March	52.0	42.7	33.3	47.8	38.9	29.9	42.1
April	64.4	54.2	43.9	60.5	50.7	40.8	53.4
May	74.9	64.2	53.5	71.7	61.6	51.4	63.5
June	83.8	73.4	63.0	81.4	71.5	61.5	72.8
July	87.5	76.9	66.3	85.3	75.2	65.1	76.3
August	86.4	75.7	64.9	83.7	73.7	63.7	74.6
September	80.3	69.0	57.6	77.3	66.8	56.2	68.0
October	68.9	57.9	46.8	66.0	55.6	45.2	56.5
November	53.2	44.6	36.0	50.1	41.8	33.5	43.8
December	42.6	35.3	27.9	39.0	31.8	23.5	34.3
Annual	64.9	55.2	45.5	61.5	52.3	43.0	54.4

Average annual temperature for the three listed stations is 54° F. The average maximum is 87.5° F and the average minimum is 22.2° F. Extreme recorded temperatures for the 1931–60 period of record are 109 F° and −17° F, both at Cincinnati. Temperatures above 100° F or below −10° F are rare. The average length of the growing season, or frost-free period, is 170 days (Pierce, 1959, fig. 34).

Although precipitation is fairly evenly distributed throughout the year, recharge to the aquifers is not. During the growing season, which is mainly the 6-month period from mid-April to mid-October, most precipitation is lost through evapotranspiration and does not reach the water table. During the winter, freezing of the ground prevents precipitation from reaching the water table. Thus, the most probable times for ground-water recharge are in the late fall and the early spring—that is October and November, and March and April. Precipitation in March and April slightly exceeds that in October and November; therefore, March and April appear to be the optimum months for recharge. This deduction, though generally valid, does not hold true after year after because climatic conditions may vary greatly from year to year. With rare exceptions, however, most of the ground-water recharge occurs during the 7-month interval October–April.

POPULATION

The predominantly urban population of the lower Great Miami River valley has steadily increased during the past half century. The study area includes parts of four counties—Butler, Hamilton, Montgomery, and Warren. Table 3 gives the population of these four counties at 10-year intervals from 1900 to 1960, the latest year for which Federal census data are available. Only about 15 percent of this population lives within the study area but almost everyone in these four counties is dependent to some extent on ground water from the lower Great Miami River valley. The ground-water resource of the report area sustains a substantial part of the industrial base of these four counties and is a potential source of public water supplies for cities outside the report area. Thus, for purposes of the present report, the total population of the four counties is more meaningful than that of the actual report area. About two-thirds of the inhabitants of these four counties live in the Cincinnati and Dayton metropolitan areas, and neither city is within the study area.

TABLE 3.—*Population of counties that include parts of the lower Great Miami River valley, Ohio, 1900–60*

Year	Counties				Total population
	Butler	Hamilton	Montgomery	Warren	
1900	56,870	409,479	130,146	25,584	622,079
1910	70,271	460,732	163,763	24,497	719,263
1920	87,025	493,678	209,532	25,716	815,951
1930	114,084	589,356	273,481	27,348	1,004,269
1940	120,249	621,987	295,480	29,894	1,067,610
1950	147,203	723,952	398,441	38,505	1,308,101
1960	199,076	864,121	527,080	65,711	1,655,988

The population of the study area alone is difficult to determine, for the area boundaries do not coincide with political boundaries and hence, with census data. The area's approximate population in 1960—based on the cities and townships which the area comprises, was 255,000. The largest cities in the area, according to 1960 population records, are Hamilton (72,354), Middletown (42,115), Miamisburg (9,893), and Fairfield (9,734).

The population of the lower Great Miami River valley seems destined to continue its growth in future years. Between 1900 and 1950 the population of the four-county area doubled. Over a comparable period, from 1910 to 1960, the population of the study area increased at an even greater rate—from 84,036 to 254,529 (or more than triple the 1910 population). Conservative estimates indicate that the population of the United States will double in the next 50 years. As the area of investigation is in a region of rapidly expanding industrial development, its population can be expected to grow at an even greater rate.

COMMERCE, INDUSTRY, AND TRANSPORTATION

Almost since pioneer days in the history of Ohio, the Great Miami River valley has been an important industrial center. Paper mills sprang up early along the river at Miamisburg, Franklin, Middletown, and Hamilton, owing largely to the river being a source of power and an avenue of transportation. The Miami and Erie Canal, linking the Great Lakes with the Ohio River, was completed in 1845. It provided the area with the most modern transportation available at the time.

Water has been largely responsible for the area's steady industrial growth and is destined to play an increasingly important role in the future. Although the earliest factories were built along the river and utilized surface-water supplies, industries have depended largely on ground water during the past 50 years, owing to its abundance and superior quality, and to the advent of modern techniques in well construction. Much surface water is still used for cooling, but ground water plays the dominant role in the area's industrial economy. The large ground-water supplies still virtually untapped in parts of the area give the Great Miami River valley great potential for future industrial development.

At present the lower Great Miami valley is served by the Baltimore & Ohio, Chesapeake & Ohio, and Penn-Central Railroads.[1] Airports at Cincinnati and Dayton provide the nearest access to major air carriers; smaller airfields at Hamilton and Middletown are served by charter flights. Interstate Route 75 skirts the Great Miami River valley and provides ready access along its route from Cincinnati to Dayton. Interstate Route 74 passes through the valley near Miamitown, en route from Cincinnati to Indianapolis.

HYDROLOGIC SYSTEM

HYDROLOGIC CYCLE

Water is our only renewable mineral resource. Coal, oil, and the metallic ores are nonrenewable resources—once they have been mined, they can never be replenished, for it has taken hundreds of millions of years for these valuable resources to form. Water, on the other hand, is continually replenished in the form of precipitation. Actually, water exists in a perenially repeating cycle. Of the water that falls on the ground as various types of precipitation, some runs off to streams and, thence, to the oceans; some also soaks into the ground. Of the water that soaks into the ground, some percolates downward to the water table and is stored in underground reservoirs, and some is returned to the atmosphere through evaporation and through transpiration from plants. Surface-water bodies also lose water through evaporation into the atmosphere. Generally, the amount of water which evaporates into the atmosphere approximately equals that which returns as precipitation. This endlessly repeating cycle is known as the hydrologic cycle, and an understanding of it is basic to any hydrologic investigation. Readers interested in a more detailed description of the hydrologic cycle in general terms are referred to Leopold and Langbein (1960, p. 3–11).

The aquifer—or the medium consisting of rocks and unconsolidated matter, that stores and transmits ground water—is equally as important as the hydrologic cycle in an areal appraisal of the ground-water resource. Not all materials have equal capacity to store and transmit water, however. Thus, an understanding of the areal distribution and transmission characteristics (in short, the geology) of the area's rock materials is also fundamental. Interaction of the aquifer with the hydrologic cycle is here referred to as the "hydrologic system," a mutually dependent system consisting of all the components described above. No single component of the hydrologic system can be disturbed or altered without ultimately affecting the entire system.

CHARACTER AND ORIGIN OF THE AQUIFERS

The large ground-water supplies of the lower Great Miami River valley occur in highly permeable sand and gravel that were deposited by glacial melt waters from receding continental ice sheets. These materials were deposited in channels which had been cut deeply into bedrock by interglacial streams. Plates 1 and 2 show the general location of the principal water-bearing sand and gravel formations, referred to in this report as aquifers. These aquifers are variously called valley-train deposits, valley fill, glacial outwash, water course aquifers, or buried-valley aquifers. The geologic history of the area is complex, but its highlights can be summarized briefly. The bedrock which underlies the entire area consists predominantly of flat-lying shale with thin interbedded layers of limestone. This rock unit, known as the Cincinnatian Series, was deposited about 450 million years ago during the late Ordovician Period in a shallow sea,

---

[1] The Pennsylvania and New York Central Railroads merged on February 1, 1968. The merged company is known as the Penn-Central Railroad.

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).

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 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).

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

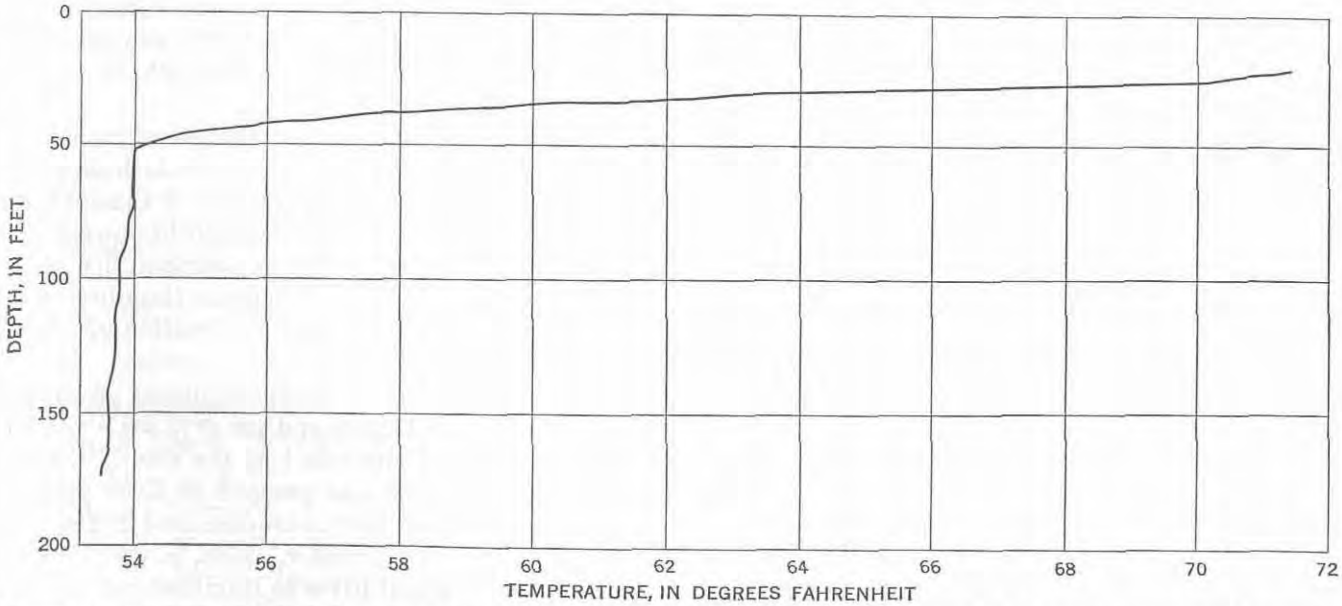


FIGURE 2.—Temperature-depth log of well 62 after well 63 had been pumped at 3,000 gpm for 2 days. Warm water above the 50-foot depth indicates that river water has entered the aquifer.

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.

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.)

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 bv 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 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	3,090	2,530	1,800	1,320	990	755	668	589	520	450	378
	3.22	1.90	1.37	1.06	0.849	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	2,3 0	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	659	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 dialy 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.

River at Miamisburg (pl. 2) based on the adjusted period 1921–45[3] is 380 cfs, or 0.140 cfs per sq. mi. The adjusted mean discharge at Miamisburg is 2,217 cfs. For Great Miami River at Hamilton (pl. 2), the 90-percent discharge for the adjusted period 1921–45 is 490 cfs, or 0.135 cfs per sq. mi., whereas the adjusted mean discharge is 3,323 cfs. Because the Hamilton station is the nearest regular gaging station to the mouth of the river, it is probably the best available index to streamflow in the Great Miami River basin as a whole.

The high base flow in the lower Great Miami River is largely due to the vast expanse of highly permeable outwash plain deposits in the upper part of the basin, particularly in the Mad River basin. These deposits, though probably not more permeable than the valley-fill aquifers in the lower Great Miami River valley, are more areally extensive in that they are spread out over a broad outwash plain rather than confined to a buried channel. Mad River near Springfield has 90-percent discharge of 152 cfs, somewhat lower than the 90-percent discharges at Miamisburg and Hamilton. The drainage area of this station, however, is only 485 square miles. The 90-percent discharge of 0.313 cfs per sq mi (Cross and Hedges, 1959, p. 143) is the highest for any major stream in Ohio.

The high sustained flow of the Great Miami River, though a direct result of the abundance of ground water, is also of direct benefit in sustaining large ground-water supplies. This high flow makes possible the widespread availability of recharge by induced infiltration, and without it, most of the area's large ground-water supplies would not be sustained.

PUMPAGE OF GROUND WATER

The various hydrogeologic environments of the lower Great Miami River valley can be regarded as components in the physical framework of the hydrological system. Under natural conditions the hydrologic cycle operates within this framework in a state of near equilibrium—that is, the total inflow generally equals the total outflow. During approximately the past 100 years, however, man has upset this state of equilibrium by his removal (pumping) of water from the system. Thus, man has brought about significant changes in the hydrologic system. One of the major purposes of the present report is to evaluate the effects of these changes caused by pumping with respect to both place and time. Before this evaluation can be made, however, the magnitude and distribution of ground-water pumpage must be defined.

DISTRIBUTION AND MAGNITUDE OF GROUND-WATER PUMPAGE IN 1964

During the present study an inventory was made of the major users of ground water in the lower Great Miami River valley. This inventory was to update an earlier inventory made in 1954 by the Miami Conservancy District. The results of the later inventory are given in table 7.

Distribution of pumpage is also shown on plates 1 and 2 by circles of appropriate magnitude.

Although the pumpage of all municipal supplies is metered, many industries do not keep records of their ground-water pumpage. Thus, the pumpage at many plants could only be estimated. The figures shown in table 7 are averages; the actual pumping rates vary considerably from day to day. Pumpage from domestic and farm wells is not included in the present survey. Also, some small industrial supplies may have been overlooked; however, these omitted supplies are probably of insignificant magnitude when compared with the total municipal and industrial pumpage in the area.

TABLE 7.—*Summary of estimated pumpage of ground water in the lower Great Miami River valley, Ohio, in 1964*

Area and use		*Average daily pumpage (mgd)*
West Carrollton area		7
Municipal	1	
Industrial	6	
Miamisburg area		8
Municipal	7	
Industrial	1	
Chautauqua (Dayton Power & Light Co.)		5
Franklin area		5
Municipal	1	
Industrial	4	
Central Middletown area		22
Municipal	8	
Industrial	14	
Southeast Middletown (Armco East Works)		10
Trenton (Municipal)		.3
New Miami (Armco)		12
Hamilton North well field		*1
Hamilton area		8
Champion Paper & Fibre Co.	5	
Miscellaneous industrial	3	
Fairfield		8.5
Hamilton South well field	8	
Fairfield Water Works	.5	
Ross area (Southwestern Ohio Water Co.)		15
Fernald (U.S. Atomic Energy Comm.)		1
Whitewater Valley (Cincinnati Shaper Co.)		.2
Cleves (Gulf Oil Co. refinery)		7
Total Municipal		26.8
Total Industrial		83.2
Grand total		110

*Hamilton North well field is used intermittently as a standby plant.

Total municipal and industrial pumpage in the lower Great Miami River valley in 1964, according to the present inventory, was 110 mgd. The three greatest concentrations of pumpage are the central Middletown area, with 22 mgd; the area including New Miami and the northern part of Hamilton, with 18 mgd; and the Southwestern Ohio Water Co. well field near Ross, with

---

[3] Since the periods of record of all gaging stations are not the same, the duration data from gaging stations must be adjusted to a "standard" period of record. This adjustment is accomplished by comparison of the duration data of one station with similar data for another station for the standard period of record. Cross and Hedges (1959, p. 16–19) described this adjustment procedure with several examples. The standard adjusted period for Ohio streams is 1921–45.

15 mgd. Other major users of ground water are the Armco East Works in southeast Middletown, with 10 mgd; the Hamilton South well field, with 8 mgd; and the Gulf Oil Co. refinery near Cleves, with 7 mgd. In general, the greatest centers of pumping are concentrated at and around the area's principal cities. (See plates 1 and 2.) The ground-water resources in much of rural part of the area have not yet been tapped.

HISTORICAL PUMPING TRENDS

Ground-water pumpage rates in the lower Great Miami River valley have increased steadily from the beginning of the area's settlement to the present and can be expected to increase in the future. No documentation exists of the exact rate at which pumpage has increased. In general, though, the rate of ground-water pumpage in 1964 is estimated to be approximately double the rate immediately prior to World War II. Pumpage in the report area increased from 90 mgd in 1954, the year the Miami Conservancy District made its inventory, to 110 mgd in 1964, when the present study was made. The Hamilton municipal water supply, for example, had an average pumping rate of about 4 mgd in 1940 compared with 8 mgd in 1964. Pumpage at the Middletown Water Works also increased, from 3 mgd in 1940 to 8 mgd in 1964. Some of the largest ground-water supplies in the area are of recent origin. The Southwestern Ohio Water Co. well field near Ross and the Atomic Energy Commission's installation near Fernald, for example, were both put into operation in 1952. The steady increase in ground-water pumpage can be attributed to several factors, such as increasing population, increasing industrial output, and the ever-increasing per-capita water demand.

FUTURE USE OF THE GROUND-WATER RESOURCE

The factors which have caused ground-water pumpage to increase in the past are certain to exist in the future. The Great Miami River valley appears to be destined for increased industrialization which will bring more people and manufacturing plants into the area, further increasing the water demand. Conservative estimates are that the rate of water use in this area will be double the 1964 rate by the year 2000.

The capacity of the hydrologic system to sustain such an increased draft is discussed in chapters C and D of the current series (Spieker, 1968 a, b). An analog-model study of the Fairfield–New Baltimore area (Spieker, 1968a) indicates that the hydrologic system in this reach of the Great Miami River valley can sustain a total initial withdrawal of 84 mgd, or nearly four times the present rate. This determination is the basis for the estimate presented in Professional Paper 605–D (Spieker, 1968b) that the ground-water system in the lower Great Miami River valley can sustain a total initial withdrawal of 300 mgd, or about three times the present rate.

The initial withdrawal should not, however, be regarded as a limit on the development of the ground-water resource. Because most of the water withdrawn from the aquifers is returned to the river as sewage, the net depletion of streamflow is slight. Therefore, pumping of ground water does not substantially reduce the amount of stream water available for induced recharge; in effect, water could be recycled many times from the aquifer to the point of use, to the river (as sewage), and thence back to the aquifer (as induced recharge). Such recycling would be limited by either the deterioration in quality of the used water or the cost of treatment necessary to maintain adequate water quality in the streams and aquifers.

AREAL CONFIGURATION OF THE GROUND-WATER SURFACE

The effects of pumping should be studied with respect to both place and time. A map of the ground-water surface, generally known as the piezometric surface, shows the areal effects of pumping. The configuration of this surface is the resultant of the two variables—the hydrogeologic environment and the effects of pumping—which have been discussed in the preceding sections dealing with the different parts of the study area. The hydrograph of an observation well expresses the resultant of these variables with respect to time. The configuration of the water surface with respect to place is considered first.

Contours representing the water surface in mid-October 1964 are shown on plates 1 and 2. The contours on plates 1 and 2 are based on 57 water-level measurements made during the period October 12–15, 1964. In addition to these actual measurements, 23 projected water levels were used in the construction of the contours. These projections were derived by adjustment of earlier water-level measurements to October 1964, based on their comparison with the hydrographs of nearby observation wells in similar hydrogeologic environments. Discharge of Great Miami River at Hamilton during this 4-day period averaged 317 cfs, a value exceeded more than 95 percent of the time (based on the adjusted period 1921–45). These measurements are representative of ground-water conditions under conditions of extremely low streamflow. The contours represent surfaces of equal ground-water potential. Ground water moves perpendicular to these contours in the direction of decreasing potential. Therefore, the movement of ground water in the lower Great Miami River valley is generally toward the south and southwest. The hydraulic gradient in the aquifer is about 5–10 feet per mile, in the same general range as the hydraulic gradient of the Great Miami River. In three areas the present course of the river deviates from the course of the ancestral river. Thus, in these areas the sand-and-gravel-filled buried valleys are now river-abandoned troughs. These three troughs are between West Carrollton and Carlisle (pl. 1), between Trenton and New Miami (pl. 1), and between Fernald and Harrison (pl. 2). In each of these abandoned troughs is a ground-water divide (pls. 1, 2), from which ground water flows, in both directions, to the junctions of the abandoned troughs with the present river valley.

Cones of depression have developed around the centers of pumping at Miamisburg, Chautauqua, Franklin, Middletown, New Miami, Hamilton, Fairfield, Ross, Fernald, and Cleves. Only the cone in the Middletown area, largely the result of pumping at the Armco East Works, is of major proportions. Some of the cones, such as those at Franklin and the Atomic Energy Commission plant near Fernald, are of such slight depth that they could not be shown on the map. The great depth of the cone around the Armco East Works is the result of heavy pumping in an area where the aquifer has a relatively low transmissibility and no available recharge by induced stream infiltration.

The contours of the ground-water surface on plates 1 and 2 are generalized to the extent that where the sand and gravel aquifer is separated by clay layers into two or more units, the water level of only the lower unit is represented. The lower unit was selected for two reasons: more data are available for this unit, and by far most of the ground water in the area is pumped from the lower aquifer. Only in the pumping centers in hydrogeologic environments I–B are II–B would there be any appreciable difference between the water levels in the two units. The approximate difference in water levels in the two units is indicated by comparison of water-level measurements made at the Middletown Water Works well field on October 14, 1964. The water levels in wells 18 and 19, both of which are screened in the lower aquifer, were 611 and 605 feet above mean sea level, respectively. The water level in well Bu–1, screened in the upper aquifer, was 619 feet above mean sea level. Therefore at the Middletown well field there was an 8- to 14-foot head differential between the two aquifers at the time the above measurements were made.

To fully determine the effects of pumping on the water surface would require construction of a contour map representing conditions prior to the development of large ground-water supplies in the area. Unfortunately, not enough water-level measurements are available to construct such a map. The systematic collection of water-level data was not begun until long after large-scale pumping of ground water in the area was begun. If a map were to show contours of the ground-water surface in a nonpumping state, it would probably closely resemble those shown on plates 1 and 2, except that the cones of depression around the pumping centers would be absent.

LONG-TERM WATER-LEVEL TRENDS

The water surface does not remain static for any period of time; it constantly changes in response to natural and artificial recharge to, and discharge from, the aquifer. Thus, much can be learned about the hydrologic regimen of an area from the long-term records of water-level fluctuations.

Generally the ground-water surface in the lower Great Miami River valley is about 15–50 feet beneath the valley floor. The only major exceptions are in parts of the river-abandoned troughs and in the vicinity of the Armco East Works, in southeast Middletown, where heavy pumping has created a major cone of depression.

In the following section, 10 hydrographs of observation wells in the lower Great Miami River valley (figs. 3–8) are discussed with respect to the part of the study area where the wells are situated. These wells are representative of a wide range of hydrogeologic environments and conditions of pumping and recharge. All wells are equipped with continuous water-level recorders and are maintained by the Ohio Division of Water as part of its cooperative program with the U.S. Geological Survey. Description of these wells and records of other observation wells are given in Bulletin 41 of the Ohio Department of Natural Resources, Division of Water (Kaser and Harstine, 1965).

AREA WEST OF WEST CARROLLTON

Observation well Mt–49 is at Whitfield, about 1 mile west of the Great Miami River at West Carrollton. This well, 220 feet deep, is in hydrogeologic environment I–B–1. Figure 3 shows the hydrograph of well Mt–49 for the period of record 1948–64. This well is far enough from the major pumping centers that water-level fluctuations are probably not much affected by pumping. Therefore it can be considered a good index well (responding only to natural recharge and discharge) of ground-water conditions in the area.

The hydrograph of Mt–49 (fig. 3) displays the characteristic annual cycle—rising in response to recharge during the winter and spring, and falling during the summer and autumn growing season in response to natural discharge. The water level generally fluctuates 5–7 feet annually. Note from figure 3 that comparatively

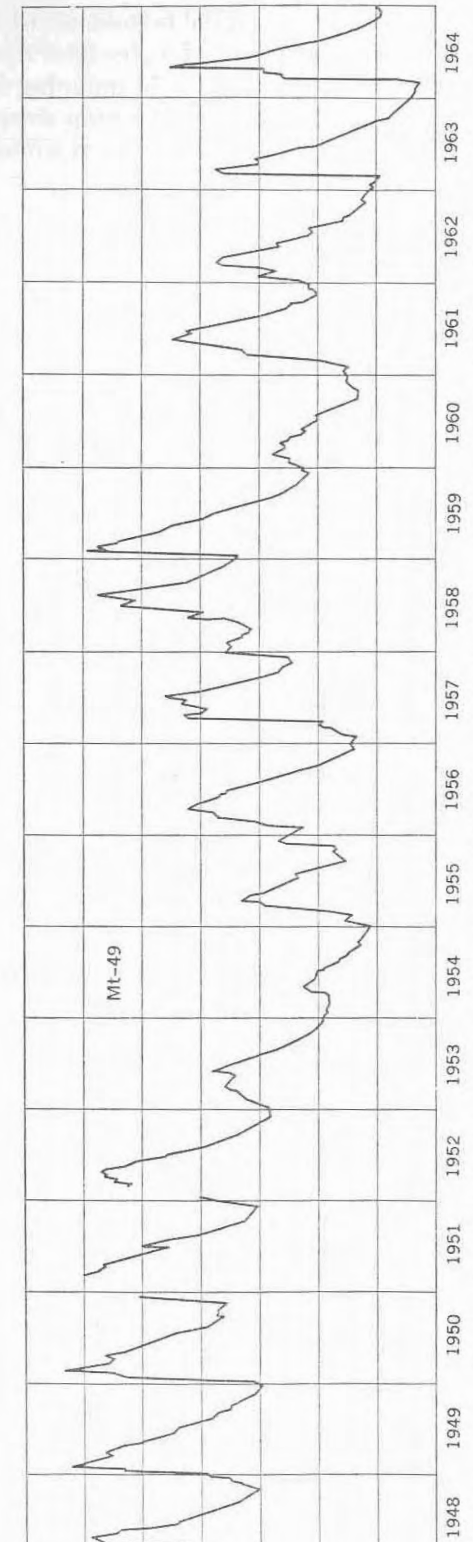


FIGURE 3.—Fluctuations of the water level in observation well Mt-49, west of West Carrollton, for the period 1948–64.

little recharge occurred during the drought period 1953–55. In 1954 there was almost no recharge. The water level in this well recovered substantially during the period of abundant rainfall 1956–59. Also, 1960 was virtually a repetition of 1956; since then, the water level has fluctuated in its normal manner, with the water level generally about 2–3 feet below typical pre-1953 levels. The hydrograph of well Mt–49 does not suggest any persistent downward trend in water levels in this vicinity; rather, it implies intermittent rises and falls in response to alternating periods of drought and abundant rainfall.

MIDDLETOWN AREA

Figure 4 shows hydrographs of three observation wells representing various conditions in the Middletown area. Observation well Bu–1, 62 feet deep, taps the upper aquifer of hydrogeologic environment I–B–1 at the Middletown Water Works. The hydrograph of this well shows an annual cyclic fluctuation ranging from about 8 to 12 feet. Very little recharge occurred in the drought years 1953 and 1954, as shown by the minimal rise of the water level. No persistent downward trend is evident, which indicates that the average recharge rate in this area is adequate to compensate for any pumping in the upper aquifer.

Well Bu–2 is screened in the lower aquifer of hydrogeologic environment I–B–1 in the downtown Middletown area. Its hydrograph exhibits the annual cyclic fluctuation characteristic of the water level in this area. The amplitude of this fluctuation, however, ranging from about 6 to 15 feet, is somewhat greater than that shown by the hydrographs of Mt–49 and Bu–1. Pumping in the downtown Middletown vicinity apparently causes a relatively large decline of the water surface during dry periods. In general, however, the recharge during periods of greater precipitation and runoff is adequate to compensate for the decline. No persistent downward trend is evident, although three was apparently very little recharge during 1953 and 1954.

The hydrograph of well Bu–3 (fig. 4) shows a sequence of persistent downward trends alternating with periods of long-term recovery. This well, 250 feet deep, is in hydrogeologic environment III at the Armco East Works. Average daily pumpage at the East Works for each year is shown above the hydrograph. The water-level fluctuations reflect changes in pumpage and in natural conditions. Inspection of the graph (fig. 4) reveals that the water level in Bu–3 has generally declined during periods of heavy pumpage and has risen during periods of reduced pumpage. Thus, from 1939 through 1941, pumpage ranged from 10.5 to 8.7 mgd, and the water level declined more than 30 feet, to a low of 130 feet below the land surface. Pumpage was reduced in 1942 and 1943, and the water level rose 20 feet. Increased pumpage in 1944 resulted in a 20-foot decline—from 110 to 130 feet below the land surface. Reduced pumpage in 1945, combined with generally abundant rainfall that year, resulted in rising groundwater levels in 1945—from 130 to about 95 feet below the land surface. Rainfall continued to be generally abundant through 1948, but the water levels remained fairly constant. By 1948, however, pumpage had again increased to 9.5 mgd. From 1949 through 1955, much of which was a dry period, the water level steadily declined, reaching a low of 138 feet below the land surface in late 1954. The water-level decline to about 145 feet below the land surface in 1955, which occurred after the break in the record, is the result of changing the recorder to a nearby well after the original well was abandoned.

In 1956 Armco instituted drastic changes in their water utilization in an attempt to arrest the continuing water-level decline. (For further discussion, see Spieker, 1968b.) The reduced pumpage, combined with abundant rainfall for the period 1956–59, resulted in rise in water level of more than 60 feet in well Bu–3—from a low of 145 feet in 1955 to a high of 78 feet in 1958 and 1959. By 1959, however, increased production at the plant had again increased water usage to 9.6 mgd; in the ensuing dry period the water level steadily declined to 132 feet at the end of 1964. Thus, the groundwater level at the end of 1964 was about the same as that in 1955, before the changes toward economic utilization of water were made.

NEW MIAMI–NORTH HAMILTON AREA

The water surface in the area comprising New Miami and the northern part of Hamilton is affected by pumping totaling 18 mgd at three major centers: the Armco New Miami plant, the Champion Paper Co. plant, and the Hamilton North well field. Figure 5 shows the hydrographs of two observation wells in this area. The entire area is in hydrogeologic environment I–A–1. Well Bu–4, 177 feet deep, is at the Armco New Miami plant. Its hydrograph shows a regular annual fluctuation of 8–12 feet. No downward trend is evident, although the beginning of a decline in the years 1953 and 1954 was arrested by a period of abundant recharge that began in 1955.

Well Bu–5 is at the Hamilton North well field, which was the main source of Hamilton's municipal water supply until 1956, when the South well field began operation. The hydrograph of Bu–5 prior to 1956 is strikingly different from the graph following that year. Through 1952 the hydrograph shows an annual cyclic

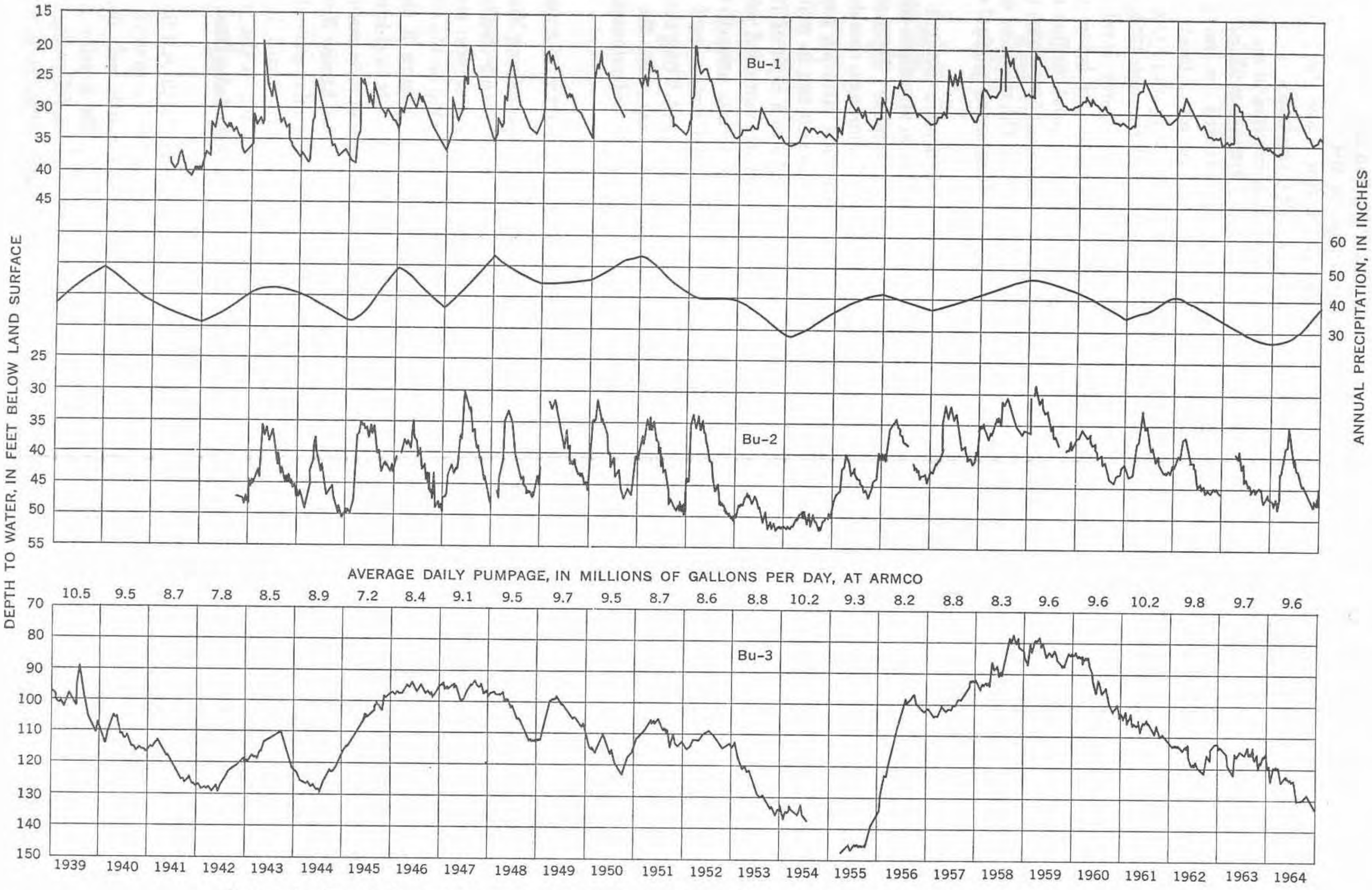


FIGURE 4.—Fluctuations of the water levels in observation wells Bu-1, Bu-2, and Bu-3 in the Middletown area.

fluctuation averaging 10–12 feet but no evident downward trend. The trend was definitely downward in 1953 and 1954; recovery in 1955 was moderate. In 1956, when the North well field was placed on a standby basis, the water level quickly recovered to an average of about 5 feet above the levels characteristic of the period prior to the drought of 1953–54. The hydrograph of Bu–3 similarly reflects this pumping change. The jagged pattern of the Bu–4 hydrograph from mid-1956 through 1964 reflects the intermittent use of the North well field during that period.

AREA SOUTHEAST OF HAMILTON

Observation well Bu–8 is in hydrogeologic environment III southeast of Hamilton (pl. 2). This well, 200 feet deep, is in the well field formerly operated by the Federal Works Agency. This well field was developed during World War II to supply industries in the Mill Creek valley. The FWA well field was described by Bernhagen and Schaefer (1947, p. 19–23). Although this field has been purchased by the city of Hamilton and is now known as the South well field, the wells along Gilmore Road near well Bu–8 have not been reactivated. These wells were pumped from 1943 through the summer of 1945. The hydrograph of Bu–8 (fig. 6) shows that the water level was therefore not affected by pumping, except for the brief period from the start of the record in 1944 through the summer of 1945. A recovery in the ground-water level of about 12 feet took place when pumping at the FWA well field ceased. The hydrograph of Bu–8 (fig. 6) shows a cyclic fluctuation of 10–15 feet annually. The greater magnitude of fluctuation in this well than in other wells not affected by pumping, such as Mt–49 (fig. 3) and H–1 (fig. 8), is probably the result of the low coefficient of storage which is characteristic of hydrogeologic environment III.

FAIRFIELD–NEW BALTIMORE AREA

The area between Fairfield and New Baltimore, west of Ross, is the site of two of the largest ground-water supplies in the lower part of the valley—the Hamilton South well field at Fairfield and the Southwestern Ohio Water Co. well field near Ross. Midway between these two well fields the city of Cincinnati proposes to develop a well field which is expected to produce as much as 40 mgd. The Fairfield–New Baltimore area is the subject of chapter C of the present series of reports (Spieker, 1968a).

Observation well Bu–7 is virtually in the middle of the Hamilton South well field (pl. 2). Its hydrograph (fig. 7) is therefore influenced somewhat by pumping at the field. The period of record began in 1944, at which time the present Hamilton South well field was being pumped by the Federal Works Agency. The water level in Bu–7 recovered about 6 feet when pumping at the field ceased in 1945. Note the similar recovery shown by the hydrograph of Bu–8 (fig. 6). When pumping was resumed in 1956, the average water level in Bu–7 declined about 4 feet. The water level fluctuates 5–10 feet annually. Pumping at the Hamilton South well field has not caused any persistent lowering trend in the water level of Bu–7.

Observation well H–2 is about 2,000 feet from collector 1 of the Southwestern Ohio Water Co. The period of record began in 1952, when the collector was placed in operation. Its hydrograph, affected by pumping in the Southwestern Ohio well field and changes in stage of the Great Miami River, shows an annual cyclic fluctuation of 5–10 feet but no downward trend. Pumping at the Southwestern Ohio well field, which averages 13–15 mgd, is sustained largely by induced recharge from the River. Dove (1961) discussed the hydrology of this well field in detail.

LOWER WHITEWATER RIVER VALLEY

The lower valley of the Whitewater River, south of Harrison, has been virtually unaffected by large-scale pumping of ground water. Therefore the hydrograph of observation well H–1 (fig. 8) from 1950 to 1964 provides an excellent record of the ground-water regimen unaffected by pumping. The similarity of this hydrograph to the hydograph of Mt–49 (fig. 3) is striking. The wells are in similar hydrogeologic environments unaffected by pumping. H–1 is in hydrogeologic environment I–A–1, and Mt–49 is in environment I–B–1. Both wells have an annual cycle of water-level fluctuation of about 5–7 feet, and neither well has shown a persistent downward trend.

CHEMICAL QUALITY OF WATER

The quality of water for most uses is fully as important as its availability. All naturally occurring water contains dissolved mineral constituents in various proportions as a result of the contact between the water and the rocks and materials which make up the earth. Also, in heavily populated areas water is often contaminated as a result of the activities of man. Although surface-water sources are generally more susceptible to contamination than ground-water supplies, the contamination of the latter is fairly common in densely populated areas.

A study of the chemical quality of ground and surface waters has been included in the present investigation for the above-stated reasons. The analyses of 30 selected ground-water samples in the area are shown in table 8. Table 9 shows nine representative analyses

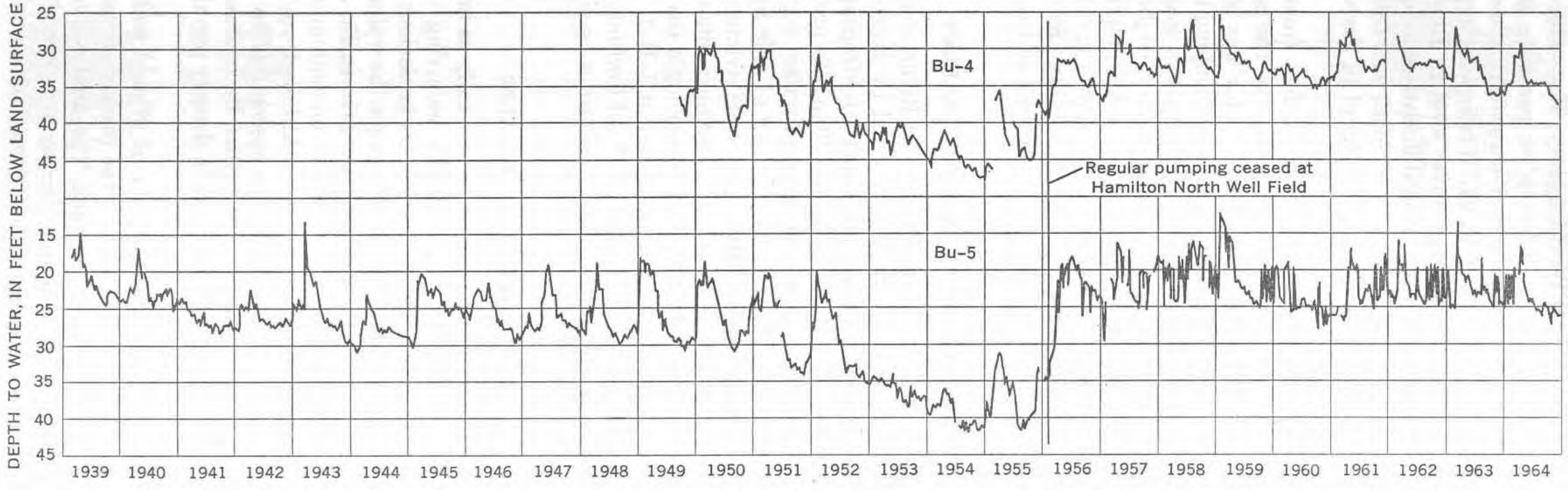


FIGURE 5.—Fluctuations of the water levels in observation wells Bu-4 and Bu-5 in the New Miami–North Hamilton area.

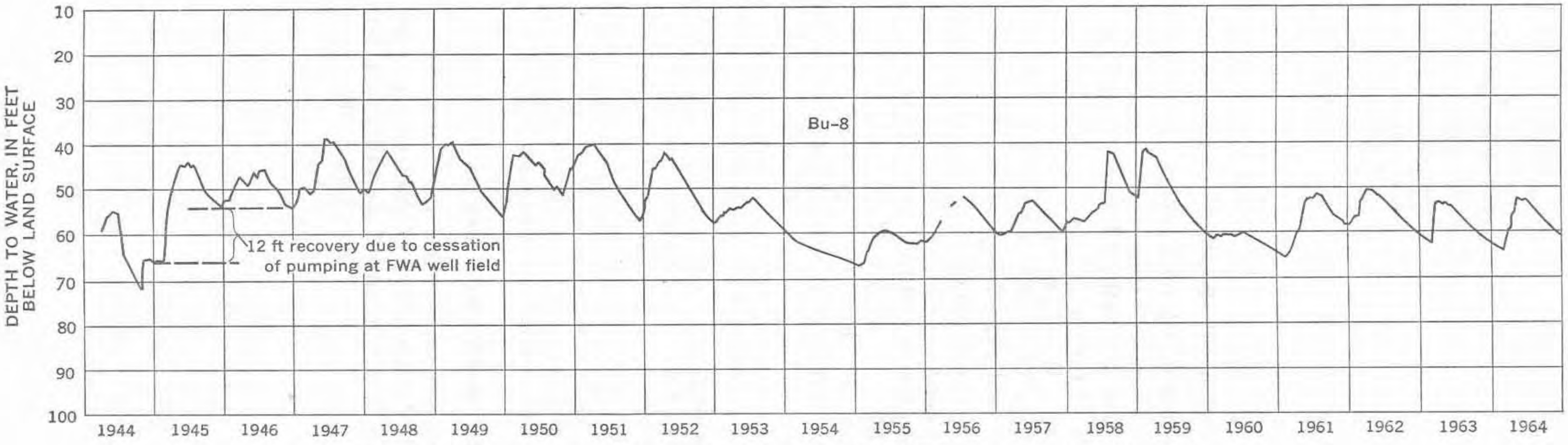


FIGURE 6.—Fluctuations of the water level in observation well Bu-8, southeast of Hamilton.

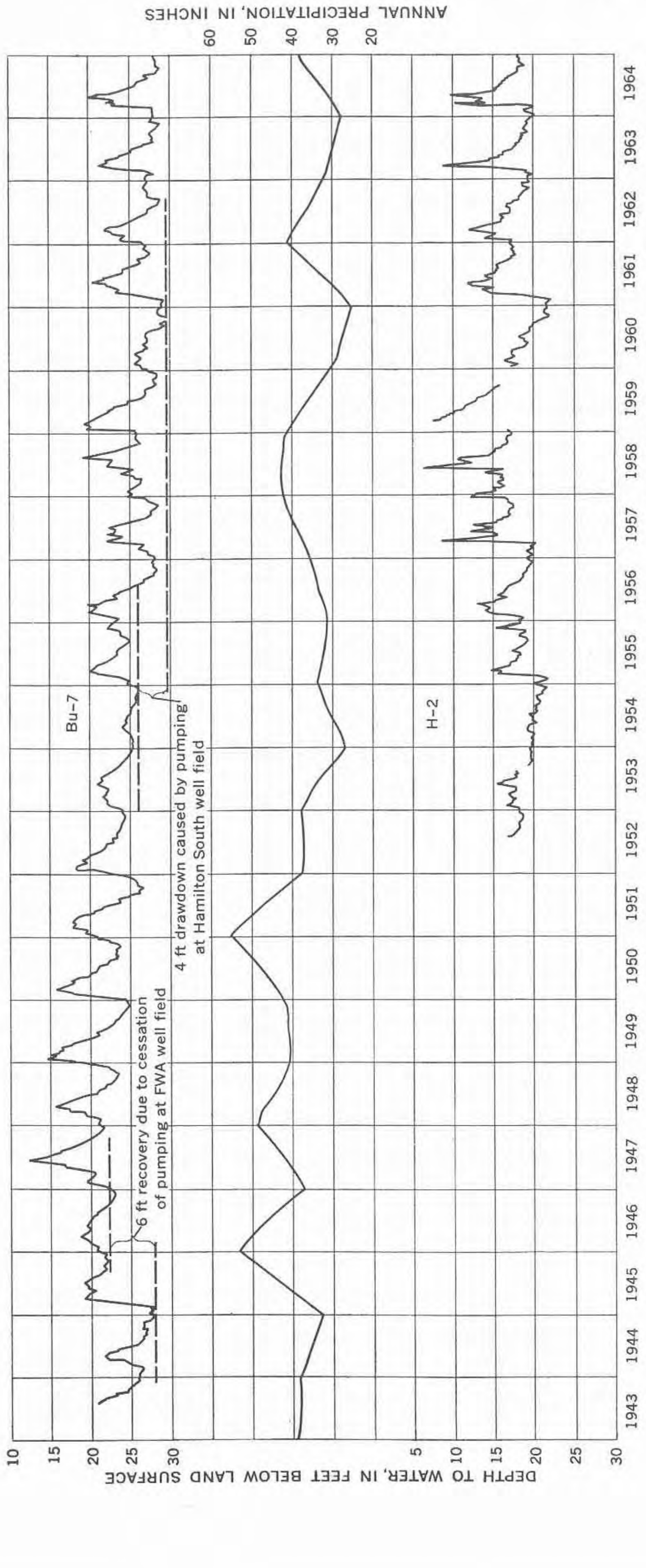


FIGURE 7.—Fluctuations of water levels in observation wells Bu-7 and H-2 in the Fairfield–New Baltimore area.

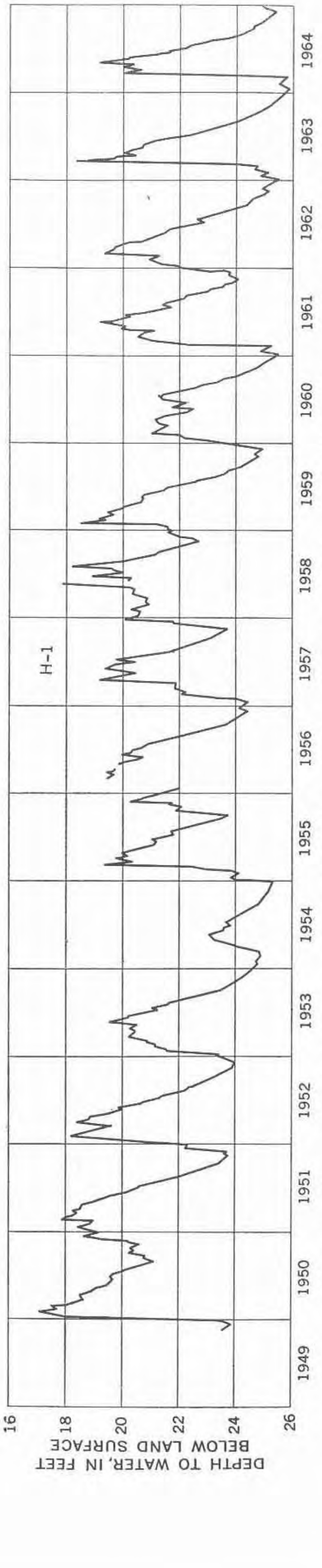


FIGURE 8.—Fluctuations of the water level in observation well H-1 in the lower Whitewater River valley, south of Harrison.

TABLE 8.—*Selected analyses of water samples from wells in the lower Great Miami River valley, Ohio*

[Data are in milligrams per liter except as indicated]

Owner	Location	Well	Date sample was collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen as NH_4	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite (NO_2)	Nitrate (NO_3)	Potential nitrate (NH_4, NO_2, and NO_3 as NO_3)	Phenols as C_6H_5OH	Alkyl benezene sulfonate (ABS)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromphos at 25°C)	pH	Color
																							Calcium, magnesium	Noncarbonate			
Drinking water standards [1]	---	---	---	---	---	0.3	0.05	---	---	---	---	---	---	250	250	[2]0.9	---	45	---	0.001	0.5	500	---	---	---	---	---
Dayton Power & Light Co., O. H. Hutchings station.	South of Miamisburg	9	10-22-64	59	14	.35	.00	84	31	31	3.0	0.0	340	57	47	.5	0.00	.4	0.4	.000	.1	445	337	58	755	7.7	6
Middletown Water Works	Middletown	20	10-22-64	63	8.1	.41	.00	79	30	28	3.2	.0	300	70	38	.5	.00	1.9	1.9	.011	.0	417	321	74	701	7.5	5
Do	do	17	10-22-64	56	14	1.0	.06	94	27	9.2	1.2	.0	356	50	15	.5	.00	.0	.0	.002	.0	382	346	54	659	7.5	5
Armco Co., East Works	do	24	1-21-65	57	15	4.0	.03	132	46	16	1.8	.5	440	142	32	.2	.00	.2	1.9	---	.0	624	519	158	966	7.2	3
Do	do	23	10-21-64	61	16	8.2	.00	210	82	29	2.1	.0	500	424	48	.5	.00	.0	.0	---	.0	1,110	862	451	1,510	7.0	3
Do	do	22	1-21-65	58	14	4.7	.14	126	47	18	1.7	.9	428	146	30	.3	.00	.0	3.1	---	.0	617	508	158	956	7.3	10
Do	do	25	10-21-64	55	14	3.0	.00	82	33	18	1.3	.0	372	40	22	.5	.00	.0	.0	---	.0	396	340	35	688	7.6	12
Hickory Flat Church	Near Hamilton	40	10-20-64	53	8.8	.24	.06	83	30	2.6	1.3	.0	324	39	7.5	.3	.00	18	18	---	.0	345	331	65	600	7.5	3
Armco Co., New Miami plant.	New Miami	43	10-21-64	56	10	.46	.19	94	30	14	3.6	12	344	113	15	.4	.05	2.6	43.9	.000	.0	456	358	76	776	7.4	5
City of Hamilton, North well field.	Hamilton	44	10-21-64	56	13	.41	.36	101	34	13	1.9	.0	326	105	28	.3	.00	.0	.0	.000	.0	486	392	125	759	7.5	4
Champion Paper Co	do	46	10-22-64	60	10	.02	.00	98	30	22	3.1	.0	318	94	36	.4	.00	3.5	3.5	.001	.0	475	368	108	764	7.5	3
Do	do	45	10-21-64	57	13	.18	.45	110	37	9.7	1.7	.0	402	87	18	.3	.00	.0	.0	.010	.0	489	427	97	796	7.4	5
Edward F. Miller	3870 Tylersville Road, Hamilton.	Spring	6- 6-63	54.5	10	.03	.03	100	26	7.6	.9	.0	346	60	15	.2	.00	4.6	4.6	---	.0	406	357	73	667	7.4	3
City of Hamilton	Fairfield	61	6- 5-63	54.5	11	.03	.03	90	28	4.0	1.3	.0	352	40	8.0	.2	.05	9.3	9.4	.005	.0	358	340	51	619	7.3	3
Do	do	53	6- 5-63	54	9.3	.22	.06	87	26	4.2	1.7	.0	338	46	7.0	.3	.00	6.8	6.8	.004	.0	359	324	47	613	7.2	3
Do	do	55	6- 5-63	55	10	.13	.17	92	27	5.4	1.5	.0	344	47	11	.2	.05	7.3	7.4	.000	.0	375	341	58	634	7.4	2
City of Cincinnati, pumping-test site.	Near Fairfield	63	6-26-62	55	12	.63	.26	80	24	3.9	1.1	---	328	24	6.0	.4	---	.2	---	---	---	310	298	29	553	7.5	0
Do	do	63	6-29-62	---	11	.45	.06	82	24	3.1	1.2	---	330	34	5.5	.1	---	.1	---	---	---	319	303	32	564	7.2	3
Southwestern Ohio Water Co.	Near Ross	77	7-17-52	54	11	.39	.25	82	20	2.5	1.5	---	310	38	5.5	.1	---	1.0	---	---	---	335	288	---	552	7.7	2
Do	do	77	1-29-54	56	12	.00	.00	94	25	9.4	2.0	---	330	64	12	.0	---	2.9	---	---	---	383	340	67	636	7.2	2
Do	do	77	11- 7-56	56	13	.11	.42	96	24	12	1.7	---	329	72	16	.1	---	1.2	---	---	---	417	340	71	657	7.6	2
Do	do	77	3-27-57	56.5	11	.10	.43	98	28	12	2.1	---	334	75	21	.1	---	2.1	---	---	---	420	360	86	697	7.7	0
Do	do	77	6- 4-58	56	10	.08	.24	88	29	12	1.8	---	315	79	16	.1	---	3.3	---	---	---	410	339	81	651	7.3	1
Do	do	77	6- 4-63	59	9.2	.31	.42	94	29	14	2.1	.1	320	82	24	.2	.05	7.0	7.4	.004	.0	423	354	92	695	7.6	3
Do	do	77	2-16-65	63	8.2	.04	.13	98	33	25	3.1	---	294	121	38	.2	---	.4	---	---	---	486	380	139	782	7.9	5
Do	do	73	11- 7-56	56	11	.04	.30	86	24	5.4	1.2	---	322	50	11	.1	---	2.0	---	---	---	356	313	49	580	7.4	2
Do	do	73	3-27-57	55.7	10	.06	.34	89	24	5.6	1.8	---	321	44	9.2	.1	---	5.7	---	---	---	368	321	58	607	7.7	0
Do	do	73	6- 4-58	53	11	.16	.20	73	25	5.7	1.8	---	268	59	9.0	.1	---	7.7	---	---	---	321	285	66	550	7.4	1
Do	do	73	1-21-65	55	13	.09	.17	93	27	8.6	2.1	.1	324	64	16	.2	.05	5.3	5.7	.003	.0	397	343	78	651	7.4	3
U.S. Atomic Energy Comm.	Near Fernald	87	6- 5-63	54	11	3.3	.44	93	24	10	1.1	.4	354	41	16	.2	.00	.5	1.9	.000	.0	369	331	40	635	7.5	4
E. I. DuPont DeNemours Corp.	North Bend	105	11- 5-64	---	17	.01	.00	95	30	20	3.3	---	306	101	29	.0	---	.2	---	---	---	491	361	110	741	7.4	3

---

[1] U.S. Public Health Service (1962).

[2] For average annual maximum air temperature of 63.9°–70.6°F.

TABLE 9.—*Representative analyses of water samples from the lower Great Miami River, Ohio*

[Data are in milligrams per liter except as indicated]

Site	Location	Discharge [1] (cfs)	Date sample was collected	Temperature (° F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen as NH_4	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite (NO_2)	Nitrate (NO_3)	Potential nitrate (NH_4, NO_2, and NO_3 as NO_3)	Phosphorus as PO_4	Phenols as C_6H_5OH	Alkyl benzene sulfonate (ABS)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH	Color	Dissolved oxygen	
																								Calcium, magnesium	Noncarbonate				Milligrams per liter	Percent saturation
1	Near Miamisburg. At Chautauqua Road Bridge about 2 miles south of Miamisburg	340	1-16-64	42	9.3	0.17	0.07	88	32	64	5.2	4.1	352	106	78	0.9	0.90	4.9	20.2	7.5	0.009	1.2	561	351	62	948	7.3	15	1.8	14
	Do	9,010	3-12-63	40	5.3	.32	.30	47	14	7.0	4.5	.8	146	47	14	.2	.15	13	15.9	.62	.010	.2	245	175	55	382	7.7	40	7.2	55
2	Middletown. At County Park dock, about 0.6 mile downstream from Penn Central RR bridge just north of Middletown	355	1-16-64	43	7.3	.12	.03	83	32	55	4.8	3.2	332	97	64	.7	.90	5.1	17.3	6.0	.000	1.1	507	339	66	872	7.2	13	3.0	24
	Do	6,800	3-18-64	46	6.7	.26	.01	71	22	11	2.5	.1	206	81	24	.3	.15	19	19.5	1.3	.000	.2	343	268	98	566	6.9	13	10.4	87
3	Near Middletown. At dock under Baltimore & Ohio RR bridge south of Middletown	355	1-16-64	39	6.8	6.8	.21	87	33	60	4.7	3.9	228	183	77	.6	.50	3.9	18.0	.11	.020	1.0	583	353	166	946	6.8	5	5.3	40
	Do	6,800	3-18-64	47	6.8	.66	.00	73	21	11	2.5	.1	200	84	22	.2	.18	18	18.6	.48	.011	.3	341	269	105	569	7.0	12	10.2	86
4	Near Hamilton. At American Materials Co. bridge, Fairfield, southwest of Hamilton	355	1-16-64	42	7.1	2.7	.21	95	30	60	4.9	4.8	244	188	75	.7	.50	5.2	22.4	.28	.000	.9	590	361	161	958	6.8	6	5.4	43
	Do	6,800	3-18-64	48	6.7	.31	.01	73	20	11	2.5	.3	198	83	23	.3	.18	18	19.3	.41	.000	.2	341	264	102	567	6.9	7	10.0	86
5	Ross. At bridge on U.S. Route 50 Bypass about ½ mile southeast of Ross	1,670	3-27-57	----	3.4	.01	.00	84	31	15	2.2	----	275	102	20	.3	----	7.0	----	----	----	----	413	337	111	664	7.8	1	----	----

[1] Discharge for site 1 measured at Miamisburg; discharge for sites 2-5 measured at Hamilton.

of water from the Great Miami River in the study area. Sampling sites are shown indicated on plates 1 and 2. The U.S. Geological Survey in cooperation with various State agencies maintains a network of surface-water stations, including five in the present area, from which samples for chemical analysis are taken at regular intervals. These analyses were compiled by Hubble and Collier (1960). The analyses for each year are summarized in a series of publications by the U.S. Geological Survey; for example, see Love and others (1964).

QUALITY OF WATER

Water in the lower Great Miami River valley is of a calcium bicarbonate type, with a concentration of total dissolved solids of generally 300–600 mg/l; thus, all water in the area is classed as hard to very hard. Some of the area's ground water contains objectionable quantities of iron and manganese. The presence of these minerals is generally greatest in hydrogeologic environments in which clay is abundant.

Although the quality of uncontaminated ground water remains generally uniform, the quality of surface water fluctuates widely according to discharge. This is readily apparent in table 9, which gives results of two analyses (one representing low streamflow, and the other, high) for four of the five sites listed. The concentrations of most constituents are significantly greater at low streamflow.

EVIDENCE OF CONTAMINATION

Surface waters, and to a lesser extent ground waters, in the lower Great Miami River valley have become contaminated as a result of the activities of man. Pollution by such constituents as phenols and detergents (ABS), which do not occur in natural waters, and by high concentrations of nitrate is evident. The low dissolved-oxygen content in some reaches of the Great Miami River is further evidence of contamination. Contamination of ground water is most evident where large quantities of surface water have been induced into the aquifer as a result of pumping. Local contamination, however, can result from leakage from improperly constructed septic tanks or from seepage of water through fertilizer on farm lands. The relatively high nitrate concentration of water from well 40 is probably the result of such causes, for the well is not in an area of heavy pumping, nor is it near enough to a major stream to be affected by induced infiltration.

Contamination of ground-water supplies, though detectable, has, as yet, been minor. The concentrations of such critical constituents as nitrate and phenols, however, should be monitored in selected wells in areas of induced infiltration so that any increase in contamination can be detected and a solution sought before the problem becomes serious.

INDIVIDUAL CONSTITUENTS AND PROPERTIES OF WATER

The concentrations and the significance of the individual constituents and properties of ground water and surface waters given in tables 8 and 9 are discussed in the following sections.

Temperature

The temperature of ground water at depths of 200 feet or less is generally very close to the mean annual air temperature, which ranges from 52° to 55°F in the lower Great Miami River valley. Temperature of stream water, however, fluctuates from as low as 33°F in the winter to as high as 90° F in the summer. Induced infiltration of river water can therefore cause wide variance in the ground-water temperature, owing to the mixing of surface and ground waters.

The temperatures of the ground-water samples given in table 8 range from 53° to 63°F and average 56°F. All ground-water temperatures above 56°F in this area are probably the result of induced stream infiltration.

Ground water, with a uniform temperature of 53°–56°F, is more desirable for public-supply use than is surface water whose temperature fluctuates over a wide range. The temperature of water to be used for industrial cooling is a critical factor. Although a ground-water supply may be the more expensive to develop, its greater utility for cooling purposes may well compensate for the additional cost.

Silica (SiO_2)

Silicon is second only to oxygen as the most abundant element in the earth's crust; it occurs naturally as the silicate radical, SiO_4, or as silica, SiO_2. Though silica has a low solubility, all natural water contains small quantities of it. The silica content of ground-water samples from the study area ranged from 8.1 to 17 mg/l and averaged 11.7 mg/l; silica in selected surface-water samples ranged from 3.4 to 9.3 mg/l and averaged 6.6 mg/l. It can cause a hard scale to form in boilers, particularly in high-pressure boilers.

Iron (Fe)

Iron is present in all rocks and, thus, is a constituent of nearly all natural water. Iron concentration in the ground-water samples in the area of investigation ranged from 0.00 to 8.2 mg/l and averaged 0.97 mg/l. The range in the surface-water samples was from 0.01 to 6.8 mg/l; the average was 0.57. A concentration of about 0.3 mg/l or more in the water will stain enamel, porcelain, and clothing. Iron concentration of more than about 0.5 mg/l gives water an unpleasant taste, but it causes no harmful physiological effects. The U.S. Public Health Service (1962) has recommended that the iron concentration in drinking water not exceed 0.3 mg/l.

The presence of "iron bacteria" in wells and water-transmission lines creates a special problem. Iron bacteria are not true bacteria but are living organisms often present in natural water. They depend upon iron for existence and thrive in slightly acid water containing 2 mg/l or more iron. *Crenothrix* is probably the most common of the several iron bacteria known. Metallic and nonmetallic materials that carry water containing iron bacteria become coated by nodules of ferric hydroxide or by a slimy scum impregnated with ferric hydroxide. The water may turn red, and its rate of flow may be affected by the activity of these organisms. They cause one of the major water-treatment problems in the report area but can be controlled by certain methods. One of the most effective methods combines the use of chlorination to kill the organisms and the addition of a polyphosphate compound to keep the iron in solution.

Manganese (Mn)

The concentration of manganese in water is generally less than that of iron; however, the two constituents affect water similarly. Of the 30 ground-water samples analyzed, 23 contained a measurable concentration of manganese, which ranged from 0.01 to 0.45 mg/l and averaged 0.17 mg/l. The manganese concentration in 19 samples equaled or exceeded the U.S. Public Health Service (1962) recommended limit of 0.05 mg/l. Manganese concentrations in the surface-water samples ranged from 0.00 to 0.30 mg/l and averaged 0.09 mg/l.

Calcium (Ca)

Calcium is one of the major constituents in natural water in a limestone terrane, such as the lower Great Miami River valley. Concentrations of calcium in the ground-water samples analyzed ranged from 73 to 210 mg/l and averaged 97 mg/l. The corresponding range for the surface-water samples was 47–95 mg/l, and averaged 78 mg/l. Calcium and magnesium are the principal causes of water hardness; their effects are discussed under the heading "Hardness."

Magnesium (Mg)

Dolomitic rock or unconsolidated materials derived from it are the principal source of magnesium. Magnesium concentrations in analyzed ground-water samples from the study area ranged from 20 to 82 mg/l and averaged 31 mg/l; concentrations in the surface-water samples ranged from 14 to 33 mg/l and averaged 26 mg/l.

Sodium (Na) and potassium (K)

The alkali metals sodium and potassium are discussed together, as their sources and their effects on water are similar. Sodium is generally the more abundant of the two and is more easily dissolved from the source rock. In the ground-water samples the concentration of sodium ranged from 2.5 to 31 mg/l and averaged 12.3 mg/l, and that of potassium ranged from 0.9 to 3.6 mg/l and averaged 1.9 mg/l. In the surface-water samples, the concentration of sodium ranged from 7 to 64 mg/l and averaged 33 mg/l, and that of potassium ranged from 2.2 to 5.2 mg/l and averaged 3.8 mg/l. Although relatively low, these concentrations of the alkalies are sufficient to cause undersirable effects in some uses, such as in high-pressure boilers.

Bicarbonate (HCO_3)

Water which contains carbon dioxide (CO_2) dissolves the carbonates of calcium and magnesium from rock, and in this reaction the bicarbonate (HCO_3) ion is formed. In a carbonate-rich terrane, bicarbonate is one of the major constituents of natural water. Concentrations in the ground-water samples analyzed ranged from 268 to 500 mg/l and averaged 344 mg/l. In the surface-water samples, concentrations were 146–352 mg/l and averaged 242 mg/l. In boilers and hot-water facilities, bicarbonate decomposes at high temperatures to yield carbon dioxide, which is corrosive.

Sulfate (SO_4)

Sulfate in the natural waters of this area is largely dissolved from gypsum, a highly soluble mineral which occurs in the limestones and dolomites of western Ohio. Concentrations of sulphate in the ground-water samples analyzed ranged from 24 to 424 mg/l and averaged 80 mg/l; in the surface-water samples (table 9) concentrations ranged from 47 to 188 mg/l and averaged 108 mg/l. For the water year ending in 1964, the sulfate content in the Great Miami River at Elizabethtown (table 10) ranged from 33 to 190 mg/l. Sulfate, which causes much of the noncarbonate hardness of water, combines with calcium to form hard scale in boilers and other heat-exchange equipment. The U.S. Public Health Service (1962) has recommended that the sulfate content of drinking water not exceed 250 mg/l.

The occurence of sulfate in waters of the Great Miami River valley deserves further study. Average sulfate concentration in the surface-water samples is higher than that in the ground-water samples, and this suggests that some of the sulfate may be the result of waste products. The sulfate concentration in collector 1 of the Southwestern Ohio Water Co. (well 77 of present report) has progressively increased for 13 years, probably because of induced stream infiltration. Water in three wells (wells 22, 23, 24) at the Armco East Works contains abnormally high concentrations of sulfate—from 142 to 424 mg/l. Whether the high concentrations are the result of contamination from industrial wastes or of the abundance of clay and silt in this hydrogeologic environment (environment III) is not yet known.

Chloride (Cl)

Chloride is a minor constituent of ground water in the lower Great Miami River valley. Concentrations in the ground-water samples analyzed ranged from 5.5 to 48 mg/l and averaged 19 mg/l. Chloride concentrations in the surface-water samples ranged from 14 to 78 mg/l and averaged 44 mg/l. The high concentrations of chloride in the surface water sampled during periods of low flow (table 9) probably reflect contamination. All the samples both ground water and surface water, contained less chloride than the 250 mg/l limit recommended by the U.S. Public Health Service (1962) for drinking water.

Fluoride (F)

Minute quantities of fluoride are present in most water from limestone terranes. In the analyses of the ground-water samples, the fluoride concentration ranged from 0.0 to 0.5 mg/l and averaged 0.013 mg/l. The range in the surface-water samples is from 0.2 to 0.9 mg/l, and the average, 0.46 mg/l. Evidence indicates that fluoride concentrations of about 0.6 to 1.7 mg/l reduce the incidence of tooth decay but that concentrations greater than 1.7 mg/l, although giving protection from decay, can cause mottling of teeth. The recommended control limits of the U.S. Public Health Service for fluoride (1962, p. 8) are based on the annual average of maximum daily air temperatures. Thus for the study area, where the annual average maximum air temperature is between 63.9° and 70.6°F, the recommended range for fluoride is from 0.7 to 1.2 mg/l, with an optimum value of 0.9 mg/l.

Nitrogen cycle

Nitrogen occurs in ground water in the lower Great Miami River valley in three forms: Ammonia (NH_4), nitrite (NO_2), and nitrate (NO_3). Of the three forms, which represent stages in the nitrogen cycle, only nitrate occurs naturally in ground water. Organic wastes, however, often contain nitrogen in all three forms. The presence of ammonia and nitrite can thus be considered as evidence of pollution.

Under oxidizing conditions, nitrate is the end product of the nitrogen cycle. An analysis for nitrate, however, may not necessarily represent all the nitrogen present in the sample; therefore, tables 8 and 9 also show ammonia, nitrite, and potential nitrate.[4]

Concentration of nitrate in the ground-water samples (table 8) ranged from zero in six samples to 18 mg/l and averaged 3 mg/l. Most nitrate concentrations in excess of 5 mg/l are probably the result of contamination. All these concentrations are well under the limit of 45 mg/l for drinking water set by the U.S. Public Health Service (1962). In the selected surface-water samples the nitrate ranged from 3.9 to 19 mg/l and averaged 10.5 mg/l.

Potential nitrate in the 19 ground-water samples ranged from zero in 5 samples to 43 mg/l and averaged 3.8 mg/l. The value of 43 mg/l for well 43 was omitted from the average as not representative. In the eight surface-water samples, potential nitrate ranged from 15.9 to 22.4 mg/l and averaged 18.9 mg/l.

Nineteen of the 31 ground-water samples listed in table 8, and 8 of the 9 surface-water samples listed in table 9 were anlyzed for ammonia and nitrite. Six of the 19 ground-water samples contained ammonia, which ranged in concentration from 0.1 to 18 mg/l and averaged 0.4 mg/l.[5] Five of the 19 samples contained nitrite, and each of these had 0.05 mg/l. Ammonia ranged from 0.1 to 4.8 mg/l and averaged 2.2 mg/l in the surface-water samples. In these samples nitrite ranged from 0.15 to 0.90 mg/1 and averaged 0.43 mg/1. These concentrations suggest that the river is generally contaminated in varying degrees by organic wastes. The presence of small amounts of ammonia and nitrite in six of the ground-water samples suggests that the wells from which the samples were collected had been recharged with contaminated water, probably induced from the Great Miami River.

The potential nitrate of the 19 ground-water samples (excluding that from well 43) analyzed for the complete nitrogen cycle (table 8) ranged from 0 to 18 mg/l and averaged 4 mg/l. In the surface-water samples (table 9) the potential nitrate ranged from 15.9 to 22.4 mg/l and averaged 19 mg/l.

Phosphorus as PO_4

Phosphates in surface or ground waters are derived from natural leaching of phosphatic rocks, from agricultural drainage, and from industrial and domestic wastes. With the greatly increased use of synthetic detergents, of which phosphates are a major constituent, phosphate concentrations in waters (particularly in surface waters) have shown significant increases.

In the samples from the Great Miami River that were analyzed in this study, phosphate concentration ranged from 0.11 to 7.5 mg/l, with the higher values observed in the area between Miamisburg and Middletown.

Phenols as C_6H_5OH

The presence of phenolic material in naturally ocurring waters is the direct result of pollution. The effluents from coking plants, chemical plants, and oil refineries often contain large concentrations of phenols.

---

[4] Potential nitrate is the sum of ammonia nitrogen (NH_4), nitrite (NO_2), and nitrate (NO_3), all reported as NO_3. To convert milligrams per liter NH_4 to milligrams per liter NO_3, multiply by 3.436. To convert mg/l NO_2 to mg/l NO_3, multiply by 1.348.

[5] The analysis of 18 mg/l from well 43 was excluded from the average, as it is considered not representative.

Inasmuch as phenols are unstable in the presence of oxygen, they are not persistent in a typical aerobic stream and are generally broken down within a short distance of their source. Thus, of the eight selected samples from the Great Miami River analyzed for phenols (table 9), only four contained measurable concentrations, which ranged from 0.009 to 0.020 mg/l. The higher concentrations generally occur at low streamflow. The fact that phenols were present in samples from stations 1 and 3 but not in samples from stations 2 and 4 suggests that the stations 1 and 3 are fairly close to sources of contamination. The relative lack of dissolved oxygen at station 1 may contribute to the presence of phenols there.

Of the 13 ground-water samples analyzed for phenols, eight continued measurable concentrations, which ranged from 0.001 to 0.011 mg/l. The occurrence of phenols in ground water in the lower Great Miami River valley is probably the result of induced infiltration of contaminated water from the river. All the wells containing phenols are in areas where induced infiltration is thought to occur.

Even very low concentrations of phenols in water can cause a disagreeable taste, and water containing phenols in sufficient concentrations to be harmful is unpalatable. The U.S. Public Health Service (1962) recommended a limit of 0.001 mg/l for phenols. Phenols from public supply wells would probably break down when the water is aerated; chlorination, however, stabilizes phenols.

Synthetic detergents

One of the principal waste products of synthetic detergents has been anionic alkyl-benezene sulfonate, more commonly termed "ABS." This waste product is resistant to breakdown by both chemical and biological processes and is therefore persistent in streams. Where the concentration is high, foaming of stream water is plainly visible. All the selected water samples from the Great Miami River that were analyzed for ABS (table 9) showed concentration ranging from 0.1 to 1.2 mg/l. Of the 19 ground-water samples analyzed, however, only one—from the O. H. Hutchings Station of the Dayton Power & Light Co.—showed a concentration of 0.1 mg/l. The U.S. Public Health Service (1962) has recommended that drinking water contain no more than 0.5 mg/l of ABS. Although the Great Miami River always contains some ABS, this substance has not significantly contaminated ground water in the study area. ABS contamination has been disappearing from stream waters as the detergent industry has changed over to making LAS (linear alykl sulfonate), or "soft" (degradable), detergents.

Dissolved solids (residue at 180°C)

The dissolved-solids content in water is determined in laboratories of the U.S. Geological Survey by a process of evaporating a suitable volume of the sample to near dryness on a steam bath and then drying the residue in an oven for 1 hour at 180°C (Hem, 1959, p. 49–50). Concentrations of dissolved solids in ground-water samples from the study area ranged from 310 to 1,110 mg/l and averaged 435 mg/l. Total dissolved solids in the selected surface-water samples ranged from 245 to 590 mg/l and averaged 436 mg/l. Water having more than 1,000 mg/l of dissolved solids is generally considered to be unsatisfactory for most purposes. The recommended maximum for dissolved solids in drinking water is 500 mg/l (U.S. Public Health Service, 1962). Some specialized industrial applications require a much lower concentration.

The extremely high dissolved solids content of 1,110 mg/l in well 23, at the Armco East Works, is problematical. (The high concentration of sulfate in this well is discussed on p. A29.) Inasmuch as this well is in hydrogeologic environment III, the abundance of dissolved solids may be the result of the water's contact with large amounts of clay. Another possibility is that much of the solids content in this well is the result of contamination from industrial wastes.

Hardness

For many years, hardness in water has been considered to be the water's soap-consuming property. Soap-consuming water contains cations, chiefly calcium and magnesium, that form insoluble compounds with soap. This traditional concept is not entirely satisfactory, however, because a great many other constituents also contribute to hardness and react with soap. In analyses by the U.S. Geological Survey a standard procedure has been adopted (Hem, 1959, p. 146). Hardness is reported under two classifications: calcium-magnesium and noncarbonate. These are approximately equivalent to the traditional terms "temporary hardness" and "permanent hardness." Hardness attributable to calcium and magnesium is reported as an equivalent quantity of calcium carbonate ($CaCO_3$).

Calcium-magnesium hardness of the ground-water samples collected in the area of investigation ranged from 285 to 862 mg/l and averaged 368 mg/l; noncarbonate hardness of the same samples ranged from 29 to 451 mg/l and averaged 88 mg/l. For the surface-water samples, the calcium-magnesium hardness ranged from 175 to 361 mg/l and averaged 301 mg/l, and the noncarbonate hardness, from 55 to 166 mg/l and averaged 102 mg/l.

Ground water in the study area would be considered hard by almost any standard. Treatment is necessary for boiler use and is desirable for most other uses. The widespread use of detergents, however, has in many localities eliminated the need for softening the water used for laundering. The lime-soda method of treatment is used by the Hamilton water system to reduce the total hardness to about 100 mg/l. Most other public water-supply systems in the area do not soften their water, and most of the small installations that do soften water use the ion-exchange or zeolite method, whereby the calcium and magnesium ions are exchanged for sodium ions.

Specific conductance

The conductance of a solution (its ability to conduct an electrical current) generally is directly related to its dissolved-solids content. Conductance is the reciprocal of resistance and is measured in mhos, the reciprocal of ohms. As the conductance of all natural water is well below 1 mho, it is measured in micromhos (mhos $\times 10^{-6}$). In water analyses by the U.S. Geological Survey, the specific conductance is reported as micromhos at 25°C (Hem, 1959, p. 38).

Although specific conductance is not always related to the dissolved-solids content of water, it can be used to estimate such content. In the ground-water samples from the lower Great Miami River valley, specific conductance ranged from 550 to 1,510 micromhos and averaged 708 micromhos. The specific conductance of water from glacial-outwash aquifers in the study area generally is about 1.5–2 times the dissolved-solids content.

Specific conductance of the surface-water samples ranged from 382 to 958 micromhos and averaged 719 micromhos. In general, the higher specific conductances occur during periods of low flow.

pH

The pH value (the negative logarithm of the hydrogen-ion concentration) is a measure of the acidity or alkalinity of a solution. A pH value of 7.0 denotes a neutral solution; a value less than 7.0, an acid solution; and one greater than 7.0, an alkaline solution. The pH of ground-water samples from the area of investigation ranged from 7.0 to 7.7, values which reflect generally alkaline conditions. The pH of the selected surface-water samples ranged from 6.8 to 7.8.

Color

Color refers to the appearance of water that is free from suspended solids. It is determined from the comparison of the water sample with the U.S. Geological Survey's arbitrary standard which consists of a series of colored glass discs that have been calibrated to units of the platinum-cobalt scale of Hazen. Most color in natural water is due to the presence of organic matter. In the ground-water samples from the study area, color ranged from 0 to 12 color units and averaged 3 color units. These values are insignificant for most uses of water and cannot be detected by the unaided eye. For the surface-water samples, however, the color ranged from 1 to 40 color units and averaged about 12 color units.

Dissolved oxygen

Ground water generally does not contain dissolved oxygen, but uncontaminated stream water invariable contains as much as 10 mg/l of oxygen dissolved from the atmosphere. Under normal stream conditions, at least 5 mg/l of dissolved oxygen is necessary to sustain a varied fish fauna in good condition. Data on dissolved oxygen in the eight selected samples given in table 9 ranged from 1.8 to 10.4 mg/l, and the percentage of saturation ranged from 14 to 87 percent. The reach of the Great Miami River between Miamisburg and Middletown has become so badly polluted that the dissolved-oxygen content in this part of the stream is usually deficient at low streamflow. South of Middletown, however, stream conditions appear to be more favorable.

CONCLUSIONS

The lower Great Miami River valley is favored with the most abundant reservoir of ground water in Ohio. Although this aquifer system has already been extensively developed, the supply should be adequate in both quantity and quality to meet all anticipated requirements for several decades.

The most favorable environments for development of large ground-water supplies are those where the sand and gravel aquifer is close enough to the Great Miami River, or to another major stream, that pumpage from wells is sustained by induced recharge from the stream. In these environments, individual wells are capable of yielding as much as 3,000 gpm. Even aquifers less than 150 feet thick or containing areally extensive clay layers can provide large ground-water supplies if wells are spaced, developed, and screened suitably.

The valley-train deposits along the entire reach of the Great Miami River in the study area are generally in these favorable hydrogeologic environments. Also, in the study area, areally extensive clay layers are present from Middletown north but are absent south of Middletown. The most favorable areas for the development of new ground-water supplies (pls. 1, 2) are as follows: The Trenton area, the reach of the Great Miami River valley from New Miami through Hamilton and that from Fairfield to New Baltimore, and the part of lower Whitewater River valley between Harrison and the Ohio River.

Hydrogeologic environments less favorable for development of large ground-water supplies are those where induced stream recharge is not available or where the sand and gravel aquifer is overlain by a semiconfining clay layer. Despite lack of available stream recharge, the vast storage capacity of the aquifer in these areas should make development of moderately large ground-water supplies possible. Many individual wells yield 500 gpm, and some wells in these environments yield more than 1,000 gpm. Where clay layers are present, both the location and the spacing of wells must be carefully planned because of the wide variation in characteristics and thickness of individual clay layers. The chief examples of these hydrogeologic environments are in the now-abandoned troughs carved by the ancestral Great Miami River between West Carrollton and Carlisle, between Trenton and New Miami, and between a point west of Ross and Harrison.

The least favorable areas for the development of large ground-water supplies are in tributary buried valleys filled largely or wholly with clay, and in the uplands where shale bedrock is overlain by 50 feet or less of clay-rich till. Many wells drilled in these environments are failures; others may yield 5 to 10 gpm, which is adequate for domestic water supplies.

The Great Miami River, the major stream of the area, has a high base flow and generally is an adequate source of induced recharge to the aquifer. The discharge equaled or exceeded 90 percent of the time for Great Miami River at Hamilton, based on the adjusted period 1921–45, is 490 cfs, or 316 mgd—nearly three times the total ground-water pumpage in 1964 in the study area.

Most of the area's large ground-water withdrawals have not caused overdraft of the aquifer. The water level in the area is generally 15–50 feet below the land surface; it fluctuates 5–15 feet annually. Minor cones of depression which developed around the pumping centers have apparently become stabilized. An exception is in the southeastern part of Middletown, where pumping 8–11 mgd at the Armco East Works has caused a fairly continuous lowering of the water level and formation of the only major cone of depression in the study area. Apparently, pumping more than 8 mgd causes dewatering of the aquifer.

The quality of ground water in the lower Great Miami River valley is generally good. Natural water in the study area is of a calcium bicarbonate type, which reflects the abundance of calcareous materials in both the bedrock and the alluvial deposits. The total dissolved-solids content of ground water is typically 400–500 mg/l. In hydrogeologic environment with abundant clay, some wells have a high iron content.

A few ground-water supplies that receive induced recharge from the Great Miami River have become slightly contaminated, as indicated by small amounts of phenols and "hard" detergents (ABS), two constituents which do not occur in natural water. Ground-water contamination has not yet become a serious problem in the Great Miami River valley. However, concentrations of contaminants should be periodically checked in wells which are known to have been slightly contaminated, so that corrective measures can be taken before the contamination becomes too great.

Total pumpage of ground water in the area was about 110 mgd in 1964. The pumping rate has approximately doubled since the beginning of World War II and is expected to have again doubled by the year 2000. Most of this pumping is concentrated in and around the area's large cities, especially Hamilton and Middletown. Many favorable areas for development between the cities remain untapped.

The ground-water system of the lower Great Miami River valley should be able to meet all the expected demands on it until the year 2000 and then continue to be an adequate source of supply for many more years, provided that future sources of supply are intelligently planned and are located in favorable hydrogeologic environments, away from the cones of influence of existing sources. Deterioration of water quality will ultimately set the limit on development of this resource. Most water pumped from the aquifers is returned (near the source of supply) to a stream hydraulically connected with these aquifers. Therefore, probably no significant depletion of streamflow nor resultant reduction in the rate of infiltration would occur because of increased pumping. Hence, water can be recycled through the system as many times as necessary. As long as the quality of water in the streams remains adequate, further beneficial development of the ground-water resource is possible. If the water recharging the aquifers were to become generally contaminated, however, the aquifers would no longer be desirable sources of water. Accordingly, man's ability to maintain adequate water quality will determine the extent to which this aquifer system can be developed.

TABLE 10.—*Records of selected wells in the lower Great Miami River valley, Ohio*

Well number: See p. A3 for description of numbering system.
Type of aquifer material: Sand and gravel.
Geologic horizon of aquifer: Pleistocene.

Type of well: Drilled.
Use: D, domestic; Ind, industrial; O, observation; PS, public supply; T, test.
Remarks: CA, chemical analysis avaliable.

Well No. (this report)	Owner	Location	Owner's well designation	Altitude (ft above mean sea level)	Date drilled	Depth (ft)	Water level		Yield		Diameter of well (in.)	Use	Remarks
							Depth (ft)	Date	Rate (gpm)	Drawdown (ft)			
1	Schell Dairy	State Route 4 at Farmersville and West Carrolton Road.	--------	730	7-15-49	74	6	7-15-49	50	10	8	Ind	
2	Russel Lakes	West of Miamisburg	--------	764	3-29-57	95	44	3-29-57	60	10	6	D	
3	Miami Paper Co	Miamisburg	--------	700	10- -46	122	24	--------	--------	--------	16	Ind	
4	City of Miamisburg	do	8	690	7- 9-55	94	14	--------	1,000	--------	26	PS	
5	Gertrude Snyder	North of Carlisle	--------	760	4-12-57	110	60	--------	30	--------	6	D	
6	Ermon Pearson	do	--------	800	6-13-62	132	112	--------	10	8	6	D	
7	Dayton Power & Light Co. O. H. Hutchings Station.	Chautauqua	1	690	1- -49	540	16	8- 1-47	1,600	3.5	38	Ind	
8	Do	do	2	690	10- -47	150	--------	--------	--------	--------	38	Ind	
9	Do	do	3	692	8-22-47	153	--------	--------	--------	--------	38	Ind	CA.
10	Do	do	4	690	9-17-47	153	18	9-17-47	1,600	5	38	Ind	
11	Do	do	5	690	7-19-49	177	26	--------	--------	--------	38	Ind	
12	Do	do	6	690	--------	--------	--------	--------	--------	--------	38	Ind	
13	Joe Florence	Carlisle	--------	705	1- 3-57	80	--------	--------	30	8	6	D	
14	Eugene Slaton	do	--------	685	9-11-58	42	14	9-8-58	50	--------	6	D	
15	Woodall Industries	Franklin	--------	675	5-15-57	82	15	--------	170	3.6	8	Ind	
16	City of Middletown	Middletown	TW-2	640	--------	--------	--------	--------	--------	--------	6	T	
17	Do	do	6	640	--------	--------	--------	--------	--------	--------	26	PS	CA.
18	Do	do	3	642	9-12-34	165	21	--------	2,000	--------	26	PS	
19	Do	do	9	640	--------	--------	--------	--------	--------	--------	26	PS	
20	Do	do	--------	640	--------	50-60	--------	--------	1,500	--------	8	PS	CA. Bank of 16 shallow wells.
21	Gardner Park	do	--------	670	1- -42	96	--------	--------	--------	--------	6	D	
22	Armco Steel Corporation East Works.	Southeast of Middleton	32	670	1-15-59	257	--------	--------	--------	--------	26	Ind	CA.
23	Do	do	30	670	12-21-54	253	149	--------	2,300	6	26	Ind	CA.
24	Do	do	23	670	--------	261	110	3-21-49	--------	--------	26	Ind	CA.
25	Do	do	35	670	1964	226	90	10- 2-64	--------	--------	26	Ind	CA.
26	Do	do	T-18	670	6- -40	262	98	--------	--------	--------	6	T	
27	Do	do	T-36	665	--------	218	43	--------	--------	--------	6	T	
28	Do	do	T-38	651	--------	203	4	--------	--------	--------	6	T	
29	Do	do	T-39	653	--------	226	5	--------	--------	--------	6	T	
30	Do	do	T-37	662	--------	195	5	--------	--------	--------	6	T	
31	Do	do	--------	681	--------	--------	--------	--------	--------	--------	6	O	"Union well."
32	Trenton Village	Trenton	2	646	--------	86	34.56	1-24-56	--------	--------	8	PS	
33	Arthur Richter	do	--------	665	--------	69	47.60	6-16-55	--------	--------	6	D	
34	Village of Trenton	do	3	645	--------	75	18	--------	600	3	12	PS	
35	Humane Association of Miami Valley.	Southwest of Trenton	--------	646	--------	38	28.20	6-13-55	--------	--------	6	D	Unused.
36	Fred Martin	South of Trenton	--------	632	--------	50	17.09	6-14-55	--------	--------	6	D	
37	Hubert Lee	Woodsdale	--------	617	--------	55	15.34	5-27-55	--------	--------	6	D	
38	Cortland Thompson	do	--------	615	--------	40	14.64	5-31-55	--------	--------	6	D	
39	C. A. Kumler	Seven Mile	--------	652	--------	50	21.94	4-29-55	--------	--------	6	D	
40	Hickory Flat Church	Northeast of Overpeck	--------	638	--------	41	25.06	4-12-55	--------	--------	7	D	CA.
41	L. Angst	North of New Miami	--------	636	--------	53	33.15	4-14-55	--------	--------	6	D	
42	Robt. Schallip	do	--------	622	--------	33	28.29	4-13-55	--------	--------	36	None	Dug.
43	Armco Steel Corp	New Miami	2	600	--------	180	33	8-19-49	1,900	45	26	Ind	CA.
44	City of Hamilton	Hamilton North well field	5	590	--------	--------	--------	--------	--------	--------	26	PS	CA.
45	Champion Paper Co	Hamilton	10	590	7-26-56	120	50	7-20-56	1,500	20	26	Ind	CA.
46	Champion Paper & FiberCo.	do	4	593	--------	--------	125.5	6- -39	--------	--------	26	Ind	CA.
47	City of Hamilton	do	B-39	593	2-23-43	205	30.10	3-30-43	--------	--------	6	O, T	See Klaer and Kazmann (1943) for description.
48	Do	do	B-38	600	2-10-43	205	38.30	3-30-43	--------	--------	6	O, T	Do.
49	Esther Spinelli	do	B-37	610	4- 5-43	75	45.97	4-27-43	--------	--------	6	O, T	Do.
50	Baltimore & Ohio RR	do	B-35	596	5-18-43	191	33.43	6-10-43	--------	--------	6	O, T	Do.
51	Do	do	B-28	602	6- 8-43	172	41.92	6-24-43	--------	--------	6	O, T	Do.
52	Fred Bantel	do	B-11	612	--------	247	43.15	7- 6-42	--------	--------	6	O, T	Do.
53	City of Hamilton	Hamilton South well field	F-8	570	4-15-43	170	--------	--------	1,700	5.4	38	PS	Do.
54	Do	do	--------	580	--------	--------	--------	--------	--------	--------	6	O	
55	Do	do	F-11	584	1- 3-43	202	--------	--------	1,660	6.5	38	PS	Do.
56	Federal Works Agency	do	1-U-4	562	11-25-42	165	16.55	1- 7-43	--------	--------	6	O,T	Do.
57	City of Hamilton	do	F-4	571	2- 2-43	170	--------	--------	1,500	6.4	38	PS, O	Do.
58	Pauline Benninghofen	do	B-8	557	--------	178	--------	--------	--------	--------	6	T	
59	City of Hamilton	do	F-3	557	3-25-43	169	--------	--------	1,800	5.9	38	PS, O	Do.
60	Joseph N. Conrad	do	B-22	563	6-23-43	197	18.60	7- 5-43	--------	--------	6	O, T	Do.
61	City of Hamilton	do	F-2	563	3-10-43	202	--------	--------	1,610	5.3	38	PS	CA.
62	City of Cincinnati	West of Fairfield	12	550	5-18-62	173	12.6	--------	--------	--------	6	T	
63	Do	do	10	550	6-26-62	134	12	6-26-62	3,000	35	24	T	CA.

TABLE 10.—*Records of selected wells in the lower Great Miami River valley, Ohio*—Continued

Well No. (this report)	Owner	Location	Owner's well designation	Altitude (ft above mean sea level)	Date drilled	Depth (ft)	Water level		Yield		Diameter of well (in.)	Use	Remarks
							Depth (ft)	Date	Rate (gpm)	Drawdown (ft)			
64	Southwestern Ohio Water Co.	Near Ross	O-3	555			34.44	10-13-64			6	O, T	
65	Do	do	O-1	549		185	27.42	10-13-64			6	O, T	
66	Do	do	LB-1	545			23.55	10-13 64			6	O, T	
67	Do	do	WK-1	546		121	24.25	10-13-64			6	O, T	
68	Do	do	EL-1	538			18.98	10-13-64			6	O, T	
69	Do	do	ER-1	538			16.36	10-13-64			6	O, T	
70	Do	do	B-3	536		171	16.03	10-13-64			6	O, T	
71	Do	do	B-2	539		174	19.95	10-13-64			6	O, T	
72	Do	do	B-1	543		165	25.32	10-13-64			6	O, T	
73	Do	do	2	550	1955	140					13 ft	Ind	CA. Horizontal collector.
74	Do	do	K-1	541		120	25.37	10-13-64			6	O, T	
75	Do	do	R-5	535			19.99	10-13-64			6	O, T	
76	Do	do	R-1	549		154	31.30	10-13-64			6	O, T	
77	Do	do	1	550	1952	144					20 ft	Ind	CA.
78	Do	do	L-1	538			19.45	10-13-64			6	O, T	
79	Do	do	O-2E	537		200	17.96	10-13-64			6	O, T	
80	Do	do	C-2	524			6.27	10-13-64			2	O	Driven.
81	Do	do	C-1	525		100	8.48	10-13-64			2	O	Do.
82	Raymond Irwin	Near Fernald		575	7-14-48	93	63.5	7-14-48			6	D	
83	U.S. Atomic Energy Comm	do	TW-3	565							6	O, T	
84	Do	do	TW-1	592							6	O, T	
85	Do	do		590		140	64	7-17-51	150		6	PS, O	Old Administration Building well.
86	Do	do	1	579	8-24-51	210	58.15	10-15-64	715		26	Ind	
87	Do	do	2	580	9-13-51	210	59.3	10-15-65	700		26	Ind	CA.
88	Do	do	3	579	10-11-51	210	54		715		26	Ind	
89	Nease Chemical Co	Fernald		525	2-16-59	96	8	2-16-59	250	12	10	Ind	
90	John Emmert	West of Fernald		605	3- 1-60	112	83				5	D	
91	Nu Maid Farms	North of New Haven		575	3-13-54	110	49		850	19	12	Ind	
92	Do	West of New Haven		605	6-20-54	142	78				8	Ind	
93	Milton Knollman	do		585	8-29-52	99	60.5				5	D	
94	Paul Wiwi	do		572	8-31-60	147	51.6				5	D	
95	Orlik's Department Store	Harrison		522	10- 1-52	70	28.6	10- 1-52			5	PS	
96	Paul Wiwi	East of Harrison		585	5- 2-59	111	62.6	5- 2-59			5	D	
97	Walter F. Corson	Southeast of Harrison		582	8-28-54	100	73	8-28-54			5	D	
98	Bommer Builders, Inc	do		584		91	71.8	3-11-55			5	D	
99	Harrison Sand & Gravel	do		515	12-16-56	93	24	12-16-56	1,025	22	12	D	
100	Paul Wiwi	do		575		95	74	12- 4-60			5	D	
101	George T. Weber	do		522		110	33	5-19-48	150	20	8	D	
102	Gulf Refining Co	Near Cleves	3	493		87	19		1,500		26	Ind	
103	Do	do	6	493							26	Ind	
104	Do	do	10	493	10-18-57	78	19		1,500		26	Ind	
105	E. I. Dupont de Nemours Co.	West of North Bend	38	490	1955	125			500		26	Ind	CA.

SELECTED REFERENCES

Bernhagen, R. J., and Schaefer, E. J., 1947, Ground-water conditions in Butler and Hamilton Counties, Ohio, 1946: Ohio Water Resources Board Bull. 8, 35 p.

Caster, K. E., Dalve, E. A., and Pope, J. K., 1955, Elementary guide to the fossils and strata of the Ordovician in the vicinity of Cincinnati, Ohio: Cincinnati Museum Nat. History, 47 p.

Cross, W. P., and Hedges, R. E., 1959, Flow duration of Ohio streams: Ohio Div. Water Bull. 31, 152 p.

Cummins, J. W., 1959, Buried river valleys in Ohio: Ohio Div. Water Inv. Plan Rept. 10, 3 p.

Dove, G. D., 1961, A hydrologic study of the valley-fill deposits in the Venice area, Ohio: Ohio Div. Water Tech, Rept. 4, 82 p.

Durrell, R. H., 1956, Illinoian boundary in southwestern Ohio and northern Kentucky [abs.]: Geol. Soc. America Bull., v. 67, p. 1751.

——— 1961, The Pleistocene geology of the Cincinnati area, *in* Pleistocene geology of the Cincinnati region [Kentucky, Ohio and Indiana]: Geol. Soc. America Guidebook Ser., Cincinnati mtg., 1961, p. 47–57.

Fenneman, N. M., 1916, The geology of Cincinnati and vicinity: Ohio Geol. Survey Bull. 9, 207 p.

——— 1938, Physiography of Eastern United States: New York, McGraw-Hill Book Co., 714 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water Supply Paper 1536–E, p. 69–174.

Forsyth, J. L., 1961, Wisconsin glacial deposits, *in* Pleistocene geology of the Cincinnati region [Kentucky, Ohio and Indiana]: Geol. Soc. America Guidebook Ser., Cincinnati mtg., 1961, p. 58–106.

Fuller, M. L., and Clapp, F. G., 1912, The underground waters of southwestern Ohio, with a discussion of the chemical character of the waters, by R. B. Dole: U.S. Geol. Survey Water Supply Paper 259, 228 p.

Goldthwait, R. P., White, G. W., and Forsyth, J. L., 1961, Map of the glacial deposits of Ohio: U.S. Geol. Survey Miscel. Geol. Inv. Ser. Map I–316.

Hanson, J. R., 1965, Ohio's secret substance: Ground Water, v. 3, no. 2, April, p. 28–31.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water Supply Paper 1473, 269 p.

Hubble, J. H., and Collier, C. R., 1960, Quality of surface water in Ohio 1946–58: Ohio Div. Water Inv. Plan Rept. 14, 317 p.

Kaser, Paul, and Harstine, L. J., 1965, Ground-water levels in Ohio, October 1959–September 1964: Ohio Div. Water Bull. 41, 133 p.

Klaer, F. H., Jr., and Kazmann, R. G., 1943, A quantitative study of the well field of the Mill Creek Valley water-supply project, Butler County, Ohio: U.S. Geol. Survey open-file report.

Klaer, F. H., Jr., and Thompson, D. G., 1948, Ground-water resources of the Cincinnati area, Bulter and Hamilton Counties, Ohio: U.S. Geol. Survey Water Supply Paper 999, 168 p.

LeGrand, H. E., 1965, Environmental framework of ground-water contamination: Ground Water, v. 3, no. 2, April, p. 11–15.

Leopold, L. B., and Langbein, W. B., 1960, A primer on water: Special publication, U.S. Geol. Survey, 50 p.

Leverett, Frank, 1902, Glacial formations and drainage features of the Erie and Ohio Basins: U.S. Geol. Survey Mon. 41, 802 p.

Love, S. K., and others, 1964, Quality of surface waters of the United States, 1962, Parts 3 and 4, Ohio River basin and St. Lawrence River basin: U.S. Geol. Survey Water Supply Paper 1942, 322 p.

Morgan, A. E., 1951, The Miami Conservancy District: New York, McGraw-Hill Book Co., 504 p.

Norris, S. E., 1959, Vertical leakage through till as a source of recharge to a buried valley aquifer at Dayton, Ohio: Ohio Div. Water Tech. Rept. 2, 16 p.

Norris, S. E. Cross, W. P., and Goldthwait, R. P., 1948, The water resources of Montgomery County, Ohio: Ohio Div. Water Bull. 12, 83 p.

Norris, S. E., and Spieker, A. M., 1962, Temperature-depth relations in wells as indicators of semiconfining beds in valley-train aquifers (*in* Short papers in geology, hydrology and topography 1962): U.S. Geol. Survey Prof. Paper 450–B, p. B103–B105.

——— 1966, Ground-water resources of the Dayton area, Ohio: U.S. Geol. Survey Water Supply Paper 1808, 167 p.

Ohio Division of Water, 1961, Preliminary study of the ground-water resources of a portion of the Miami River valley: Ohio Div. Water open-file report UP–14, 30 p.

Pierce, L. T., 1959, The occurrence of freezing temperatures in late spring and early fall: Ohio Agricultural Experiment Station Special Circular 94, Wooster, Ohio, 16 p., 33 figs.

Ray, L. L., 1966, Pre-Wisconsin glacial deposits in northern Kentucky *in* Geological Survey research: U.S. Geol. Survey Prof. Paper 550–B, p. B91–B94.

Rorabaugh, M. I., 1956, Ground water in northeastern Louisville, Kentucky, with reference to induced infiltration: U.S. Geol. Survey Water Supply Paper 1360–B, p. 101–169.

Schmidt, J. J., 1959, Underground water resources [of] Mill Creek basin and adjacent Ohio River tributaries: Ohio Div. Water Inv. Plan Rept., file-index J [Map and cross section, with brief explanatory text].

Shoecraft, E. C., Drury, W. R., and McNamee, R. L., 1942, Report upon water supply for municipalities and industries in the Mill Creek valley and vicinity: Consulting Engineers to Ohio Water Supply Board, August, 94 p.

——— 1943, Report on water resources of the American Rolling Mill Company, Middletown, Ohio: Consulting Engineers to Ohio River Water Supply Board, April, 76 p.

Spieker, A. M., 1961, A guide to the hydrogeology of the Mill Creek and Miami River valleys, Ohio, with a section on the geomorphology of the Cincinnati area, by Richard H. Durrell: Geol. Soc. America Guidebook Ser., Cincinnati mtg., 1961, p. 217–251.

——— 1968a, Effect of increased pumping of ground water in the Fairfield-New Baltimore area, Ohio—a prediction by analog model study: U.S. Geol. Survey Prof. Paper 605–C, 34 p.

——— 1968b, Future development of the ground-water resource in the lower Great Miami River valley, Ohio: problems and alternative solutions: U.S. Geol. Survey Prof. Paper 605–D, 15 p.

Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., 1943 Geology of water in Ohio: Ohio Geol. Survey Bull. 44, 694 p.

U.S. Public Health Service, 1962, Drinking-water standards: U.S. Dept. Health, Education, and Welfare, Public Health Service, Pub. 956.

Walker, A. C., 1960a, Underground water resources [of] Miami River basin [lower middle part]: Ohio Div. Water Inv. Plan Rept., file-index H–9 [map and cross section, with brief explanatory text].

———1960b, Underground water resources [of Miami River basin [lower part]: Ohio Div. Water Inv. Plan Rept., file-index H–11 [map and cross section, with brief explanatory text].

———1960c, Underground water resources [of] Miami River basin [showing some of middle part] and lower Mad River basin: Ohio Div. Water Inv. Plan Rept., file-index H–4 and H–5 [maps and cross sections, with brief explanatory text].

Watkins, J. S., 1963, Refraction seismic studies in the Miami River, Whitewater River, and Mill Creek valleys, Hamilton and Butler Counties, Ohio: U.S. Geol. Survey open-file report, 9 p.

Watkins, J. S., and Spieker, A. M., 1964, Seismic refraction survey in the Great Miami River valley and vicinity, Montgomery, Warren, and Butler Counties, Ohio: U.S. Geol. Survey open-file report, 6 p.

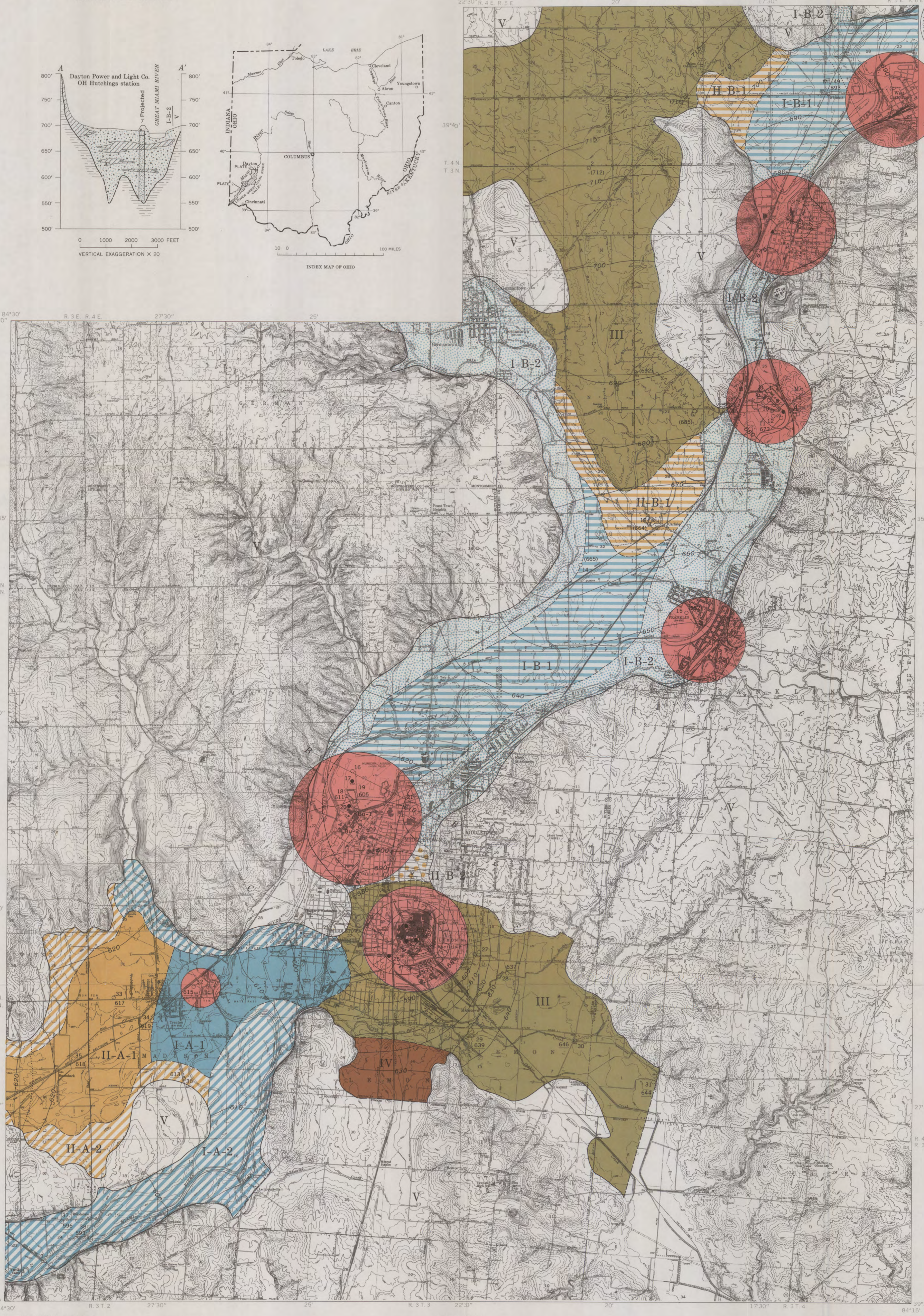
———1968, Seismic refraction surveys of Pleistocene drainage channels in the lower Great Miami River valley, Ohio: U.S. Geol. Survey Prof. Paper 605–B (in press).

Weiss, M. P., and Norman, C. E., 1960, Development of stratigraphic classification of Ordovician rocks in the Cincinnati region, pt II *of* The American Upper Ordovician Standard: Ohio Geol. Survey Information Circ. 26, 14 p. and correlation chart.

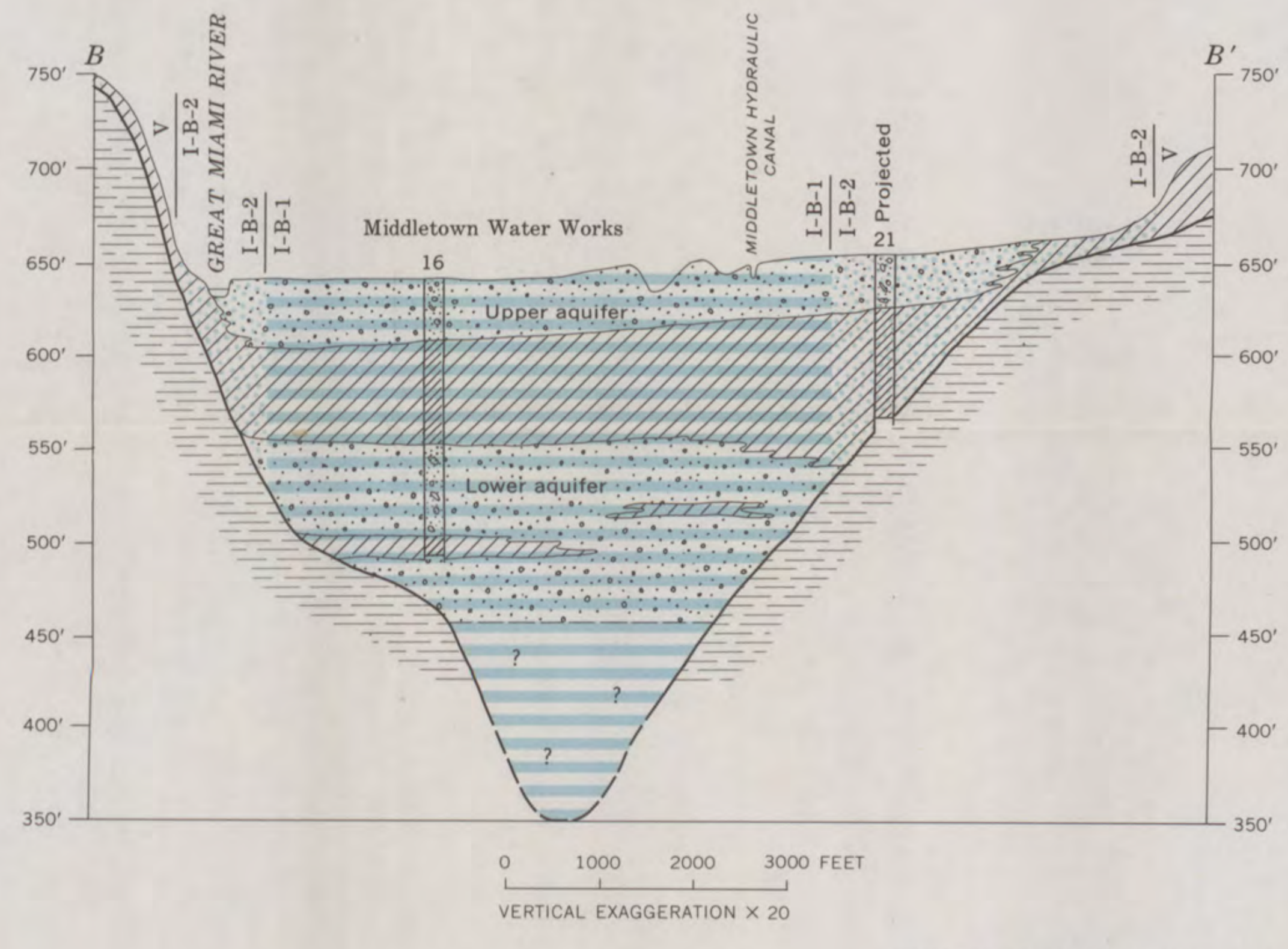
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

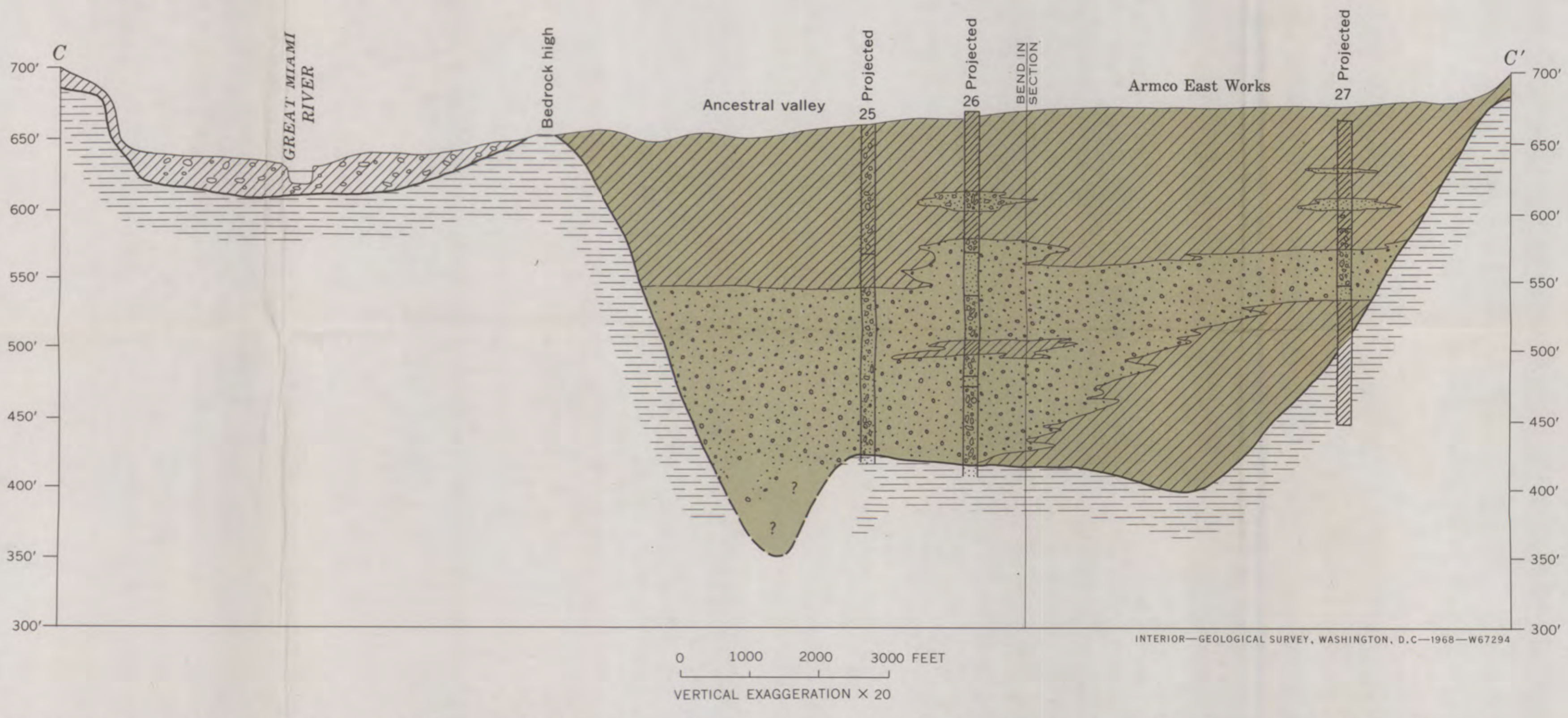
PREPARED IN COOPERATION WITH THE
MIAMI CONSERVANCY DISTRICT
AND THE
OHIO DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER

PROFESSIONAL PAPER 605–A
PLATE 1



Hydrogeology by Andrew M. Spieker





INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C—1968—W67294

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

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 wells can yield 100-500 gpm

II-B-2

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

III

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

IV

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

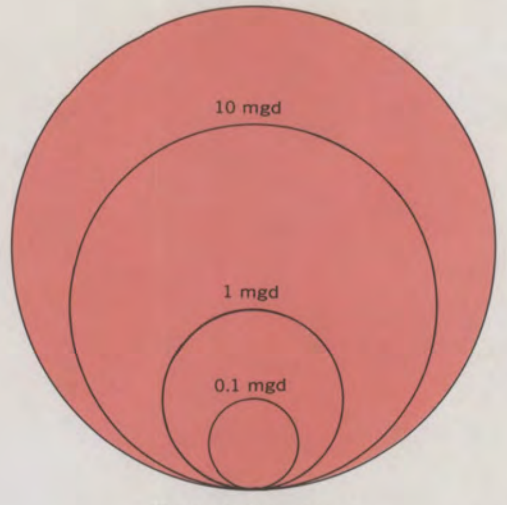
△1
Stream-sampling station and number
(See table 9)

▲
Stream-gaging station

Boundary of buried valley

Arbitrary limit of area of investigation

Ground-water divide



Scale of diameters

Size of circle indicates magnitude and distribution of ground-water pumpage, in millions of gallons per day

SECTIONS

Soil

Till

Sand

Fine sand and silt

Sand and gravel

Dirty sand and gravel

Poorly stratified gravel mixed with till

Clay and till

Clay
Weathered bedrock in section E-E'

Bedrock
Shale in sections E-E' and F-F'
Shale and thin interbedded limestone in remaining section

△
Seismic depth determination

Boundary of buried valley
Dashed where approximately located

——?——
Lithologic boundary
Dashed where approximately located; queried where doubtful

HYDROGEOLOGIC MAP AND SECTIONS OF THE LOWER GREAT MIAMI RIVER VALLEY FROM WEST CARROLLTON TO NEAR WOODSDALE, SOUTHWESTERN OHIO

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MIAMI CONSERVANCY DISTRICT
AND THE
OHIO DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER

PROFESSIONAL PAPER 605-A
PLATE 2

Hydrogeology by Andrew M. Spieker

SEE PLATE 1
FOR EXPLANATION

Base from U.S. Geological Survey
Shandon, 1955 and Hamilton NE, 1955

HYDROGEOLOGIC MAP AND SECTIONS OF THE LOWER GREAT MIAMI RIVER VALLEY FROM NEW MIAMI TO NEAR ELIZABETHTOWN, SOUTHWESTERN OHIO