Hydrology of Upper Black Earth Creek Basin Wisconsin

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-C

Prepared in cooperation with the Wisconsin Geological and Natural History Survey

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By DENZEL R. CLINE

With a section on SURFACE WATER
By MARK W. BUSBY

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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HYDROLOGY OF UPPER BLACK EARTH CREEK BASIN, WISCONSIN

By Denzel R. Cline

ABSTRACT

The upper Black Earth Creek drainage basin has an area of 46 square miles and is in Dane County in south-central Wisconsin. The oldest rock exposed in the valley walls is the sandstone of Late Cambrian age. Dolomite of the Prairie du Chien Group of Ordovician age overlies the sandstone and forms the resistant cap on the hills. The St. Peter Sandstone, Platteville and Decorah Formations, and Galena Dolomite, all Ordovician in age, form a narrow belt along the southern boundary of the area. Outwash and alluvium of Pleistocene and Recent age fill the valleys. The eastern half of the area was glaciated and is covered with till.

The sandstone of Late Cambrian age and the sand and gravel of the outwash deposits are hydraulically connected. Ground water occurs under unconfined (water-table) conditions in the western unglaciated part of the basin and under artesian conditions beneath the till locally in the eastern part.

The source of most of the ground water is direct infiltration of precipitation; however, some ground water enters the area as underflow from the south. About 7 inches of the 30 inches of average annual precipitation recharges the ground-water reservoir. The ground water generally moves toward Black Earth Creek where it is discharged. Some ground water moves out of the basin as underflow beneath the valley of Black Earth Creek, and some is discharged by evapotranspiration or is withdrawn by pumping from wells.

Water levels in shallow nonartesian wells respond rapidly to precipitation. The effect of precipitation on water levels in artesian wells is slower and more subdued. Water levels are generally highest in spring and lowest in fall and winter.

The flow of upper Black Earth Creek is derived mostly from ground-water discharge, except during short periods of and immediately after precipitation when most of the flow is derived from surface runoff.

The runoff from upper Black Earth Creek basin decreased from an average of 8.72 inches per square mile of drainage area in 1955 to 5.55 inches in 1958; the decrease reflects the generally decreasing precipitation and declining water levels in the basin during that period. On July 10, 1958, the discharge from the basin was 0.367 cubic feet per second per square mile, and the greatest discharge was 0.84 cubic feet per second per square mile from the southwest subbasin.

The ground water has an average temperature of about 50°F. It is a calcium magnesium bicarbonate type water and is very hard.

INTRODUCTION

PURPOSE AND SCOPE

This report describes the relationships of the geology to the source, occurrence, and movement of ground water and the general relationships between ground water, surface water, and precipitation in the upper Black Earth Creek drainage basin, a small area in south-central Wisconsin. The eastern boundary of the basin is about 2 miles from the western limits of the city of Madison (pl. 1). The study of the upper Black Earth Creek basin was made by the U.S. Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey as part of a detailed investigation of the geology and ground-water resources of Dane County. The investigation was made under the immediate supervision of C. L. R. Holt, Jr., district geologist in charge of ground-water investigations in Wisconsin.

PREVIOUS INVESTIGATIONS

Weidman and Schultz (1915) described briefly the geology and the ground-water supplies of Dane County. Alden (1918) described in more detail the Quaternary geology and the older rock formations in the area. The physical geography of the area was described in detail by Martin (1932). The bedrock geology of the area is shown on the geologic map of Wisconsin (Bean, 1949). In 1934, B. W. Meek reported on the geology of the area for a Bachelor of Arts thesis, University of Wisconsin.

METHODS OF INVESTIGATION

The investigation of the upper Black Earth Creek basin was begun in March 1958 and completed in September 1958. Information obtained on selected wells in the upper Black Earth Creek basin included the location, altitude, depth, depth to water, depth and diameter of casing, geologic source of water, and use. Periodic water-level measurements were made in 10 wells; recording gages were installed on 2 wells, and samples of water for chemical analysis were collected from 6 wells. Samples of till, outwash, and alluvium were collected for particle-size analysis. The geologic maps were modified from existing maps through the use of well-log data and field observations.

A water-stage recorder was installed in 1954 on Black Earth Creek at Black Earth by the Surface Water Branch of the U.S. Geological Survey in cooperation with the Wisconsin Conservation Department.

Sediment samples and data on the temperature of Black Earth Creek have been collected at the site of the stream gage since 1954.

The location of the wells, stream gage, stream-discharge measurement sites, and sampling sites are shown on plate 1.

PHYSIOGRAPHY

The term "upper Black Earth Creek basin," as used in this report, refers to an irregularly shaped area of about 46 square miles, upstream from a stream gage 0.7 mile east of the village of Black Earth in northwestern Dane County, Wis. (pl. 1). An area of 2 square miles between the gage and the village was included on the maps because of the valuable information provided by the two wells in the village. Black Earth Creek flows into Mounds Creek about 6 miles west of Black Earth, and Mounds Creek empties into the Wisconsin River. Black Earth Creek is about 24 miles long and has an average gradient of 8.3 feet per mile. The upper part of the creek is about 12½ miles long from the gage to the divide and has an average gradient of 10.4 feet per mile.

The upper Black Earth Creek basin is hilly and has a maximum relief of about 430 feet (pl. 2). Steep-sided valleys have been cut into the upland. The slopes are steeper in the western unglaciated part of the area than in the eastern glaciated part. The tributary valleys in the western part are V-shaped and in the eastern part are U-shaped. Between the villages of Cross Plains and Black Earth the floor of the main valley of Black Earth Creek is nearly flat and about half a mile wide.

The drainage pattern of the area is rectangular; that is, the valleys generally trend northwestward and northeastward. The orientation of the stream pattern is controlled by the major jointing in the region.

CLIMATE

The precipitation and temperature data included in this report were collected by the U.S. Weather Bureau at Truax Field, Madison, Wis., about 20 miles east of the village of Black Earth.

The average monthly precipitation for 1921–50 and the monthly precipitation for 1958 are given in table 1. The precipitation in 1958 was 8.91 inches below the long-term average of 30.00 inches. The cumulative departure from the normal monthly precipitation from January 1957 to September 1958 is shown in figure 1. The graph shows a general downward trend after August 1957.

The average monthly and annual air temperature for 1921–50 and the average monthly air temperature for 1958 are given in table 1. The average annual temperature is 46.6° F. The average monthly air temperature in 1958 approximated the long-term average.

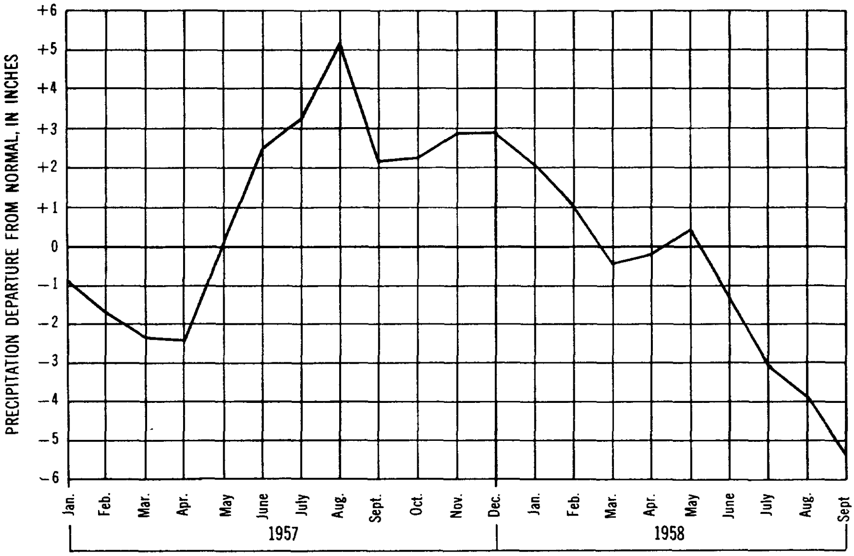

FIGURE 1.—Cumulative departure from normal monthly precipitation at Truax Field, Madison, Wis., January 1957 to September 1958.

TABLE 1.—*Average monthly precipitation and temperature, 1921–50, and monthly precipitation and temperature for 1958 at Truax Field, Madison, Wis.*

Month	Precipitation (inches)		Temperature (° F)	
	Average for 1921–50	1958	Average for 1921–50	1958
January	1. 31	0. 52	19. 1	20. 9
February	1. 13	. 08	21. 9	17. 0
March	1. 83	. 38	32. 5	34. 0
April	2. 49	2. 73	45. 7	46. 8
May	3. 27	3. 93	57. 5	58. 4
June	4. 02	2. 16	67. 4	62. 7
July	3. 30	1. 69	73. 0	69. 4
August	2. 89	2. 06	70. 7	71. 1
September	3. 99	2. 44	62. 1	61. 5
October	2. 08	2. 50	50. 4	52. 8
November	2. 29	2. 29	35. 3	37. 6
December	1. 40	. 31	23. 0	16. 4
Year	30. 00	21. 09	46. 6	45. 7

WELL-NUMBERING SYSTEM

A system of letters and numbers is used to designate a well in Wisconsin. The letter designation is derived from the name of the county in which the well is located; for example, the prefix Dn indicates the well is in Dane County. The number designation following the county prefix is based on the Federal system of land subdivision and consists of the township, range, and section numbers. The last numerals, the serial number, are assigned in the order that the wells were inventoried in the county. For example, well Dn–8/6/26–11 is located in Dane County; it is in township 8 north, range 6 east, sec. 26 and was the eleventh well inventoried in the county. The same numbering system is also used to designate sites where samples were collected for particle-size analysis, except that the serial numbers are prefixed by R. Only serial numbers of the wells and the rock-sampling sites are shown on the location map (pl. 1).

ACKNOWLEDGMENTS

The collection of data for this report was to a great extent made possible by the cooperation of well owners, well drillers, local officials, and private citizens. Special acknowedgment is made to the Wisconsin State Board of Heath for supplying well records, to the Wisconsin State Laboratory of Hygiene for chemical analyses of water samples, and to Mr. G. F. Hanson, State Geologist, for his review of this report.

GEOLOGY AND WATER-BEARING CHARACTERISTICS OF THE ROCK UNITS

The upper Black Earth Creek basin is underlain by deeply buried crystalline rocks of Precambrian age. These rocks are overlain by sedimentary rocks of Cambrian and Ordovician age that are in turn overlain in the eastern part of the basin and in the valleys by unconsolidated deposits of Quaternary age. Table 2 gives the lithology and water-bearing characteristics of the rock units in the basin.

Rocks of Silurian age occur about 6 miles to the southwest and 50 miles to the east of the basin, and Devonian and Mississippian rocks occur about 80 miles to the east. The proximity and distribution of these rocks suggest that they once covered the basin in the past but have been eroded away (Bean, 1949). Pennsylvanian through Quaternary time was probably a period of erosion in the area. During the Pleistocene Epoch glaciers advanced over the eastern part of the basin and covered the land with sediments. The valleys in the western part of the basin were filled with sediments carried by the melt water from the glaciers.

CONSOLIDATED ROCKS

The map showing the bedrock geology of the upper Black Earth Creek basin (pl. 3) was modified from a map by B. W. Meek (Geology of the Cross Plains quadrangle, Dane County, Wisconsin, 1934, unpublished thesis, University of Wisconsin, Madison, Wis.) by means

TABLE 2.—*Lithology and water-bearing characteristics of rock units in upper Black Earth Creek basin, Wisconsin*

System	Rock unit	Thickness (feet)	Lithology	Water-bearing characteristics
Quaternary	Recent deposits	0–150	Soil alluvium consisting of silt and clay	Outwash sand and gravel locally an important aquifer that yields small to large quantities of water. Deposits other than outwash may yield small quantities where not situated above the water table.
	Pleistocene deposits		Outwash deposits consisting of sand and gravel. Glaciolacustrine deposits consisting of sand, silt, clay, and marl. Till consisting of clay, silt, sand, gravel, and boulders.	
	— Unconformity —			
Ordovician	Galena Dolomite Decorah Formation Platteville Formation	0–100	Dolomite, light- to yellowish-gray, thin-bedded.	Situated above the water table; not an aquifer in this area.
	St. Peter Sandstone	0–200	Sandstone, very fine- to coarse-grained, light-gray.	Situated above the water table; not an aquifer in this area.
	— Unconformity —			
	Prairie du Chien Group	0–200	Two units of dolomite, light-gray to yellowish-brown, cherty, sandy; seperated by a few feet of sandstone.	Locally may yield small quantities of water from openings along fractures and bedding planes. Situated above the water table in most of area.
Cambrian	Trempealeau Formation Franconia Sandstone Galesville Sandstone of Dresbach Group Eau Claire Sandstone of Dresbach Group Mt. Simon Sandstone of Dresbach Group	600–900	Sandstone, very fine to coarse-grained, white, light-gray, yellowish-gray, dolomitic in places; some layers of shale, siltstone, and dolomite.	Important aquifer. Yields large quantities of water.
	— Unconformity —			
Precambrian rocks		Unknown	Crystalline rocks	Relatively impermeable; not an aquifer.

of well-log data and field observations. Outcrops of bedrock in the glaciated area are not common but occur on steep slopes, such as valley walls, and on the tops of hills where glacial deposits are generally thin. In the unglaciated area, bedrock is generally within a few feet of the surface and is exposed in many places.

Crystalline rocks of Precambrian age do not crop out in upper Black Earth Creek basin but do occur at about 150 feet above sea level at the village of Middleton. The crystalline rocks are nearly impermeable and are not an aquifer in this area. Well-log data in southern Wisconsin show that the surface of the Precambrian rocks is irregular and has a gentle regional southerly slope.

Rocks of Late Cambrian age unconformably overlie the Precambrian crystalline rocks and are present throughout the area. They are divided, in ascending order, into the Mt. Simon Sandstone, Eau Claire Sandstone, Galesville Sandstone, Franconia Sandstone, and Trempealeau Formation (table 2). The Mt. Simon Sandstone, Eau Claire Sandstone, and Galesville Sandstone are formations of the Dresbach

Group. The Galesville and Franconia Sandstones and the Trempealeau Formation crop out or occur beneath the Quaternary deposits in the area, but they were not differentiated and are shown as a unit on plate 3.

The rocks of Late Cambrian age have a stratigraphic thickness of about 800 to 900 feet. The erosion of Black Earth Creek valley has reduced the thickness of the rocks to about 600 feet in the valley. The rocks dip to the south about 10 to 15 feet per mile. They consist of very fine to coarse-grained sandstone that is dolomitic in many places. Layers of shale, siltstone, and dolomite are also present.

The sandstone units of Cambrian age constitute the most important aquifer in the area and in Dane County. The specific capacity of the village well (Dn–8/6/26–38) at Black Earth was reported in 1948 to be about 16 gpm (gallons per minute) per ft of drawdown at a pumping rate of about 1,100 gpm, and well Dn–7/8/10–93, near Middleton, was reported in 1950 to be 25 gpm per ft of drawdown at a pumping rate of 600 gpm. In the area investigated, no wells penetrate the full thickness of the aquifer.

Rocks of the Prairie du Chien Group of Ordovician age conformably overlie sandstone of Late Cambrian age. The Prairie du Chien Group caps most of the hills and occurs beneath the Quaternary deposits in a large part of the upland area. The dolomite of the Prairie du Chien Group is more resistant to erosion than the underlying sandstone of Cambrian age. Valleys that are cut through the dolomite into the underlying sandstone have steep sides, and the dolomite protects the sandstone from erosion.

The Prairie du Chien Group consists of two dolomite units separated by a few feet of sandstone. Although the group has a stratigraphic thickness of about 200 feet, erosion prior to the deposition of the St. Peter Sandstone had reduced the thickness in most areas and completely removed the group in some areas. At well Dn–8/7/13–99 in the northeastern part of the basin, the St. Peter Sandstone lies directly on the sandstone of Late Cambrian age. The Prairie du Chien Group lies above the zone of saturation in most of the area, although locally the lower part is saturated. Water occurs in the dolomite in openings along fractures and bedding planes that have been enlarged by solution. The distribution of the openings is irregular.

The St. Peter Sandstone of Ordovician age was deposited on the extensively eroded surface of the rocks of the Prairie du Chien Group. It occurs in a narrow belt along the southern boundary of the area and as outliers (pl. 3). The St. Peter Sandstone consists of light-gray very fine to coarse-grained sandstone that ranges in stratigraphic thickness from 0 to about 200 feet. At some places the Prairie du Chien

Group was completely removed, and the St. Peter Sandstone lies on rocks of Late Cambrian age. In most of upper Black Earth Creek basin, the St. Peter Sandstone has been removed by erosion. The St. Peter Sandstone is not an aquifer in this area because it lies above the water table.

The Platteville and Decorah Formations and the Galena Dolomite of Ordovician age successively overlie the St. Peter Sandstone. They occur in a narrow belt along the southern boundary of the area and as outliers capping the highest hill (pl. 3). These formations consist of dolomite, whose eroded remnants are as much as 100 feet thick. In this area they lie above the water table and are not aquifers.

SURFICIAL DEPOSITS

The distribution of the surficial deposits of Quaternary age in upper Black Earth Creek basin is shown in plate 4. The map of surficial deposits was modified from a map prepared by B. W. Meek (written communication, 1934).

During the Pleistocene Epoch, continental glaciers advanced over all Wisconsin except the southwestern part. The glaciers advanced over the eastern half of upper Black Earth Creek basin to the vicinity of Cross Plains, as indicated by deposits of till (pl. 4). Drillers' logs of wells Dn–7/7/3–230 and Dn–7/7/5–186 suggest that remnants of till may be present west of the deposits of till shown on the map. The poor sorting of the sediments as indicated by the driller's log of well Dn–7/7/3–229, sample log of well Dn–7/7/3–32, and sample Dn–7/7/11–R2 (table 3), suggests that the sediments are reworked till.

The thickness of the glacial deposits is variable. In general, the deposits are relatively thick in the valleys and thin on the tops of hills. The deposits are locally absent from some areas, which are too small to be shown on plate 4; these areas are common enough to show the distribution of the bedrock units.

The surficial deposits consist of till, glaciolacustrine deposits, outwash, Recent alluvium, and soil (pl. 4). These deposits are 130 feet thick in well Dn–8/6/26–38 at Black Earth and are estimated to have a maximum thickness of about 150 feet in the area. Till overlies bedrock in most of the upland in the eastern half of the area. In the valleys it locally overlies outwash deposits of sand and gravel. The till consists of an unsorted or poorly sorted mixture of clay, sand, gravel, and boulders (Dn–8/7/25–R5 and Dn–8/7/23–R7, table 3).

Glaciolacustrine deposits of glacial Lake Middleton occur in a small area in the southeastern part of the basin. These deposits consist of a few feet of stratified sand and silt with some clay and marl (F. T. Thwaites, 1908, written communication, and B. W. Meek, 1934, written communication).

Deposits of outwash overlie the bedrock in the valley of Black Earth Creek and in the downstream parts of the valleys of the tributary streams. Recent alluvium generally overlies the outwash, and, in the upstream parts of the tributary valleys, it lies directly on bedrock. The outwash consists mostly of moderately sorted stratified sand and gravel. The alluvium consists mostly of a few feet of silt and clay (Dn–7/7/11–R1, Dn–8/7/31–R3, and Dn–7/8/10–R4, table 3). In the unglaciated western part of the area, a few feet of soil generally overlies the bedrock.

The outwash sand and gravel is generally well sorted and permeable, and it is locally an important aquifer. In 1952, well DN–7/7/3–32 was reportedly pumped at 112 gpm and had a specific capacity of 24 gpm per ft of drawdown. The till is poorly sorted, contains much fine-grained material, and generally yields only small amounts of water. It is much less permeable than the outwash or the sandstone of Late Cambrian age. The alluvium and glaciolacustrine deposits generally lie above the water table and are not aquifers.

GROUND WATER

SOURCE

The source of most of the ground water in the upper Black Earth Creek basin is direct infiltration of the precipitation in the basin. Some ground water, however, enters the area from outside the basin as underflow from the south. A part of the precipitation flows into Black Earth Creek and its tributaries as direct runoff, a part returns to the atmosphere through evapotranspiration, and a part, called recharge, seeps downward to the zone of saturation to become ground water.

OCCURRENCE

Ground water in upper Black Earth Creek basin occurs in the sandstone of Late Cambrian age and in the outwash and till deposits of Pleistocene age and may be considered as one body of ground water. Because of the low permeability of the till, only the sandstone and outwash are considered as parts of the aquifer.

The piezometric surface of an aquifer is an imaginary surface that everywhere coincides with the static level of water in the aquifer (Meinzer, 1923). Under artesian conditions water in an aquifer is confined by relatively impermeable material, and the piezometric surface is above the top of the aquifer. If the water in an aquifer is not confined by impermeable material, the piezometric surface is called the water table. Ground water occurs under both artesian, actually leaky artesian, and water-table conditions in the aquifer in upper

TABLE 3.—*Particle-size analyses of surficial material in upper Black Earth Creek basin, Wisconsin*

Sample	Location	Topographic situation	Depth below land surface (feet)	Rock unit	Character of material	Percent (by weight) of particle size (mm) indicated												
						Clay	Silt	Sand					Gravel					
						<0.004	0.004–0.0625	0.0625–0.125	0.125–0.25	0.25–0.5	0.5–1	1–2	2–4	4–8	8–16	16–32	32–64	>64
Dn-7/7/11-R1	NW¼SE¼	In valley	2	Alluvium	Silt and clay, light-brown, loose, not plastic. Deposit is 4 ft thick and overlies sample R2.	30	65	1	3	1	----	----	----	----	----	----	----	----
7/7/11-R2	NW¼SE¼	In valley	6–7	Outwash	Gravel, very fine to very coarse, light-gray, very poorly sorted, subangular to subrounded; mostly dolomite with some igneous and metamorphic rocks. Very fine to very coarse sand of very poorly sorted mostly rounded quartz grains. Contains boulders as much as 2 ft in diameter; many of the boulders are 6 in. or more in diameter, rounded, and of igneous or metamorphic origin; some are weathered. Collected 4 ft below sample R1.	1		2	10	13	5	6	10	13	3	6	27	3
8/7/31-R3	SE¼NW¼	In valley	3	Alluvium	Silt and clay, light-yellowish-brown, plastic.	33	65	1	1	----	----	----	----	----	----	----	----	----
7/8/10-R4	NE¼NW¼	In valley	3–4	Alluvium(?)	Sand, very fine to medium; mostly rounded quartz grains. Light-yellowish-brown, plastic silt and clay. Contains scattered small pebbles.	17	19	4	28	33	----	----	----	----	----	----	----	----

8/7/25-R5	SW¼NE¼	Edge of tributary valley.	8	Till	Gravel, very fine to very coarse, light-grayish-brown, very poorly sorted, angular; some subrounded pebbles, mostly dolomite. Very fine to very coarse silty poorly sorted sand; consists of quartz grains with a few igneous and metamorphic rock grains. Contains many large angular pieces of dolomite as much as 1 ft in diameter.	4	11	5	10	10	6	7	5	5	11	20	6	----
8/7/23-R7	NE¼NE¼	Top of ridge	4.5	Till	Sand, very fine to very coarse, silty, red-orange-brown, very poorly sorted; mostly rounded quartz grains with a few igneous and metamorphic rock grains. Very fine to very coarse poorly sorted angular to subangular gravel; mostly dolomite with some igneous and metamorphic rocks. Contains rounded boulders as much as 2 ft in diameter that are of igneous and metamorphic origin and are very weathered.	7	19	10	20	12	4	2	3	3	7	9	3	----

Black Earth Creek basin. The water levels in both water-table and artesian wells, the surface-water elevations, and the topography were used in preparing the map showing the piezometric surface in July 1958 (pl. 5).

In the eastern glaciated part of the area where till overlies sandstone or outwash, the ground water in the sandstone and outwash is commonly partially confined by the less permeable till and is under a small hydrostatic pressure. The piezometric surface is relatively flat and conforms to the topography only regionally. In the western part of the basin the ground water is unconfined or under water-table conditions, and the piezometric surface is therefore a subdued replica of the land surface. All the tributary streams drain the ground-water body and create depressions in the water table. The hills and ridges are areas of recharge and form local ground-water divides. The water levels in the eastern part of the basin behave more like those of a leaky artesian system and in the western part more like those of a water-table system. This effect is caused by the presence or absence of till.

MOVEMENT

The movement of ground water is controlled by discharge, recharge, topography, structure, and permeability of the rocks. The direction of movement of ground water in upper Black Earth Creek basin is shown by the piezometric map (pl. 5). Water moves down the slope of the hydraulic gradient, from points of higher altitude to points of lower altitude, approximately at right angles to the contour lines on the piezometric map.

Movement of ground water is chiefly toward Black Earth Creek and its tributaries from a ground-water divide that roughly coincides with the topographic boundary of the basin. An exception is in the southern part of the area where the ground-water divide is about 2 or 3 miles south of the southern boundary of the drainage basin (pl. 5). Thus, the area contributing ground-water discharge to Black Earth Creek is larger than the area contributing surface runoff.

RECHARGE

Recharge generally results in a rise in water levels. In shallow wells in upper Black Earth Creek basin, water under unconfined conditions rises almost immediately in response to precipitation; however, in wells in which the depth to water is great or in which water is under confined conditions water levels generally respond days or weeks later.

Recharge approximately equals discharge within the ground-water basin if storage remains constant. The discharge is estimated to have been about 5 inches in 1958. Recharge to the ground-water reservoir was somewhat less than this amount as indicated by the declining water levels in the area (fig. 6).

Less recharge per square mile occurs in the glaciated eastern part of the area than in the unglaciated western part. The till covering about 22 square miles of the eastern part has a low permeability and retards the downward infiltration of water so that much of the precipitation runs over the surface into the streams. The relatively permeable sandstone, dolomite, and outwash at or near the surface in about 35 square miles of the western part provide conditions much more favorable for recharge. The recharge in the area covered by till is probably about one-tenth of the total recharge to the basin, whereas the recharge in the sandstone, dolomite, and outwash areas is probably about nine-tenths of the total recharge. The recharge to the outwash is probably about equal to the recharge to the consolidated rock.

The effect of about 4 inches of precipitation on May 30 to June 1, 1958, on water levels in wells Dn–8/6/26–11 and Dn–7/8/4–184 is shown in figure 2. The water level in well Dn–8/6/26–11, a shallow nonartesian well tapping outwash deposits of sand and gravel, responded to the precipitation almost immediately and rose about 0.75 foot by June 2; after this date it gradually declined. The water level in well Dn–7/8/4–184, tapping sandstone of Cambrian age in an area overlain by till, responded more slowly to the precipitation and fluctuated less than did the level in well Dn–8/6/26–11. Although the

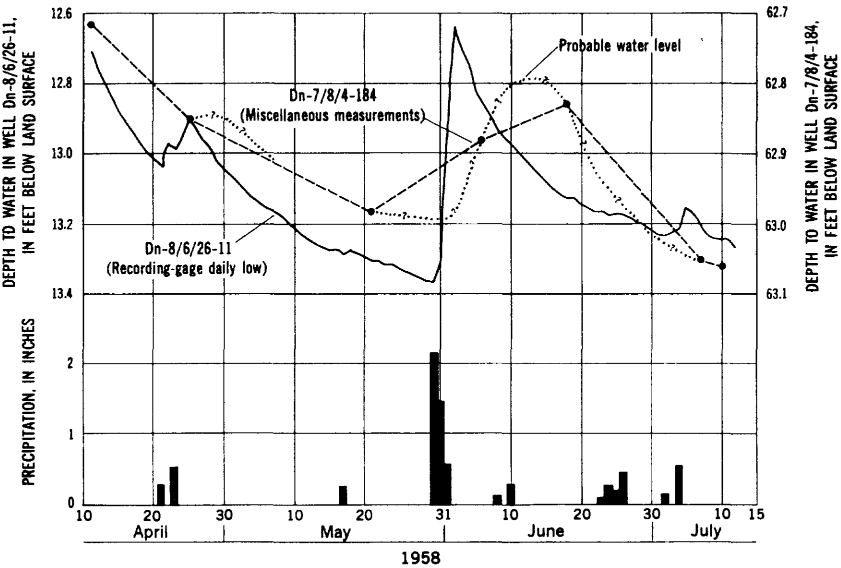

FIGURE 2.—Hydrographs of wells Dn–8/6/26–11 and Dn–7/8/4–184, upper Black Earth Creek basin, and daily precipitation at Truax Field, Madison, Wis., April 10 to July 12, 1958.

hydrograph of well Dn–7/8/4–184 represents miscellaneous measurements, it demonstrates the delayed response. The highest water level measured for well Dn–7/8/4–184 occurred on June 18, which was 20 days after the rain began, whereas the water level in well Dn–8/6/26–11 was already declining.

DISCHARGE

Ground water in the upper Black Earth Creek basin is discharged naturally by seepage into Black Earth Creek and its tributaries and by evapotranspiration and artificially by pumping from wells. Some ground water also moves out of the area as underflow beneath the valley of Black Earth Creek. Seepage into Black Earth Creek probably accounts for most of the natural discharge of ground water.

The discharge of ground water by evapotranspiration is restricted to areas where the water table is shallow or at the surface. Evapotranspiration is greatest in the growing season when the air temperature is highest. The discharge of ground water by evapotranspiration is estimated to be less than one-fifth of the total ground water discharged from the basin in 1958, and during July 1958 it was probably about one-half of the total discharge for the month (Thornthwaite, 1958). The total discharge of ground water from the ground-water basin in 1958 is estimated to be about 5 inches.

Most of the wells in the area supply water for domestic and stock use and are equipped to pump 5 to 20 gpm each; however, two large-capacity wells in the basin and two just outside the basin are reportedly pumped at rates of 100 to 650 gpm each for a few hours each day. About 300,000 gpd (gallons per day) is estimated to have been discharged by pumping from the ground-water basin in 1958. The underflow out of the basin and the discharge from wells were estimated to have been less than one-tenth of the total ground-water discharge in 1958.

WATER-LEVEL FLUCTUATIONS

Fluctuations in water levels in wells are caused chiefly by variations in recharge and natural discharge and by pumping and indicate that the ground-water reservoir is adjusting to changes in storage. When recharge exceeds discharge, water levels in wells rise, and when discharge exceeds recharge, water levels decline (figs. 2–6). The hydrographs shown in figure 3 are representative of the fluctuations of the water table in the western part of the basin. The hydrographs are similar, although well Dn–8/7/31–271 is in sandstone and wells Dn–7/7/3–32 and Dn–7/7/3–304 are in outwash.

Other factors, such as changes in atmospheric pressure, also affect water levels; however, the changes in water levels are generally minor and of short duration. The water level in well Dn–7/7/5–176 responds almost immediately to changes in atmospheric pressure, but the water level generally returns in 2 to 4 hours to the trend it followed prior to the pressure change.

Water-level fluctuations may be classed as short term, seasonal, and long term. Short-term fluctuations reflect day-to-day variations in recharge and in natural discharge or intermittent pumping in the area. The fluctuations occur within hours or, at most, within a few weeks, and water levels and ground-water storage are only locally affected. An example of short-term fluctuations in response to recharge and natural discharge is shown by the hydrographs of wells Dn–8/6/26–11 and Dn–7/8/4–184 (fig. 2). Figure 4 shows short-term fluctuations superimposed on a longer trend of declining water levels.

Seasonal fluctuations reflect variations in recharge and natural discharge. Water levels are generally highest in the spring owing to snowmelt and spring rains. The levels decline slowly during the summer when recharge from precipitation is slight and when natural discharge by seepage into Black Earth Creek and by evapotranspiration is large. Typical fluctuations for the period of December 1956 through August 1958 are shown by the hydrograph of well Dn–7/7/5–176 (fig. 5). Occasional heavy rains may result in small rises in water levels. A small rise in water levels generally occurs in the fall after the first killing frost because of increased recharge due to increased precipitation and decreased evapotranspiration (fig. 5). Water levels continue to decline during the winter because recharge is negligible when the ground is frozen and seepage into Black Earth Creek continues.

Long-term fluctuations in water levels reflect differences between recharge and natural discharge from year to year. The water level rises in years of above-average precipitation and declines in years of below-average preciptation. The cumulative deficiency in precipitation from 1952 to the fall of 1958 was about 7 inches. The deficiency in precipitation and subsequently also in recharge is reflected by declining water levels in wells in the area (fig. 6 and table 4). The trends of the water levels in wells Dn–7/8/4–184 and Dn–8/8/20–172 (fig. 6) correlate with the trend of the cumulative departure from normal precipitation (fig. 1). Although data regarding declines in the upper Black Earth Creek basin are not available for all the time from 1952 to the fall of 1958, the water levels during this period in a well near Sun Prairie, 25 miles east of Cross Plains, and in a well near Belleville, 18 miles south, declined about 14 feet.

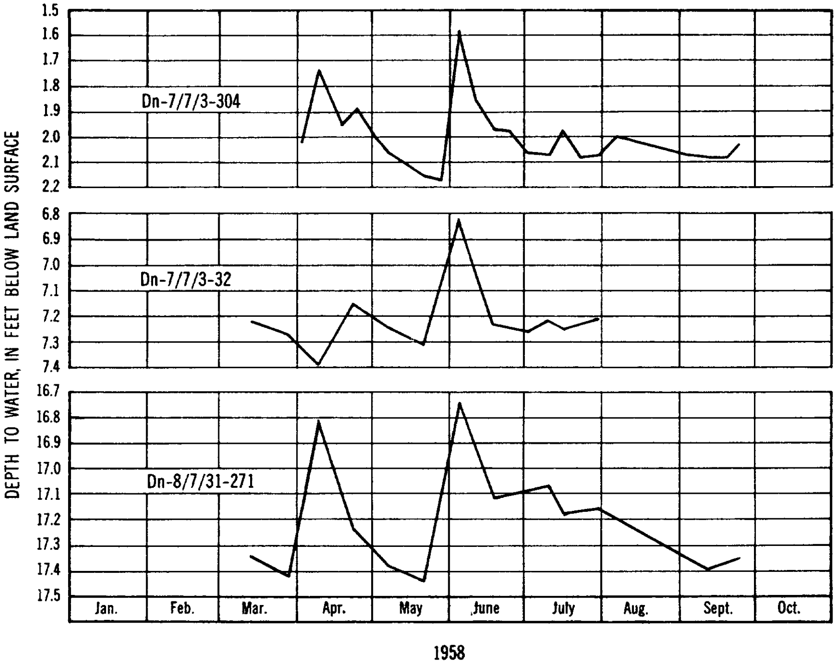

FIGURE 3.—Hydrographs of wells Dn–7/7/3–32, Dn–8/7/31–271, and Dn–7/7/3–304 during the spring and summer of 1958 in upper Black Earth Creek basin, Wisconsin.

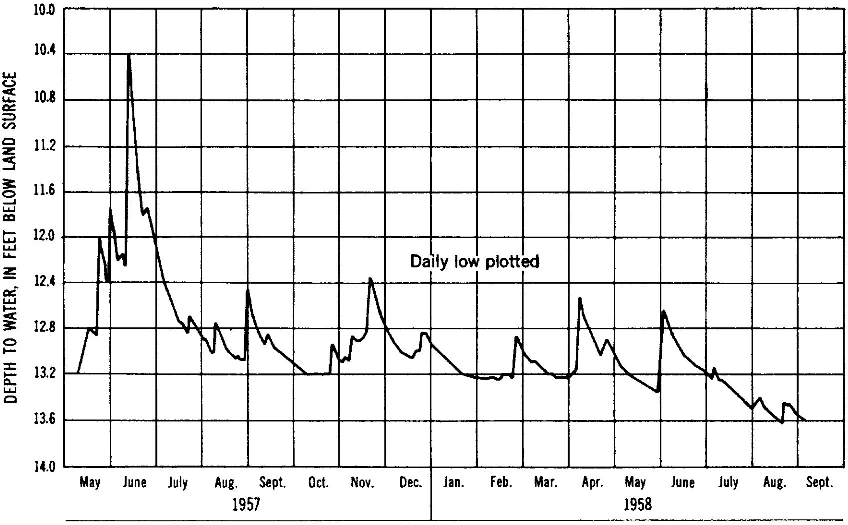

FIGURE 4.—Hydrograph of well Dn–8/6/26–11, Black Earth, Wis., May 1957 to September 1958.

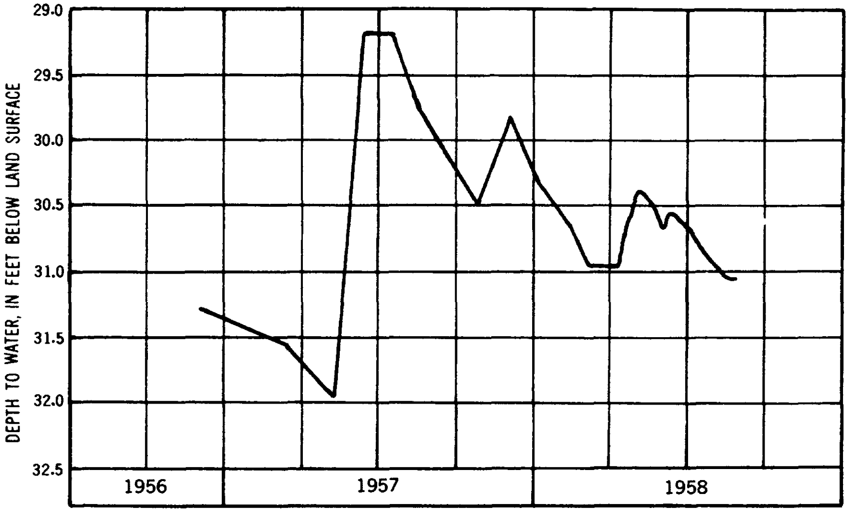

FIGURE 5.—Hydrograph of well Dn–7/7/5–176, upper Black Earth Creek basin, Wisconsin, December 1956 to August 1958.

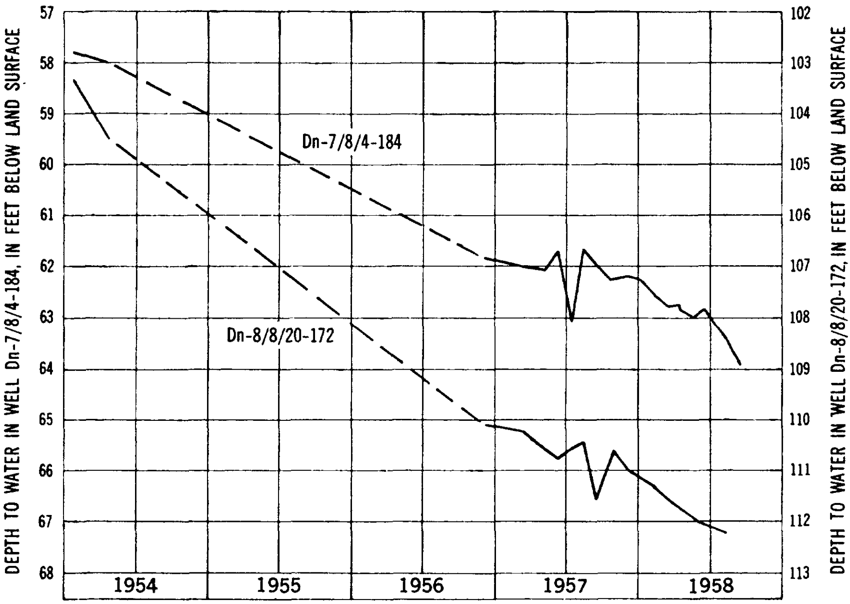

FIGURE 6.—Hydrographs of wells Dn–8/8/20–172 and Dn–7/8/4–184, upper Black Earth Creek basin, Wisconsin, 1954–58.

TABLE 4.—*Water levels in feet below land surface in wells in upper Black Earth Creek basin, Wisconsin*

Well Dn-8/7/22-241

Date	Water level
1954	
Feb. 2	[1] 113.2
Apr. 24	[1] 107.9
1957	
June 26	111.37
1958	
July 11	111.54

Well Dn-8/7/22-279

Date	Water level
1958	
Apr. 11	101.73
July 10	101.89
Aug. 28	101.81
Sept. 3	101.80

Well Dn-8/7/31-270

Date	Water level
1958	
Apr. 22	4.91
May 7	5.07
May 21	5.12
June 18	4.73
July 2	4.68
July 10	4.61
July 16	4.62
July 30	4.71

Well Dn-8/8/17-249

Date	Water level
1954	
Feb. 5	[1] 112.6
Apr. 24	[1] 112.8
1956	
Dec. 5	117.87
1957	
July 3	117.99
1958	
July 10	119.61

Well Dn-7/7/2-227

Date	Water level
1954	
Jan. 29	[1] 39.3
Apr. 24	[1] 39.0
1956	
Dec. 4	42.08
1957	
June 19	41.82
1958	
July 10	42.78

Well Dn-7/7/3-229

Date	Water level
1957	
June 19	20.13
1958	
Apr. 23	19.76
May 21	21.29
June 18	19.83
July 2	19.89
July 10	19.90
July 30	19.95
Sept. 24	19.95

Well Dn-7/7/10-226

Date	Water level
1957	
June 19	36.80
1958	
Apr. 23	37.92
May 21	38.16
June 18	37.86
July 2	38.00
July 10	38.01
July 30	38.14
Sept. 12	38.31
Sept. 24	38.25

Well Dn-7/8/7-224

Date	Water level
1954	
Jan. 24	[1] 32.7
Apr. 20	[1] 31.9
1957	
June 19	36.33
1958	
July 10	37.60

[1] Measurement by G. M. Randall (written communication, 1954).

SURFACE WATER

By MARK W. BUSBY

The gaging station on Black Earth Creek, established in February 1954, is in a reach where the creek flows through a broad valley. Channel storage is relatively large, and flood discharges are of long duration and have moderately high stages. The small tributaries draining the steep adjoining hills have peak discharges of short duration and very high stages, although stages are not as high as on the main stream. The peak discharges generally result from rainfall rather than snowmelt.

In 1954–57, the low flows were fairly uniform at about 20 cfs (cubic feet per second). The hydrograph of daily mean discharges for January to August 1958 (fig. 7) shows few large rises and a steady decline in low flow from about 20 cfs in June to about 14 cfs in August. The maximum and minimum discharges each year from 1954 to 1958 are as follows:

Year	Maximum discharge (cfs)	Date	Minimum discharge (cfs)	Date
1954	1, 750	July 3	12	Mar. 3.
1955	654	Feb. 20	16	Sept. 19.
1956	408	May 13	6	Nov.17 (freezeup).
1957	1, 030	June 11	14	Jan. 1, 10.
1958	180	Feb. 25	13	Feb. 8, Aug. 23.

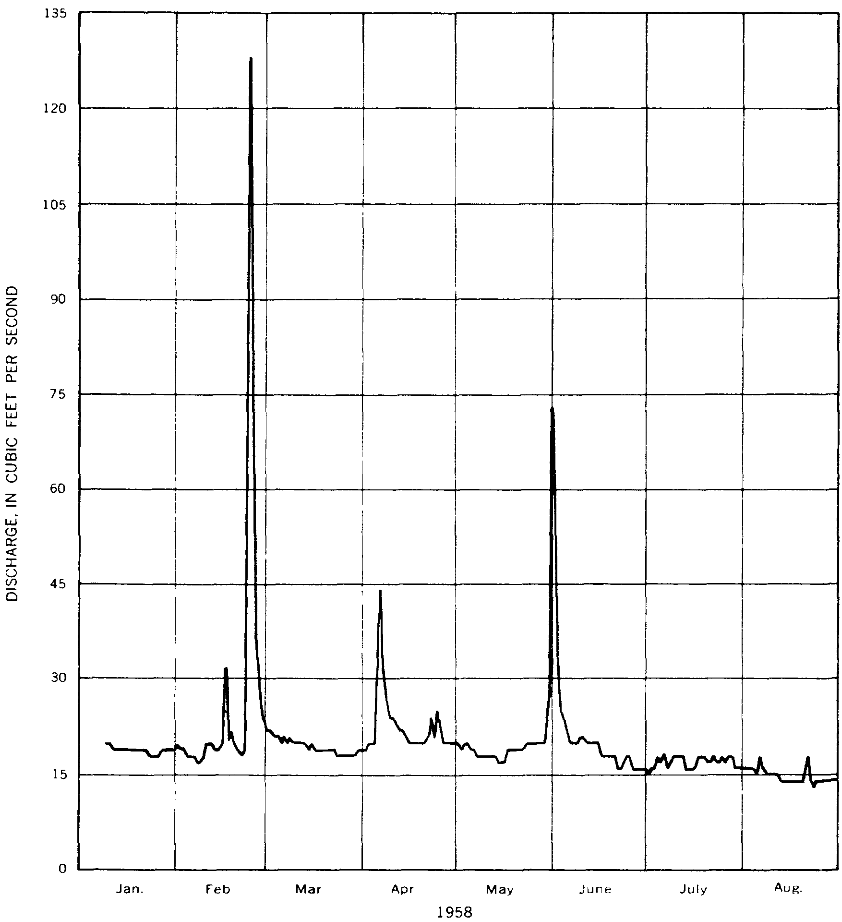

FIGURE 7.—Daily mean discharge of Black Earth Creek at Black Earth, Wis., January to August 1958.

The flow of Black Earth Creek was measured at five sites and at the gaging station on July 10, 1958. The last precipitation prior to the measurements occurred on July 4, 1958, and the streamflow at the time of the measurements probably consisted mostly of ground-water discharge. The locations of the flow-measurement sites and the drainage subbasins between adjacent sites are shown in plate 1. Results of the streamflow measurements are given in table 5. The discharge measured at site M_E may be too large. Measurements in January 1961 indicated that the discharge at site M_E was less than at the gaging station. The flow at each site is the flow from the basin upstream from the site; the contribution from individual subbasins (table 6) is obtained by subtraction. The figures in the columns "Drainage area" and "Computed discharge" in table 6 were computed from the corresponding columns in table 5; the figures for the subbasin were obtained by subtracting from the figure for the site given in table 5 the figure preceding it in the column. The discharge per square mile is obtained by dividing the computed discharge by the drainage area.

TABLE 5.—*Results of streamflow measurements of Black Earth Creek, July 10, 1958*

Site	Drainage area (sq mi)	Measured discharge (cfs)	Average discharge per sq mi of drainage area (cfs)
M_A	3.20	0.24	0.075
M_B	11.9	4.31	.362
M_C	26.6	7.78	.292
M_D	32.7	11.7	.358
M_E	38.8	16.8	.433
Gage	45.8	16.8	.367

TABLE 6.—*Computed contributions of drainage subbasins to flow of Black Earth Creek, July 10, 1958*

Subbasin	Topographic situation	Drainage area (sq mi)	Computed discharge (cfs)	Computed discharge per sq mi of drainage area (cfs)
A	Relatively flat and swampy	3.20	0.24	0.075
B	Moderately steep slopes	8.7	4.07	.47
C	do	14.7	3.47	.236
D	Steep slopes	6.1	3.9	.64
E, F	Moderately steep slopes, wide flat valley.	13.1	5.1	.39

RELATIONSHIP OF GROUND WATER, SURFACE WATER, AND PRECIPITATION

The flow of upper Black Earth Creek consists mostly of ground-water discharge, except for short periods during and immediately after precipitation when most of the flow is from surface runoff. About eight-tenths of the flow in 1957 and nine-tenths in 1958 came from ground-water discharge. In July 1958, when a series of measurements was made of the flow of Black Earth Creek, the streamflow consisted mostly of ground-water discharge. Ground water was also being discharged at this time by evapotranspiration and by pumping from two large-capacity and many small-capacity wells in the area. Thus, the discharges from the various drainage subbasins (table 6) reflect only the ground-water discharge appearing as streamflow in Black Earth Creek and do not represent the total ground-water discharge from the area.

The variation in discharge per square mile among the subbasins is mainly due to differences in recharge and evapotranspiration and to the movement of ground water into the drainage basin from the south. The discharge per square mile from subbasin A is less than from subbasins B, C, or D because the cover of till has reduced recharge and because in July 1958 the evapotranspiration from the extensive swamps was probably very large (pls. 1, 2, and 4). The discharge per square mile from subbasin B was higher than from subbasins A or C because of the addition of ground water from an area outside surface-water subbasin B. The evapotranspiration in B was probably large.

The discharge per square mile from subbasin C was greater than that from A and less than that from B because the cover of till reduced recharge and because evapotranspiration was probably less than in A. The discharge per square mile from subbasin D was greater than that from A, B, or C because much of the lower part of subbasin D is not covered by till and because evapotranspiration of ground water is probably effective in only a small area. Because the measurement at site M_E (table 5) is questionable, subbasins E and F cannot be discussed separately. Together they have a discharge per square mile of 0.39 cfs, which is moderately large. Evapotranspiration is probably large from the wide flat valley in subbasin F and the swamp area in E. Ground water moves into subbasin E from an area outside the surface-water subbasin. Recharge to both E and F is large because the till cover is absent.

The relationship of precipitation, ground water, and surface water at Black Earth is shown in figure 8.

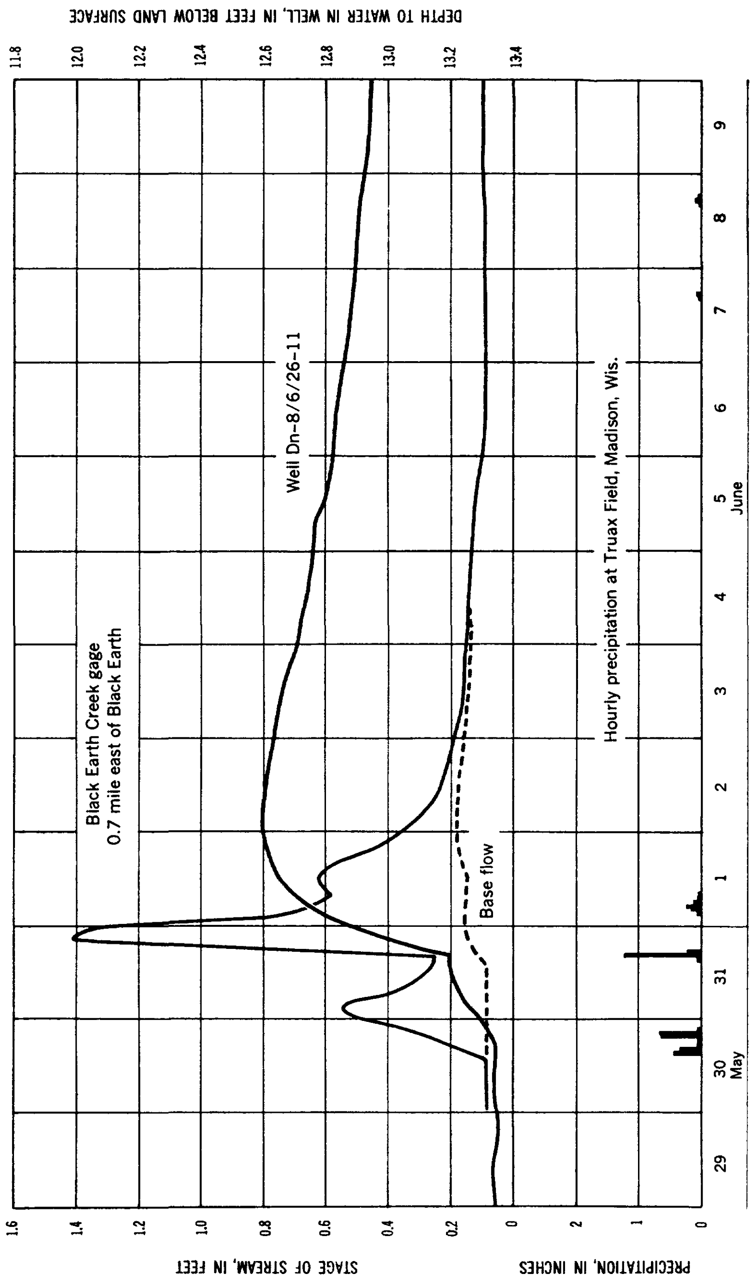

FIGURE 8.—Hydrograph of well Dn-8/6/26-11, stream stage of Black Earth Creek near Black Earth, and precipitation at Truax Field, Madison, Wis., May 29 to June 9, 1958.

From May 30 to June 1, 1958, heavy rains occurred in upper Black Earth Creek basin, and 4.17 inches of rain was recorded at Truax Field at Madison. The precipitation occurred in three storms: 2.15 inches in 7 hours on May 30; 1.45 inches in 3 hours on May 31, 1.22 inches of which fell in 1 hour; and 0.57 inch in 6 hours on June 1.

The hydrograph of the stage of Black Earth Creek at the gaging station shows 3 peaks that correlate with the 3 periods of precipitation. The maximum stages occur 4 to 6 hours after the precipitation ceased (fig. 8). The stage of the creek increased from about 0.09 foot (20 cfs) to a peak of 0.55 foot (57 cfs) after the precipitation on May 30 and gradually decreased to 0.26 foot (32 cfs), after which it increased rapidly to 1.42 feet (169 cfs) in response to the precipitation on May 31. At first the discharge began to decrease rapidly and then more gradually until June 4, when the discharge was back to base flow. The discharge fluctuated only slightly in response to the precipitation of 0.57 inch on June 1. The increase in base flow on May 31 and June 1 was due to the increased discharge of ground water into the creek following recharge.

The hydrograph of well Dn–8/6/26–11, tapping outwash deposits of sand and gravel, shows the effect of recharge to the ground-water reservoir from the precipitation on May 30 to June 1, 1958. The maximum water levels occurred 20 to 36 hours after the precipitation. The water level rose slowly about 0.15 foot, in response to the precipitation on May 30, and then, in response to the precipitation on May 31, rose rapidly about 0.60 foot more. The level, fluctuating only slightly, then gradually declined (fig. 8).

In 1954–58, the precipitation was below normal, and water levels in wells in the area declined (fig. 6). A definite correlation between precipitation and water levels is shown by a comparison of figures 1 and 5. These figures show that the graph of cumulative departure from normal monthly precipitation and the hydrograph of well Dn–7/7/5–176 are very similar. The deficiency of precipitation from August 1957 to September 1958 is reflected in the declining water level in the well. Well Dn–8/6/26–11 (fig. 4) also shows a declining water level during this period.

During June to September 1958, precipitation was below normal (fig. 1), water levels in wells declined (figs. 4 and 5), and daily mean discharge in Black Earth Creek decreased (fig. 7). The declining water levels in wells were accompanied by a decrease in ground-water discharge to the stream and a reduction in the base flow of the stream.

The runoff from the upper Black Earth Creek basin, as determined from records of streamflow at the gaging station near Black Earth, and the precipitation at Truax Field in Madison in 1955–58 are as follows:

Year	Runoff (inches)	Precipitation (inches)
1955	8. 72	22. 49
1956	7. 45	31. 51
1957	7. 64	32. 86
1958	5. 55	21. 09

Because most of the surface runoff is ground-water discharge, it is estimated from the data in the foregoing table that about one-fourth of the precipitation recharges the ground-water reservoir.

QUALITY OF WATER

Chemical analyses of water from six wells and from Black Earth Creek are given in table 7; their locations are shown in plate 1. The sample of water from Black Earth Creek, collected during a period when the stream-flow consisted mostly of ground-water discharge, is similar in chemical character to the samples collected from the wells.

Ground water in the area is of the calcium magnesium bicarbonate type and is very hard, ranging in carbonate hardness from 256 to 368 ppm (parts per million). The dissolved-solids content ranges from 264 to 424 ppm.

The temperature of the water from five wells and from Black Earth Creek was measured periodically from January through September 1958 (table 8). The temperature of the water from the wells ranged from about 49° to 52°F except for the water from well Dn–7/8/7–272, which ranged from about 43° to 56°F. The temperature of Black Earth Creek at the gaging station ranged from 33°F in February to 68°F in July. The temperature of the stream is affected by the air temperature and by the temperature of the ground water discharging into the stream. Air temperature also affects the temperature of ground water near the surface. The temperature of the water in well Dn–7/8/7–272 is affected by variations in air temperature because the well is shallow.

Sediment samples have been collected from Black Earth Creek at the gaging station twice daily since 1954. Each sample is a composite of the sediment and water obtained at various depths in the creek but does not include sediment from the bed of the creek. The particle size of the sediment is predominantly clay with some silt. Even when the creek is at flood stage, only a small part of the sediment load consists of sand. The particle-size distribution of the maximum and minimum daily sediment loads of Black Earth Creek in 1954–58 is given in table 9.

TABLE 7.—*Chemical analyses, in parts per million, of water from upper Black Earth Creek basin, Wisconsin*

[Analyses by Wisconsin State Laboratory of Hygiene unless otherwise indicated]

Well or stream	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Dissolved solids (residue on evaporation at 105°C)	Hardness as $CaCO_3$		pH
																	Calcium, Magnesium	Noncarbonate	
Dn-8/7/31-271	4- 9-58	------	0.6	------	------	59	30	3		283	17	4.5	0.1	------	------	272	256	------	7.8
7/7/3-32	4- 9-58	------	.1	------	------	67	39	3		364	12	2.5	.1	------	------	310	311	------	7.7
7/7/3-229	4-23-58	------	.1	0.0	------	57	32	2		290	16	3.0	.1	------	------	264	256	------	7.7
7/7/10-226	4-23-58	------	.1	.0	------	69	41	3		329	28	10	.1	------	------	360	318	------	7.5
7/8/7-272	4- 9-58	------	.1	------	------	79	46	6		344	58	16	.1	------	------	424	368	------	7.6
7/8/17-275	4-10-58	------	.1	------	0.1	71	40	3	1.5	366	18	4.5	.1	------	------	348	328	------	7.7
Black Earth Creek [1]	1-10-55	14	.1	------	------	62	34	2.6	.9	338	12	2.6	.0	4.2	0.0	295	311	18	8.0

[1] Analysis by U.S. Geological Survey.

TABLE 8.—*Temperature, in degrees Fahrenheit, of water in upper Black Earth Creek basin, Wisconsin, in 1958*

Date	Well					Black Earth Creek
	Dn-8/7/31-271	Dn-7/7/3-32	Dn-7/7/3-229	Dn-7/7/10-226	Dn-7/8/7-272	
Jan. 15	--------	--------	--------	--------	--------	41
Feb. 15	--------	--------	--------	--------	--------	33
Feb. 27	--------	--------	51.0	50.2	--------	41
Mar. 14	[1] 49.5	49.8	--------	--------	45.0	41
Mar. 28	[1] 49.5	50.0	50.2	50.0	43.2	50
Apr. 9	[1] 48.5	[1] 49.5	--------	--------	[1] 43.5	48
Apr. 23	[1] 48.5	50.0	50.1	50.3	[1] 44.5	49
May 7	49.0	49.8	--------	--------	45.3	64
May 21	48.9	50.2	50.3	50.2	47.0	--------
June 4	49.1	50.1	--------	--------	49.4	56
June 18	49.2	50.2	50.9	50.7	50.5	58
July 2	[1] 49.5	50.4	50.2	51.2	51.9	68
July 16	49.5	49.8	--------	--------	55.8	62
Sept. 12	51.2	--------	--------	50.8	--------	--------
Sept. 24	51.8	--------	[1] 51.5	52.1	--------	--------
Sept. 25	--------	50.5	--------	--------	[1] 55.5	--------

[1] ± 0.5° F.

TABLE 9.—*Particle-size analyses of maximum and minimum daily sediment loads of Black Earth Creek at gaging station near Black Earth, Wis., 1954–58*

Maximum and minimum daily sediment load (tons)	Date	Discharge (cfs)	Percent (by weight) of particle size (mm) indicated								
			Clay		Silt				Sand		
			<0.002	0.002–0.004	0.004–0.008	0.008–0.016	0.016–0.031	0.031–0.062	0.062–0.125	0.125–0.25	>0.25
3,960	July 3, 1954	1,640	60	12	9	11	3	1	1	1	2
0.1	June 21, 1956	28	77	7	12	2	2	------	------	------	------

SUMMARY

Sandstone of Late Cambrian age and outwash deposits of sand and gravel of Quaternary age are important sources of ground water in upper Black Earth Creek basin, Wisconsin. The sandstone and outwash are hydraulically connected and form a single aquifer which is unconfined except in a few places in the eastern part of the area. Adequate supplies of ground water for domestic and stock uses and for most municipal, industrial, and irrigation requirements can be obtained from wells tapping the sandstone. The deposits of sand and gravel in the valleys also yield water for domestic and stock uses.

The sources of the ground water in the area are direct infiltration of precipitation and ground-water underflow from the south. About one-fourth of the precipitation recharges the ground-water reservoir. Most of the ground water is discharged by seepage into Black Earth Creek, and some is discharged by evapotranspiration and by pumping from wells. Some water also moves out of the area as underflow beneath the valley of Black Earth Creek.

Most of the streamflow is from ground-water discharge except for short periods during and immediately after precipitation.

The ground water is of the calcium magnesium bicarbonate type and is very hard. In most wells, the temperature of the water is about 50° F.

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