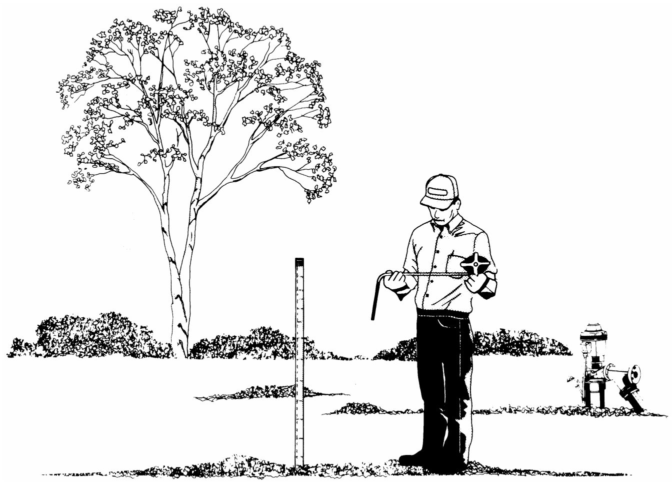
GEOHYDROLOGY AND WATER QUALITY OF KALAMAZOO COUNTY, MICHIGAN, 1986-88



By S.J. Rheaume

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4028

Prepared in cooperation with

MICHIGAN DEPARTMENT OF NATURAL RESOURCES, GEOLOGICAL SURVEY DIVISION

KALAMAZOO COUNTY

Lansing, Michigan

1990

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
6520 Mercantile Way, Suite 5
Lansing, Michigan 48911

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center
Box 25425, Bldg. 810
Denver, Colorado 80225-042

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Inch-pound units in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon	0.003785	cubic meter (m^3)
million gallons (Mgal)	0.04381	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second	28.32	liter per second (L/s)
cubic foot per second per square mile [($ft^3/s)/mi^2$]	10.93	liter per second per square kilometer [($(L/s)/km^2$]
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
pound (lb)	0.4536	kilogram (kg)
pound	453.6	gram (g)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
ton, short	907.2	kilogram (kg)
ton per square mile (ton/mi^2)	3.503	kilogram per hectare (kg/ha)
	Hydraulic properties	
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]
gallon per day per foot [(gal/d)/ft]	12.4	liter per day per meter [(L/d)/m]
gallon per day per square foot [(gal/d)/ft^2]	40.7	liter per day per square meter [(L/d)/m^2]

Temperature

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 1.8 \times °C + 32$$
or
$$°F = 9/5\ (°C) + 32$$

The following terms and abbreviations are also used in this report:

microgram per liter (µg/L)
microsiemens per centimeter at 25 degrees Celsius (µS/cm)
milligrams per liter (mg/L)

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929 ."

ABSTRACT

Thick, glacial sand and gravel deposits provide most ground-water supplies in Kalamazoo County. These deposits range in thickness from 50 to about 600 feet in areas that overlie buried bedrock valleys. Most domestic wells completed at depths of less than 75 feet in the sands and gravels yield adequate water supplies. Most industry, public supply, and irrigation wells completed at depths of 100 to 200 feet yield 1,000 gallons per minute or more. The outwash plains include the most productive of the glacial aquifers in the county. The Coldwater Shale of Mississippian age, which underlies the glacial deposits in most of the county, usually yields only small amounts of largely mineralized water.

Ground-water levels in Kalamazoo County reflect short- and long-term changes in precipitation and local pumpage. Ground-water levels increase in the spring and decline in the fall.

Ground-water recharge rates, for different geologic settings, were estimated from ground-water runoff to the streams. Recharge rates ranged from 10.86 to 5.87 inches per year. A countywide-average ground-water recharge rate is estimated to be 9.32 inches per year.

Chemical quality of precipitation and dry fallout at two locations in Kalamazoo County were similar to that of other areas in the State. Total deposition of dissolved sulfate is 30.7 pounds per acre per year, of total nitrogen is 13.2 pounds per acre per year, and of total phosphorus is 0.3 pounds per acre per year. Rainfall and snow data indicated that the pH of precipitation is inversely proportional to its specific conductance.

Water of streams and rivers of Kalamazoo County is predominately of the calcium bicarbonate type, although dissolved sulfate concentrations are slightly larger in streams in the southeastern and northwestern parts of

the county. The water in most streams is hard to very hard. Concentrations of dissolved chloride in streams draining urban-industrial areas are slightly larger than at other locations. Concentrations of total nitrogen and total phosphorus in streams are directly proportional to streamflow. Except for elevated concentrations of iron, none of the trace elements in streams exceeded maximum contaminant levels for drinking water established by the U.S. Environmental Protection Agency. Pesticides were detected in some streams.

Ground water in the surficial aquifers is of the calcium bicarbonate type, although sodium, sulfate, and chloride ions predominate at some locations. Specific conductance and hardness and concentrations of total dissolved-solids slightly exceed statewide averages. Concentrations of dissolved sodium and dissolved chloride in 6 wells were greater than most natural ground waters in the State, indicating possible contamination from road salts. Water samples from 6 of the 46 wells sampled contained concentrations of total nitrate as nitrogen greater than 10.0 milligrams per liter. Elevated concentrations of total nitrate as nitrogen in water from wells in rural-agricultural areas probably are related to fertilizer applications. Results of partial chemical analyses by the Michigan Department of Public Health indicates specific conductance, and concentrations of hardness, dissolved fluoride, and total iron are fairly uniform throughout the county. Concentrations of dissolved sodium, dissolved chloride, and total nitrate as nitrogen differed among townships. Pesticides were detected in water from only one well. Water from five wells contained volatile organics.

A map of susceptibility of ground water to contamination in Kalamazoo County was developed using a system created by the U.S. Environmental Protection Agency. Seven geohydrologic factors that affect and control ground-water movement are mapped and composited onto a countywide map. All seven factors have some effect on countywide susceptibility, but the most important factors are depth to water and composition of the materials above the aquifer.

INTRODUCTION

Kalamazoo County depends almost entirely on glacially derived sand and gravel aquifers for drinking water. These permeable aquifers are susceptible to contamination over much of the county. Major industrial and commercial chemicals and compounds, such as chlorinated hydrocarbons, fuel substances, and plating wastes, have been identified in the ground water of the county. In addition, concentrations of total nitrate as nitrogen in ground water have increased substantially in the county during the past two decades. Recharge areas for some aquifers have not been identified accurately. Studies of the relation of geology, hydrology, and land use to ground-water quality have not been made and strategies for protecting ground water could not be developed until knowledge of these relations could be improved.

This investigation was conducted as a cooperative effort among the Geologic Survey Division of the Michigan Department of Natural Resources, Kalamazoo County, and the U.S. Geological Survey in an attempt to address these information needs.

Purpose and Scope

This report describes the physical and chemical characteristics of surface and ground water in Kalamazoo County, relates these characteristics to geology, hydrology, and land use, and identifies areas susceptible to ground-water contamination from point and nonpoint sources. Accomplishment of these goals required a thorough understanding of the geology and hydrology of the study area, extensive water-quality sampling countywide, and the updating of existing land-use maps. Land-use data were used to estimate the quantities of selected chemicals that enter the hydrologic system. Potential input sources considered were municipal and industrial waste, animal wastes, septic tanks, agricultural fertilizers, and atmospheric deposition. A map showing the susceptibility of ground water to contamination was developed using the DRASTIC[1] system, a standardized U.S. Environmental Protection Agency (USEPA) method for evaluating contamination potential in different geohydrologic settings. This map identifies relative areas in the county that are more likely to be susceptible to ground-water contamination; it does not show areas that will be contaminated, or areas that cannot be contaminated.

This report is based on data collected from 1986 through 1988 and provides information that will be useful to water-resource planners and managers in developing ground-water protection strategies.

[1]DRASTIC is an acronym for a rating system designed to help prioritize the vulnerability of areas to ground-water contamination. The acronym stands for the rating factors used in the system: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose (unsaturated) zone, and hydraulic Conductivity.

Previous Studies

Water resources of the area were described by Allen and others (1972) in a study of the availability of water in Kalamazoo County. The glacial history of Kalamazoo County has been discussed by Leverett and Taylor (1915), Martin (1957), Deutsch and others (1960), Straw (1976), Passero (1978), Monaghan and others (1983), and Passero (1983).

Acknowledgments

The author acknowledges the assistance of personnel of the Kalamazoo County Planning Department who were responsible for the collection of land-use data that included information on fertilizer and pesticide use, acreage irrigated, animal populations, and septic-tank

installations. The Kalamazoo County Health Department provided additional information on the geology and on the quality of the ground water of the county. The Michigan Department of Public Health made partial chemical analyses of water from 35 U.S. Geological Survey observation wells. Many county and local officials, as well as citizens, provided data and took an active interest in the project.

GENERAL DESCRIPTION OF STUDY AREA

Kalamazoo County is located in southwestern Michigan (fig. 1) and has an area of 576 mi^2 (square miles). About 18 percent of the county is considered "developed" (Passero, 1978). Agriculture is the largest land-use category. The land surface is flat to rolling and ranges in elevation from 740 ft (feet) above sea level where the Kalamazoo River leaves the county, to 1,040 ft in the west-central part (fig. 2). Eight general soil types have been identified in the county (U.S. Department of Agriculture, 1979) (fig. 3). All eight soil types are suitable for cultivated crops, except in areas where steep slopes or poor drainage cause problems.

Three major drainage basins dissect the county, each of which drains west to Lake Michigan (fig. 4). The northern two-thirds of the county is drained by the Kalamazoo River and its tributaries. A small area in the western part of the county is drained by the Paw Paw River, and the remaining area in the south is drained by tributaries of the St. Joseph River. The county has 356 lakes and ponds; they range in size from less than 1 acre to 2,050 acres. The largest lake is Gull Lake in the northeastern part of the county (Humphreys and Green, 1962).

L. S. Rosen (1985), estimated the 1985 population of Kalamazoo County at 217,200 a 1.6 percent increase from the 1980 U.S. Bureau of Census figures. The two largest cities, Kalamazoo and Portage, have 65 percent of the residents of the county. Population by townships is indicated in table 1.

Mean monthly air temperatures range from 23 °F (degrees Fahrenheit) in January to 73 °F in July (National Oceanic and Atmospheric Administration, 1986). Mean annual precipitation is about 35 in. (inches). Precipitation is slightly greater in the western upland areas than in the central and eastern parts of the county.

GEOHYDROLOGY

Geology

Kalamazoo County is underlain by unconsolidated deposits that consist of glacially derived deposits of Pleistocene age and alluvial deposits of Holocene age. These deposits range in thickness from less than 50 ft in a small area in the north-central part of the county to about 600 ft in the northwestern part. Thickness of the glacial deposits and selected geologic sections are shown in figures 5 and 6. Geologic sections were produced from the elevation of bedrock-surface map (fig. 7) and the elevation of land-surface map (fig. 2). Alluvial deposits, which consist mostly of recent sand and gravel deposited in the valleys of present-day streams, are interconnected with and usually indistinguishable from glacial deposits. Therefore, the alluvial deposits are considered to be part of the glacial deposits for this report. Bedrock, which consists of the Coldwater Shale and Marshall Formation of Mississippian age, underlies the glacial deposits and are nowhere exposed at land surface (fig. 7).

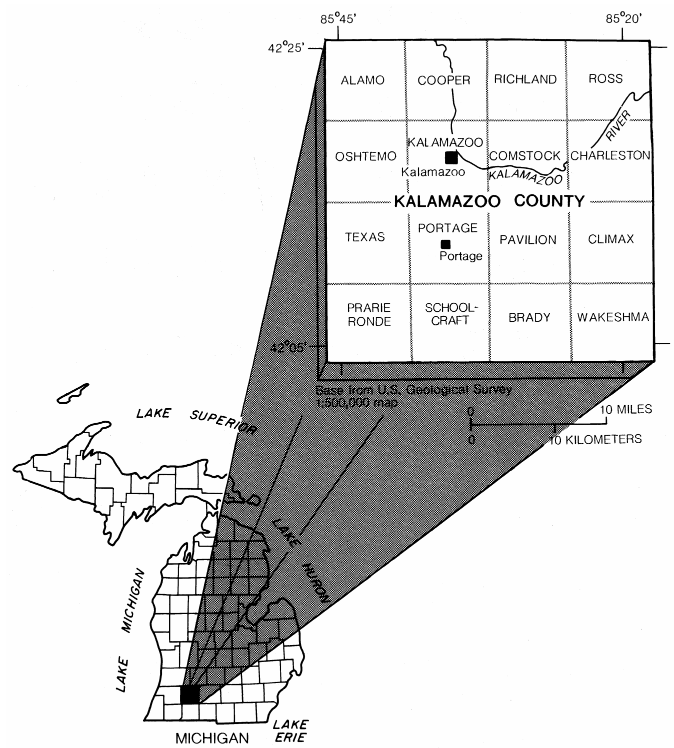


Figure 1.--Location of Kalamazoo County.

Glacial Deposits

Kalamazoo County lies in a region glaciated by a succession of several continental ice sheets. Main topographic features of the area largely were derived from the most recent continental glacier (the Wisconson), about 15,000 to 17,000 years ago (Passero, 1978). At that time, two large ice lobes, preceding the ice sheet, moved southward and came together in Kalamazoo County. The Saginaw lobe moved from the east side of the State, and the Michigan lobe moved from the west side (fig. 8). Melting of these lobes, and deposition of their entrained material, gave rise to the present-day (1989) landforms. For this report, these landforms are termed till plain, upland moraines, outwash plains, and downcut glacial drainage channels (fig. 9). The lithology of the upper part of these deposits is documented by the logs of 35 wells (table 2 and fig. 9) installed by the U.S. Geological Survey.

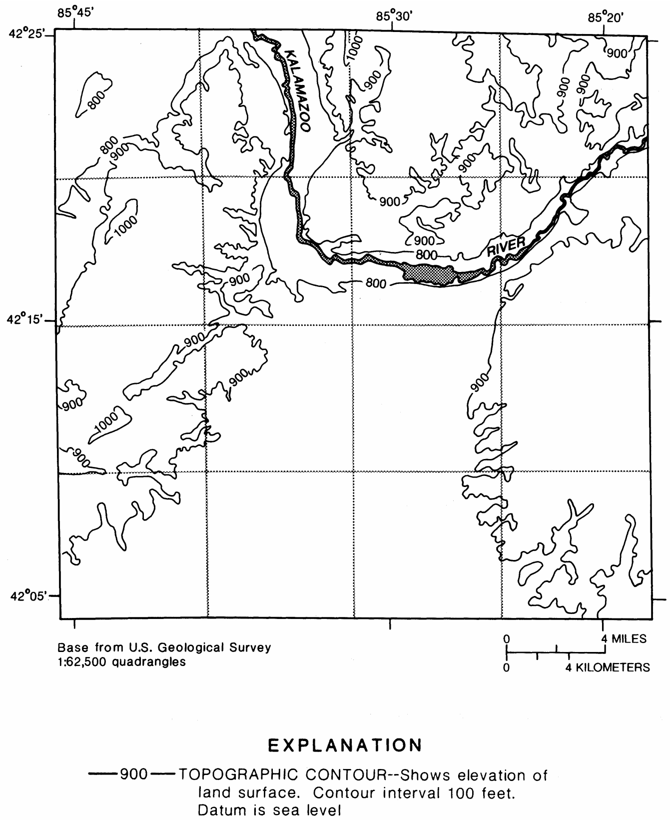


Figure 2.--Elevation of land surface.

The Saginaw lobe is thought to have arrived first and covered at least the southeastern part of the county (Martin, 1957). This lobe probably was thin and overrode previously deposited sands and gravels. The ice evaporated and melted slowly, depositing unsorted glacial drift in the undulating till plain of Climax, Wakeshma, and eastern Brady Townships (fig. 8). Monaghan and others (1983) describe the till as varying from mostly clay to primarily sand. This till seldom is more than from 15 ft thick; boulders at land surface are common. Lithologic data for wells 15, 19, 20, 21, and 22 illustrate the range of grain sizes for shallow wells in till-plain deposits (table 2).

During a subsequent advance of the ice sheet, the Michigan and Saginaw lobes merged and halted in Charleston Township (Martin, 1957) (fig. 8). In this township, the lobes deposited glacial debris, and the hills known as the Tekonsha moraine were formed (fig. 9). Monaghan and others (1983) describe the Tekonsha moraine as a composite of massive to poorly bedded, coarse sand to sandy-clay till, and at places, as massive to poorly bedded sand and gravel containing boulders and cobbles.

Some of the glacial sands and gravels washed southward from the Tekonsha moraine and were deposited over the northern part of the till plain. This sand and gravel outwash is referred to as the Climax-Scott outwash plain (fig. 9).

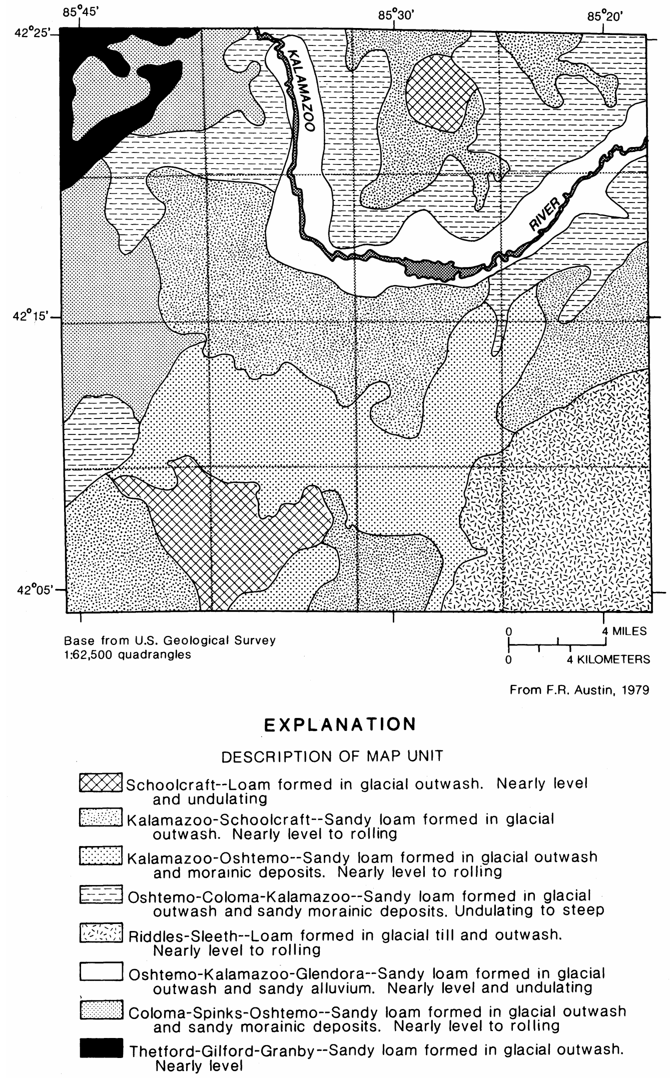


Figure 3.--Generalized soil types.

Retreat of the ice lobes from the Tekonsha moraine was rapid (Martin, 1957); the Saginaw lobe melted to the northeast and the Michigan lobe melted to the northwest. As the lobes retreated, large quantities of outwash sands and gravels, carried by the waters from the melting ice, drained southward to form the Galesburg-Vicksburg outwash plain (fig. 9). During this period, large blocks of ice broke away from the main lobes and were buried by outwash. The ice blocks within and above the outwash slowly melted and the sands and gravels collapsed to form numerous kettle lakes throughout the county. Gull Lake, in the northeastern corner of the county, is 6 mi (miles) long and 110 ft deep; this Lake is the largest of the kettle lakes (fig. 4).

The Galesburg-Vicksburg outwash primarily consists of medium to coarse sand and gravel that generally decreases in coarseness from northeast to southwest (Monaghan and others, 1983). The range of grain sizes is illustrated by lithologic logs for wells 4, 11, and 17 (table 2).

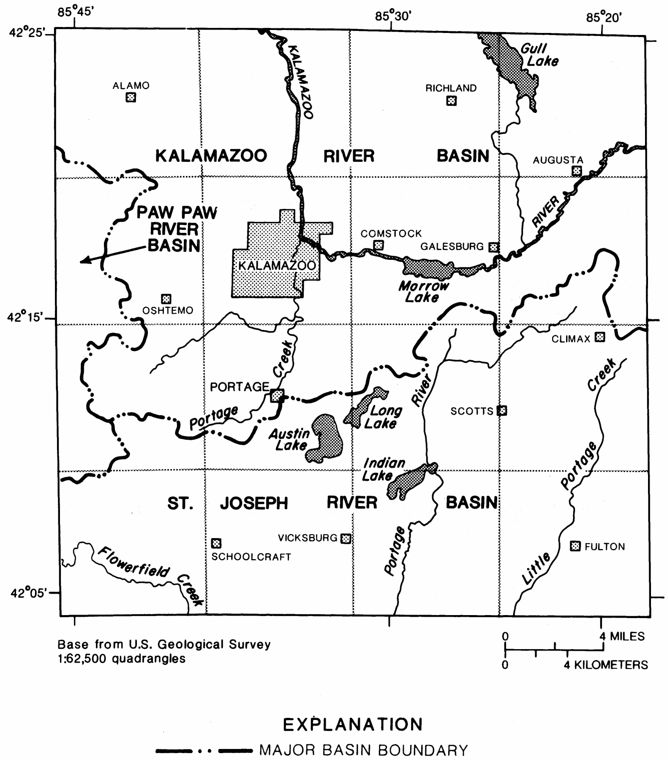


Figure 4.--Major surface-water drainage basins.

Table 1.--Estimated population in 1985, by township

Township name	1980 [1]	1985 [2] (Estimated)
Alamo	2,909	2,934
Brady	3,116	3,116
Charleston	1,719	1,769
Climax	3,353	3,353
Comstock	12,984	13,236
Cooper	8,434	8,414
Kalamazoo	102,471	103,358
Oshtemo	10,958	11,197
Pavilion	4,811	4,811
Prairie Ronde	1,189	1,250
Portage	38,157	39,911
Richland	4,677	4,703
Ross	4,776	4,811
Schoolcraft	7,171	7,261
Texas	5,643	5,782
Wakeshma	1,375	1,294

[1] U.S. Bureau of Census (1982).

[2] Reported by Kalamazoo County Planning Department (1988).

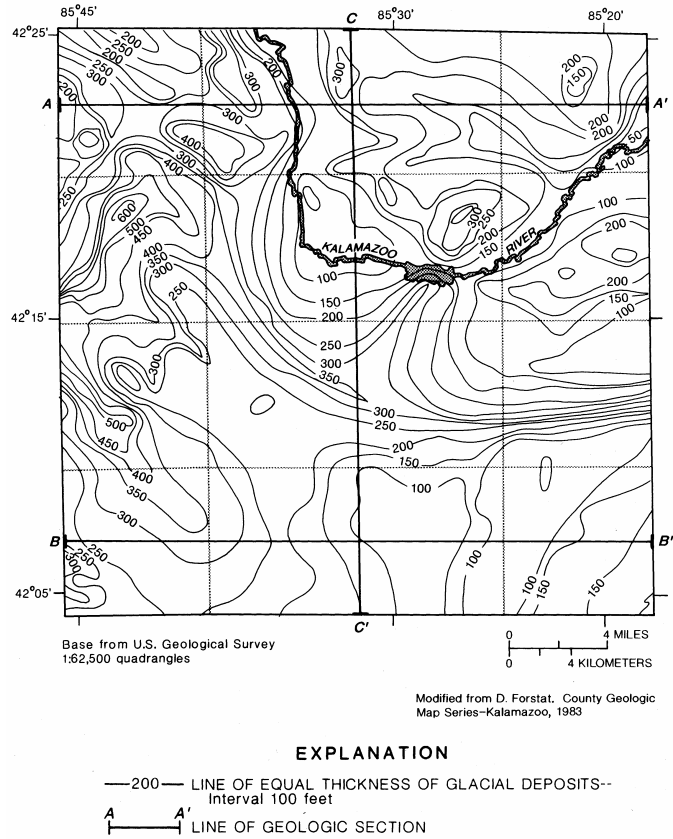


Figure 5.--Thickness of glacial deposits and location of geologic sections.

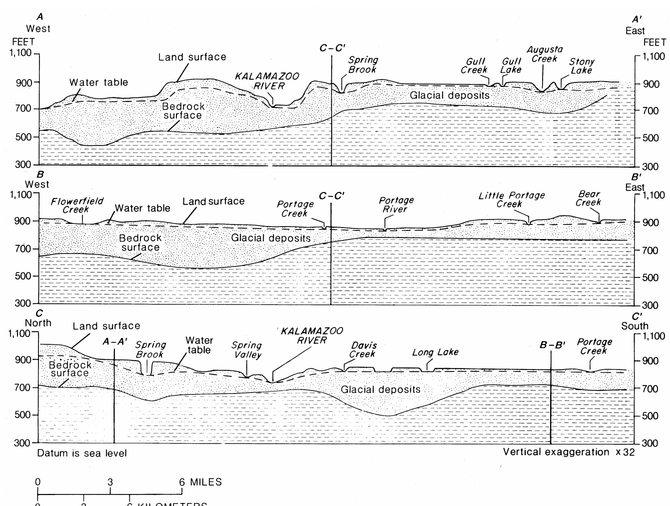


Figure 6.--Geologic sections showing thickness of glacial deposits.

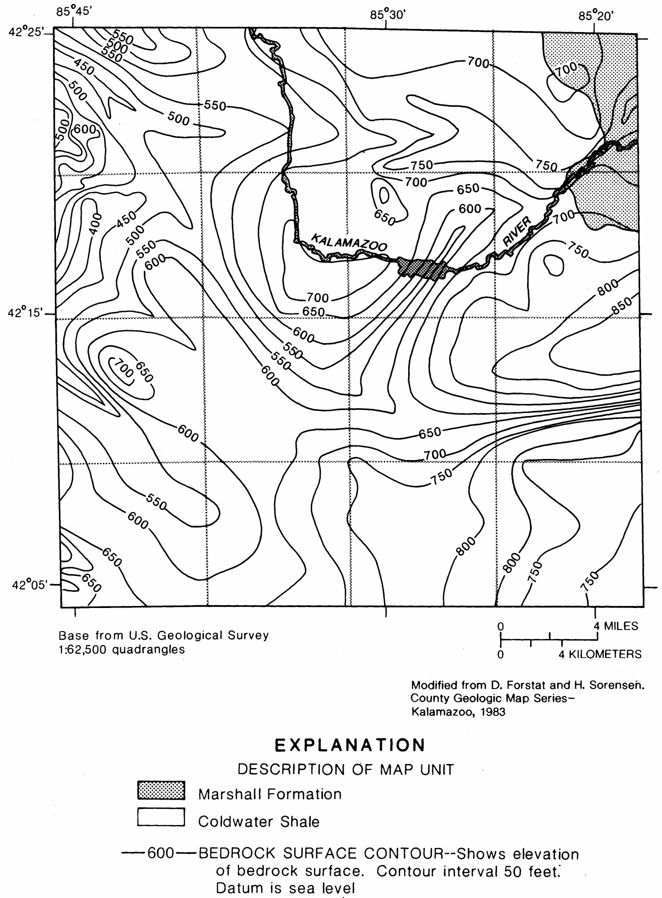


Figure 7.--Elevation and areal extent of bedrock surface.

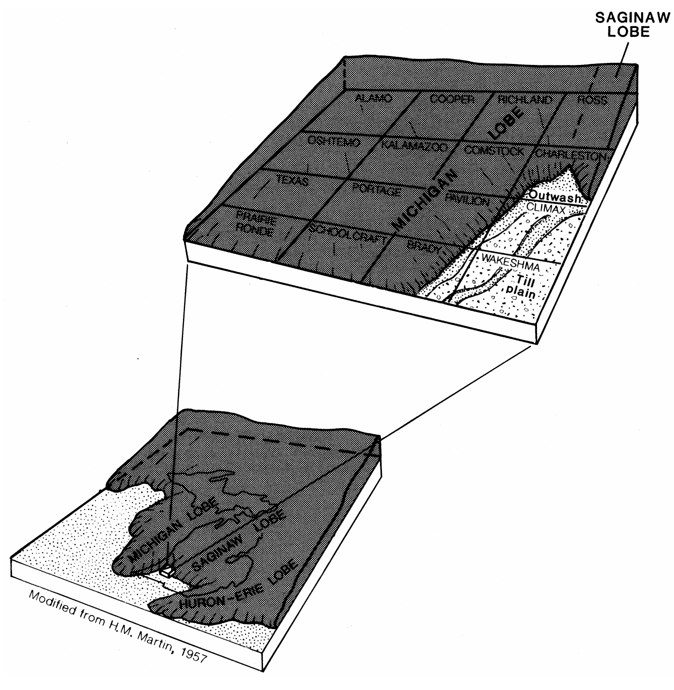


Figure 8.--Location of ice lobes in Kalamazoo County during the most recent continental glaciation.

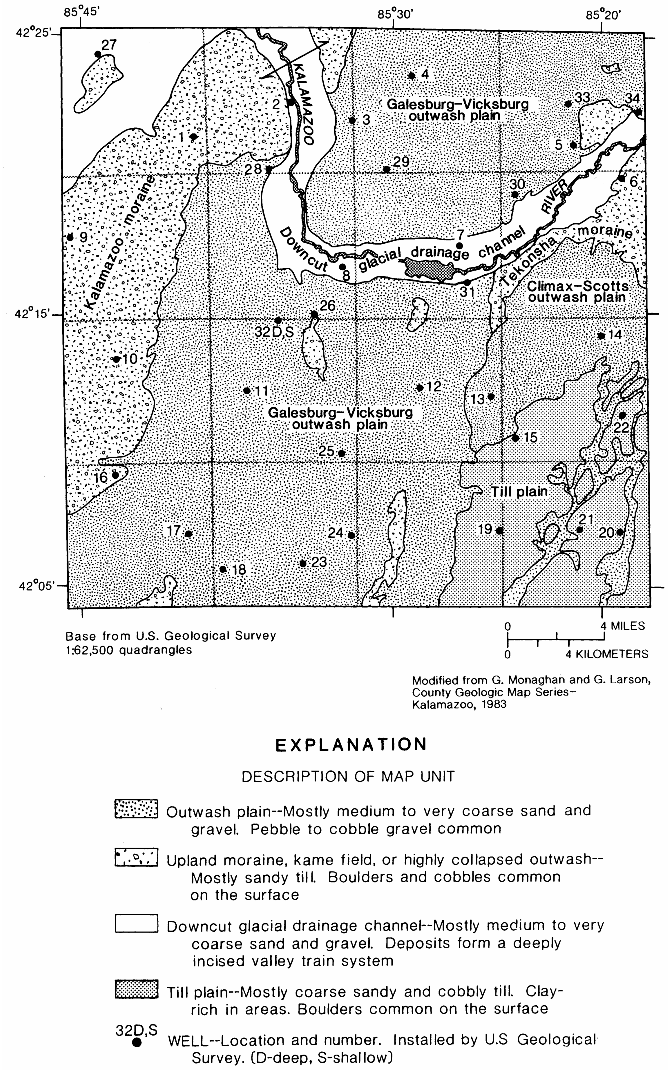


Figure 9.--Areal extent of surficial deposits.

Table 2.--Lithologic data from observation wells installed by the U.S. Geological Survey

[Well locations are shown in fig. 9 and on plate 1. All wells are cased to within 3 ft of the bottom of the hole]

Well number	Lithology	Depth to bottom (feet)
1	Sand	5
	Sand, some clay	18
	Sand and gravel	75
	Sand	90
	Sand and gravel	103
	Clay and sand	132
	Sand and gravel	146
2	Silt, sand and gravel	12
	Sand and gravel	15
	Sand and gravel, some clay	18
	Sand	20
	Sand and gravel	29
	Sand	33
	Sand and gravel	37
3	Sand	10
	Sand and gravel	18
	Sand and gravel, some clay	32
	Sand	40
4	Sand and gravel, some clay	14
	Sand	18
	Gravel	27
	Sand	49
5	Sandy clay	5
	Sandy clay, some gravel	12
	Sand and gravel	32
	Gravel	35
	Sandy clay	40
6	Sand and gravel, stones	5
	Sand and gravel	12
	Sand	15
	Sand and gravel	35
	Gravel	37
7	Sand	5
	Sand and gravel	15
	Sand	24
	Clay	25
	Gravel and sand	30
8	Sandy clay, some gravel	8
	Gravel and sand	18
	Silty sand and gravel	28
	Sand	32
	Gravel and sand	37
9	Sand	15
	Sand, some gravel	20
	Sand	55
	Sand and gravel, stones	64
	Clay	65
	Sand	70
10	Sand	5
	Sand and gravel	30
11	Sand and gravel	10
	Sand	50
	Sand, some gravel	55
	Clay	56

Table 2.--Lithologic data from observation wells installed by the Geological Survey--Continued

Well number	Lithology	Depth to bottom (feet)
12	Fill	12
	Sand and gravel	24
	Sand	28
	Gravel and sand	30
	Sand	35
	Sand and gravel	37
13	Sandy clay	4
	Sand	15
	Sand, gravel, some clay	20
	Clay, sand, and gravel	25
	Gravel, some clay	27
	Gravel and sand	35
	Clay, sand, and gravel	37
14	Sandy clay	3
	Sand	5
	Sand and gravel	22
	Sand	24
	Sand and gravel	39
15	Sandy clay	5
	Clay, sand, and gravel	10
	Sand and gravel, some clay	38
	Sand and gravel	43
	Sand and gravel, some clay	48
16	Sandy clay, gravel, stones	30
	Sand and gravel, some silt	45
	Gravel and sand, some silt	50
	Sand and gravel	52
17	Sand, some clay	3
	Sand and gravel, some silt	19
	Sand	31
18	Sand, some clay	3
	Sand and gravel	5
	Sand	18
	Sand and gravel	20
	Sand	50
19	Sandy clay and stones	5
	Sand and gravel, some clay	16
	Sandy clay, some gravel	40
	Clay, some sand and gravel	90
	Clay	102
	Gravel, some clay	103
	Sand	105
	Sandy clay	108
	Sand	112
20	Sandy clay, gravel, stones	5
	Sand and gravel, some clay	14
	Gravel and sand	15
	Sand and gravel, stones	29
	Sand	35
	Sand, some gravel	38

Table 2.--Lithologic data from observation wells installed by the Geological Survey--Continued

Well number	Lithology	Depth to bottom (feet)
21	Sandy clay	12
	Sandy clay, stones	18
	Sand, some clay	21
	Sandy clay	28
	Sand and gravel, some clay	31
	Sand and gravel, stones	37
	Sand and gravel, some clay	43
	Sand	45
	Sand and gravel	47
	Sand and gravel, clay	48
22	Sandy clay	2
	Sandy clay, gravel, stones	20
	Sand, some clay	25
	Sand and gravel, some clay	28
	Clay, some sand and gravel	35
	Sand and gravel, stones	38
23	Sand	5
	Sand, some clay	7
	Sand	10
	Sand and gravel	37
	Sand	45
	Sand and gravel	48
24	Fill	7
	Gravel and sand, some silt	18
	Sand and gravel	28
	Sand	35
	Sand and gravel	38
25	Sand	4
	Gravel and sand, some clay	14
	Gravel and sand	30
	Gravel	35
	Gravel and sand	38
26	Fill	5
	Sand, gravel, clay, stones	20
	Sandy clay, gravel	25
	Gravel and sand, some clay	28
	Sandy clay, gravel	50
	Sand	57
	Sand and gravel, stones	68
	Sandy clay	83
	Sand	89
	Sandy clay	91
27	Marl	5
	Silt	12
	Gravel and sand	15
	Gravel, stones	28
	Sand	38
28	Sandy clay, gravel, stones	20
	Sand and gravel, some clay	31
	Sandy clay, gravel	33
	Sand and gravel, stones	48
	Gravel and sand	56

Table 2.--Lithologic data from observation wells installed by the Geological Survey--Continued

Well number	Lithology	Depth to bottom (feet)
29	Sandy clay, some gravel	4
	Sand	8
	Sand and gravel	40
	Sand	65
30	Sandy clay, gravel, stones	5
	Sand and gravel, stones	12
	Sand	26
	Sand and gravel	28
31	Sand and gravel, stones	20
	Sand and gravel	35
	Sand and gravel, some silt	45
	Sand and gravel	48
[1]32	Sand	25
	Sand and gravel, some clay	28
	Sand	33
	Gravel, some clay	36
	Sand, some clay	60
	Sand and gravel, some clay	106
	Sand and gravel	120
	Sand	122
	Sand and gravel, some clay	135
	Sand and gravel	145
33	Sand and gravel, stones	15
	Sand and gravel	18
	Sand, stones	25
	Sandy clay	26
	Sand, stones	31
	Sandy clay, stones	51
	Sand and gravel, some clay	58
	Silty clay, gravel, stones	63
	Clay	70
	Sand	71
	Clay	72
	Gravel and sand	75
	Clay	76
34	Sand and gravel	20
	Sand	39
	Gravel, some clay	44
	Sandstone	62

[1]Deepest of two wells installed at this site.

The retreat of the Michigan lobe continued until the ice reached the western edge of the county. There, the lobe halted and built the massive Kalamazoo moraine which rises more than 100 ft above the outwash plain in some places. The moraine forms one of the longest continuous ridges in southern Michigan and has been traced for a distance of over 80 mi (Leverett and Taylor, 1915). Monaghan and others (1983) describe the moraine as sandy to very sandy till and massive to poorly bedded cobbly sand. Isolated lenses and pockets of sandy clay also are present. Surface boulders and cobbles are commonly found along the crest and eastern side of the moraine. Lithologic data for wells 1, 9, and 16 illustrate the variable grain sizes and materials of the Kalamazoo moraine (table 2).

Further retreat by the ice opened a drainageway in front of the Michigan lobe in Allegan and Van Buren Counties to the north and west. Ponded waters in the center of Kalamazoo County that had been draining to the south began to drain to the north through a topographic low in the moraine in Cooper Township. This change in direction of drainage resulted in downcutting of the outwash plain (by 80 to 100 ft) (Deutsch and others, 1960) and in forming the down-cut glacial-drainage channels of the present-day (1989) Kalamazoo River valley (fig. 9). Most of the drainage-channel deposits have a grain size of medium to very coarse sand to gravel with some layers of clayey silt (Monaghan and others, 1983). Lithologic data for wells 7 and 8 illustrate the range of grain sizes for drainage-channel deposits (table 2).

Eventually the ice lobes retreated out of Kalamazoo County, and new drainage channels were opened, directing meltwater away from the area. When this glacial drainage changed, the large discharge of the glacial Kalamazoo River was reduced substantially to its present size.

Bedrock

The Coldwater Shale, a bedrock formation of Mississippian age, directly underlies the glacial deposits throughout most of the county. This shale is 500 ft or more thick in the Kalamazoo area and gently dips northeastward (Deutsch and others, 1960). The Coldwater Shale primarily is composed of shale that contains limestone and clayey limestone in some areas.

The Coldwater Shale grades upward into the Marshall Formation in the northeastern part of the county (fig. 7). The Marshall Formation is composed of gray to white sandstone that consists of rounded to subangular grains of very fine to medium sand in alternating soft and hard layers (Passero, 1983).

Hydrology

Precipitation in Kalamazoo County averages 35 in/yr (inches per year), of which an estimated 12 in. (inches) is discharged by streams (Allen and others, 1972). Of the 12 in., about 3 in. originates as overland surface runoff, and about 9 in. originates as ground-water inflow (Allen and others, 1972). Evapotranspiration and regional ground-water flow out of the county account for 23 in.

Surface Water

Three surface-water basins drain Kalamazoo County. The Kalamazoo River basin (in the northern part of the county), drains 54 percent of the county. The remaining 46 percent is the St. Joseph River basin, of which 5 percent (in the western part of the county) forms the headwaters of the Paw Paw River basin, a major subbasin of the St. Joseph River system.

The U.S. Geological Survey currently (1989) operates eight streamflow-gaging stations in Kalamazoo County (pl. 1). Runoff for these stations varies from 7.05 in/yr at West Fork Portage Creek (site 23) on the upland moraine, to 15.47 in/yr, at Portage Creek (site 21) on the outwash plain. Hydrographs for four of these stations, from January 1986 to July 1988, are shown in figure 10. Kalamazoo River at Comstock (site 19) represents the largest river system in the county and has the longest period of record. Average discharge, for a 50-year period of record, is 861 ft^3/s (cubic feet per second). The maximum discharge was 6,910 ft^3/s in April 1947; the minimum discharge was 119 ft^3/s in May 1958.

During this investigation, measurements of discharge were made periodically at 23 other sites at the time water-quality samples were collected. The location of these sites and their drainage areas are shown in figure 11; maximum and minimum discharges are reported in table 3.

Kalamazoo County has over 350 lakes and ponds. They comprise about 3 percent of the county (Passero, 1983). Seven of the largest lakes, all over 200 acres in size, are Indian, Long, Austin, West, Gourdneck, Gull, and Barton Lake. Gull Lake, the largest, is about 2,000 acres (fig. 4). Morrow Lake, an impoundment of the Kalamazoo River, is about 1,000 acres.

An additional 3 percent of the county is covered by marshes or wetlands; the majority of marshes and wetlands are located in the south-central part of the county on the Galesburg-Vicksburg outwash plain (Passero, 1983). These wetlands and lakes play an important role in recharge of the ground-water system.

Ground Water

Source

Glacial deposits, consisting largely of sands and gravels, are the source of most ground-water supplies in Kalamazoo County. Data collected for this report indicate that these deposits vary in thickness and permeability, but all deposits can at least produce sufficient supply for domestic use. Aquifers underlying the outwash plains and the downcut glacial drainage channels, which together cover about two-thirds of the county, are the most productive (fig. 9). Allen and others (1972) identified an upper unconfined aquifer throughout almost the entire county and a lower semiconfined aquifer in about one-third of the county. At many locations, the hydraulic connection between the upper and lower aquifers is good enough that, under pumping stress, water will move readily between aquifers.

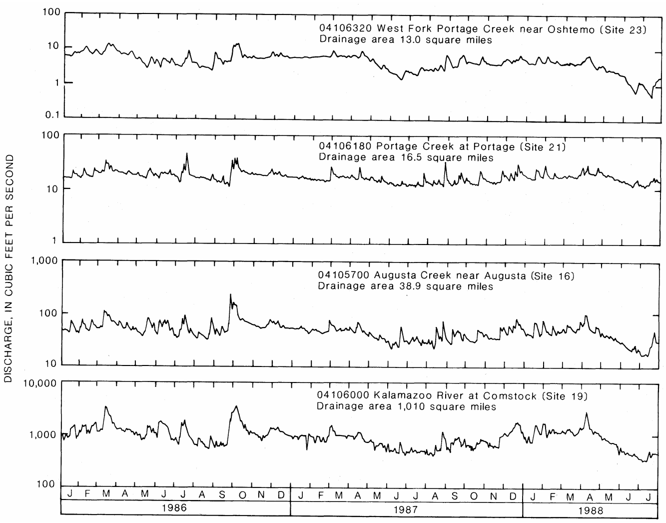


Figure 10.--Hydrographs showing discharge at selected streamflow-gaging stations, January 1986 through July 1988.

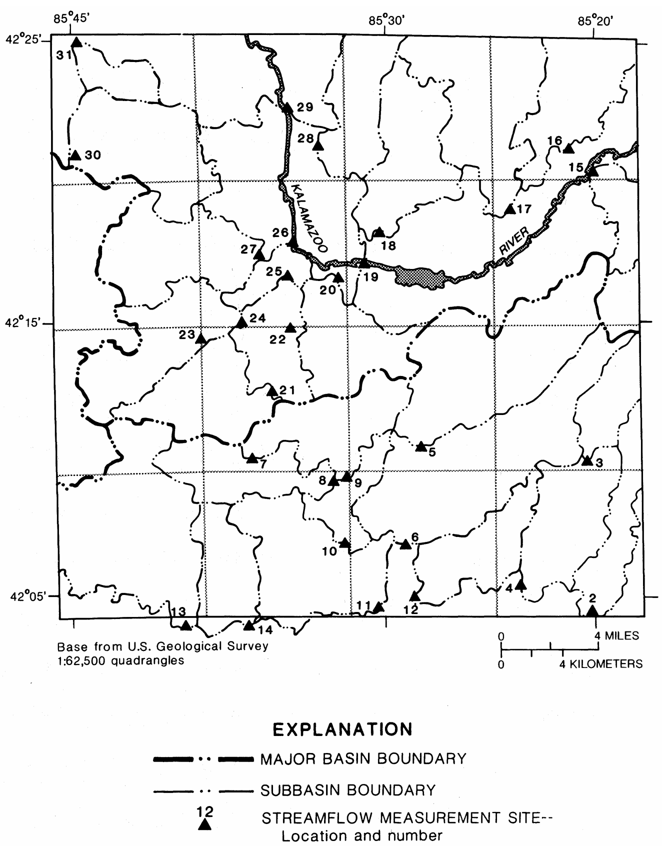


Figure 11.--Streamflow measuring sites and their corresponding drainage areas.

Table 3.--Maximum and minimum discharge at periodically measured sites, January 1986 to July 1988

[Site locations are shown in fig. 11 and on plate 1; mi^2, square miles; ft^3/s, cubic feet per second]

Site number	Drainage area	Number of measurements	Maximum (ft^3/s)	Minimum (ft^3/s)
[1]1	149	22	563	40.8
2	10.8	4	51.9	2.81
3	10.1	4	27.2	1.92
4	27.0	4	59.7	8.04
5	32.8	4	69.0	15.2
6	68.2	4	169	20.6
7	[2]--	23	2.09	.03
8	13.1	4	37.0	7.34
9	15.6	4	13.7	.52
10	35.2	4	65.0	4.75
11	57.7	4	137	29.8
12	13.1	4	48.9	3.11
[1]13	42.6	4	54.3	8.73
[1]14	10.9	4	9.15	6.28
15	7.3	4	16.0	5.15
16	38.9	23	106	21.8
17	38.1	4	102	15.4
18	18.3	4	19.5	4.54
19	1,010	22	3,610	400
20	15.2	4	[3]12.8	3.29
21	16.5	22	40.1	12.2
22	20.3	22	177	26.8
23	18.1	22	12.7	1.38
24	18.5	23	22.8	1.34
25	46.8	8	190	33.0
26	51.4	4	[4]--	37.9
27	20.0	4	6.16	3.39
28	31.1	4	30.2	17.6
29	1,250	4	2,980	482
30	21.2	4	30.5	9.33
31	5.3	4	30.7	8.32

[1] Site is located in St. Joseph County.
[2] Indeterminate. Canal diverts water from Gourdneck Creek to West Lake to sustain lake levels.
[3] Downstream from diversion channel.
[4] Not measurable. Site is under backwater from the Kalamazoo River at high stages.

The Coldwater Shale underlies glacial deposits throughout most of the county. Where a few wells have penetrated the shale, yields are small and the water is largely mineralized. Therefore, the Coldwater Shale is not used for water supply except in rare instances. In the northeastern part of the county, the Coldwater Shale grades upward to Marshall Formation. Where the glacial deposits are thin, sufficient quantities of good-quality water may be obtained for domestic use.

Allen and others (1972) grouped the upper and lower sand and gravel aquifers of Kalamazoo County into ten major ground-water reservoirs. The locations and physical descriptions of these ground-water reservoirs are reported in figure 12 and in table 4. This information is provided as a necessary framework for understanding areas that may need special ground-water protection measures.

Allen and others (1972) estimated that the ground-water resources of Kalamazoo County can support sustained withdrawals of 147 Mgal/d (million gallons per day). Current estimates indicate that ground-water withdrawals for domestic use are about 20 Mgal/d, and industrial-commercial withdrawals are from 45 to 50 Mgal/d. Much of this water is returned to the streams or to the ground-water system through recharge ponds. Even at these large withdrawal rates, the county has an adequate ground-water supply, providing that existing supplies do not become contaminated. Data in table 5 indicate the source and pumpage rate for some of the major ground-water users; data in figure 13 indicate the locations of some of the major public water-supply and industrial water-supply well fields in Kalamazoo County.

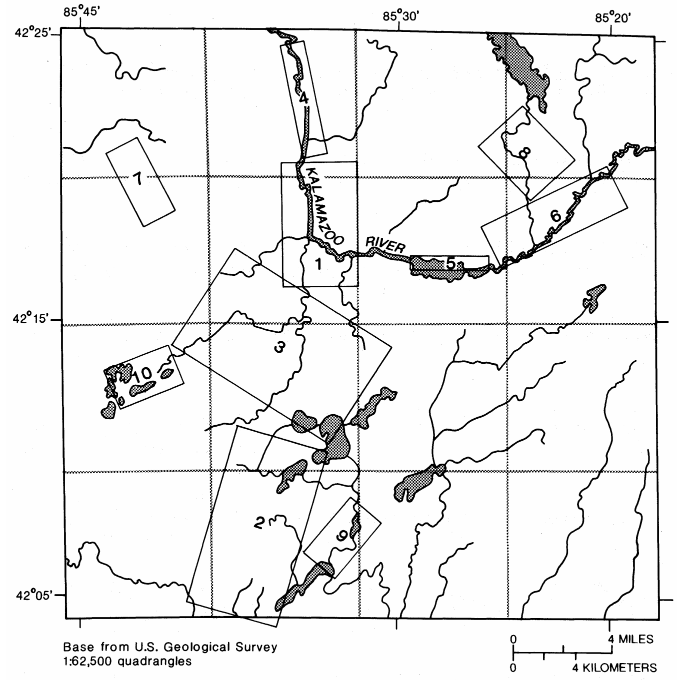
In general, the thicker the sand and gravel deposit, the more productive the aquifer. An example of these productive aquifers is the Kalamazoo-Portage ground-water reservoir, where more than 300 ft of glacial outwash overlie a buried bedrock valley. The Upjohn Company, located in the center of the valley, withdraws more than 6 billion gallons of water annually. In addition, withdrawals by the cities of Kalamazoo and Portage, with municipal wells at a number of locations, make this ground-water reservoir the most developed and heavily used in the county.

Most domestic wells in the county obtain water from the glacial sands and gravels at relatively shallow depths. Analysis of well logs of 551 domestic wells indicates that well depths range from 25 to 328 ft (fig. 14); most domestic wells are less than 75 ft deep. Wells yielding 1,000 gal/min or more for industry water supply, public water supply and irrigation are usually from 100 to 200 ft deep. Domestic wells drilled in the upland moraine areas are generally deeper (average, 108 ft) than those located in the downcut Kalamazoo River valley (average, 56 ft), because depth to water is greater.

Bedell and Van Til (1979) estimated that there are less than 50 irrigators that use ground water in Kalamazoo County. Most irrigation wells are located on the outwash plains, with yields from 500 to 1,000 gal/min common. Corn is the principal crop irrigated.

<u>Water table</u>

Generally, the configuration of the water table in Kalamazoo County (pl. 2) shows that ground water moves from topographically high areas to discharge areas in ponds, streams, marshes, and other lowland areas. Annual cycles of higher ground-water levels in spring, and lower levels in fall, were apparent. Some water also discharges to wells, especially near large-capacity wells used for municipal, industrial, or irrigation supplies. Most of the ground water in the county moves through unconfined sand and gravel systems; therefore, ground water divides closely parallel local surface-water drainage divides. Two exceptions are the following: (1) the upland moraine area in Oshtemo Township, where local surface-water runoff is to the east but regional ground-water flow is to the west; and (2) the city of Portage, where large ground-water withdrawals have lowered water levels and altered natural ground-water flow lines.



EXPLANATION

DESCRIPTION OF MAP UNIT

Ground-water reservoir and corresponding number

1 Kalamazoo River
2 Schoolcraft
3 Kalamazoo-Portage
4 Cooper
5 Morrow Lake
6 Augusta-Galesburg
7 Alamo-Oshtemo
8 Sherman Lake
9 Vicksburg
10 Texas

Figure 12.--Generalized locations of ground-water reservoirs. (From Allen and others, 1972.)

Table 4.--<u>Description of ground-water reservoirs and their potential for development</u>

[Data from Allen and others, 1972. Storage coefficients of 0.20 and 0.005 are estimated for the upper and lower aquifers, respectively; (gal/d)/ft, gallons per day per foot; Mgal/d, million gallons per day; ft, feet]

Ground-water reservoir name	Description	Transmissivity [(gal/d)/ft]	Estimated limits of development (Mgal/d)
Kalamazoo River	Located along the Kalamazoo River in Kalamazoo Township. Unconfined aquifer from 40 to 140 ft thick. Grades into the Cooper reservoir to the north.	20,000 to 120,000	[1]39
Schoolcraft	Underlies most of Schoolcraft Township. Upper unconfined aquifer from 20 to 80 ft thick. Transmissivity ranges from 40,000 to 80,000 [(gal/d)/ft]. Lower leaky-confined aquifer from 20 to 80 ft thick. Transmissivity ranges from 10,000 to 100,000 [(gal/d)/ft]. Lower aquifer grades and thins into the lower Vicksburg reservoir to the east and the lower Kalamazoo-Portage reservoir to the north.	10,000 to 100,000	[2]17
Kalamazoo-Portage	Underlies part of the cites of Kalamazoo and Portage. Upper unconfined aquifer from zero to 60 ft thick. Transmissivity ranges from 10,000 to 100,000 [(gal/d)/ft]. Two lower leaky-confined aquifers have a combined thickness of about 70 ft. Transmissivity ranges from 10,000 to 160,000 [(gal/d)/ft]. The lower Kalamazoo-Portage reservoir connects with the lower Schoolcraft reservoir to the south, the lower Texas reservoir to the west, and the upper Kalamazoo River reservoir to the north.	10,000 to 160,000	[2]24

Table 4.--Description of ground-water reservoirs and their potential for development--Continued

Ground-water reservoir name	Description	Transmissivity [(gal/d)/ft]	Estimated limits of development (Mgal/d)
Cooper	Located along the Kalamazoo River in Cooper Township. Unconfined aquifer from zero to 60 ft thick. Aquifer connects to the Kalamazoo River reservoir to the south.	20,000 to 80,000	[1]13
Morrow Lake	Underlies an area of Comstock Township where the Kalamazoo River has been dammed. Unconfined aquifer from zero to 60 ft thick. Aquifer connects to the Kalamazoo River reservoir to the west and the Augusta-Galesburg reservoir to the northeast.	40,000 to 80,000	[1]10
Augusta-Galesburg	Underlies an area from Augusta to Galesburg along the Kalamazoo River valley. Unconfined aquifer from zero to 60 ft thick. Connects to the Morrow Lake reservoir to the southwest and the Sherman Lake reservoir to the north.	20,000 to 80,000	[1]26
Alamo-Oshtemo	Underlies the southern part of Alamo Township and the northern part of Oshtemo Township. Unconfined aquifer from zero to 100 ft thick.	20,000 to 60,000	[2]3
Sherman Lake	Underlies an area extending from Gull Lake on the north to Augusta on the south. Unconfined aquifer from zero to 80 ft thick. Connects to the Augusta-Galesburg reservoir to the south.	20,000 to 140,000	[2]6

Table 4.--Description of ground-water reservoirs and their potential for development--Continued

Ground-water reservoir name	Description	Transmissivity [(gal/d)/ft]	Estimated limits of development (Mgal/d)
Vicksburg	Underlies the village of Vicksburg and surrounding area. Upper unconfined aquifer averages 20 ft thick. Transmissivity ranges from 20,000 to 40,000 [(gal/d)/ft]. Lower leaky confined aquifer averages 40 ft thick. Transmissivity ranges from 20,000 to 60,000 [(gal/d)/ft]. Both upper and lower aquifers join the upper and lower aquifers of the Schoolcraft reservoir to the west.	20,000 to 60,000	[2]6
Texas	Underlies the central part of Texas Township. Upper unconfined aquifer averages 80 ft thick. Transmissivity ranges from 20,000 to 80,000 [(gal/d)/ft]. Lower leaky confined aquifer averages 50 ft thick. Transmissivity ranges from 20,000 to 140,000 [(gal/d)/ft]. Both upper and lower aquifers join the upper and lower aquifers of the Kalamazoo-Portage reservoir to the east.	20,000 to 140,000	[2]3

[1]Sustained by induced recharged from overlying river or streams.

[2]Estimated withdrawal rate for a 180 day period without recharge.

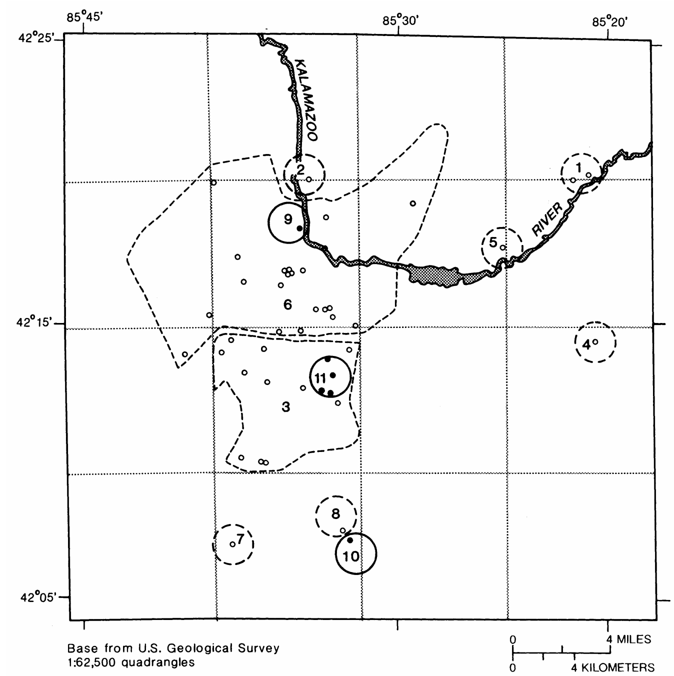
Table 5.--Source of water and pumpage rate for major communities and industries

[All wells tap glacial deposits. Well-field locations shown in figure 13. ft, feet; Mgal, millon gallons]

Name of community or industry	Depth of wells (ft)	Number of wells in service	Total pumpage[2] in 1987 (Mgal)
Community			
Augusta	105-110	2	30.4
City of Parchment	50-55	3	167.1
City of Portage	92-184	19	1,373.7
Climax	115-120	3	12.4
Galesburg	64-66	2	75.9
Kalamazoo area[1]	130-254	84	6,450.3
Schoolcraft	196-200	2	55.3
Vicksburg	154-154	2	112.7
Industry			
James River	30-60	6	2,555.0
Simpson Paper	90-90	2	310.0
Upjohn Company	150-170	25	8,235.7

1 The city of Kalamazoo has water-distribution agreements with the townships of Kalamazoo, Cooper, Richland, Comstock, Oshtemo, Texas, and part of Pavilion.

2 Reported by community or industry.



EXPLANATION

(4) APPROXIMATE BOUNDARY OF PUBLIC WATER-SUPPLY SERVICE AREA--Number indicates community (1-Augusta, 2-Parchment, 3-Portage, 4-Climax, 5-Galesburg, 6-Kalamazoo, 7-Schoolcraft, 8-Vicksburg)

(11) APPROXIMATE BOUNDARY OF INDUSTRIAL WATER-SUPPLY SERVICE AREA--Number indicates industry (9-James River, 10-Simpson Paper, 11-Upjohn Company)

○ PUBLIC WATER-SUPPLY WELL FIELD

● INDUSTRIAL WATER-SUPPLY WELL FIELD

Figure 13.--Location of major public water-supply and industrial water-supply well fields.

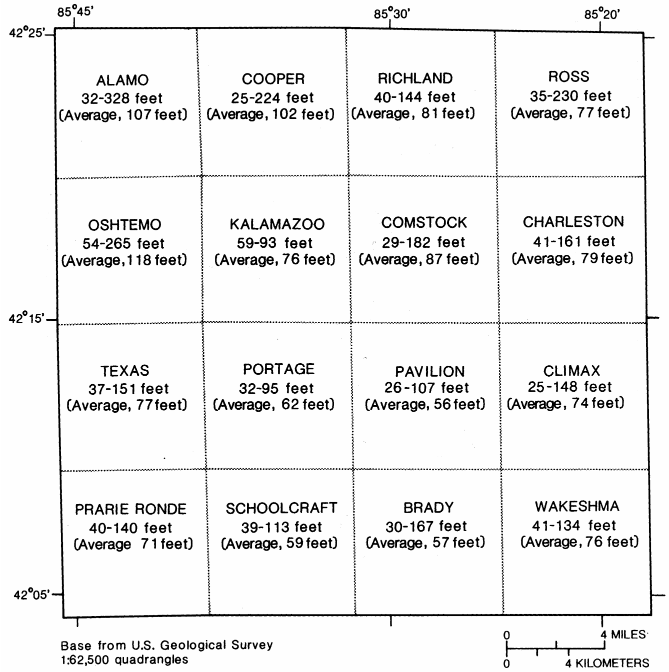


Figure 14.--Range in depth of domestic water wells, by township.

Changes in water levels

Ground-water levels in Kalamazoo County reflect short- and long-term changes in precipitation and local pumpage. To document long-term trends, the U.S. Geological Survey operates 15 continuous ground-water recorders; periods of record range from 7 to 30 years. Of these recorders, only water levels in well 37 (pl. 1), located in Schoolcraft Township, are unaffected by pumping. A hydrograph of this well shows the effects of changes in precipitation during the last 20 years (1969-88) (fig. 15). Annual cycles are apparent; however, ground-water levels throughout the area fluctuate only from 2 to 3 ft. even during extended dry periods, such as the summer of 1988. Data in figure 15 also compares ground-water fluctuations to monthly precipitation.

To improve understanding of how water levels fluctuate in different glacial deposits, ground-water recorders were installed on wells at selected locations. Changes in water levels in four different surficial deposits and the Kalamazoo River were compared to daily precipitation data for a 1-yr period (fig. 16).

Water levels in well 1, located in the Kalamazoo moraine in Alamo Township, dropped about 1 ft between August 1987 and February 1988. The well, screened at a depth from 143 to 146 ft, is open to the lower semiconfined aquifer. The water levels do not respond rapidly to rainfall and snowmelt but do respond to nearby domestic pumping.

Water levels in the outwash plain (well 18) and in the till plain (well 21) respond relatively quickly to rainfall and snowmelt. Well 18, in Schoolcraft Township, is screened from 44 to 48 ft. Water levels in this well fell slowly from August until December 1987 and then rose about 2.5 ft between December 1987 and April 1988. Water levels fell rapidly, by about 2 ft, from April until July 1988. Water levels in well 21, located in the till plain in Wakeshma Township and screened at a depth from 44 to 47 ft., have similar responses to rainfall and snowmelt; however, the water levels in this well are more affected by local domestic pumpage. These responses indicate that well 21 is partly confined by the sandy clay till above the aquifer (table 2).

Well 31, located in the downcut glacial drainage channel in Comstock Township, is screened from 24 to 28 ft and is hydraulically connected to the Kalamazoo River. Although the well is about 1,000 ft away from Morrow Lake, an impoundment of the Kalamazoo River, water levels change in a pattern similar to changes in stage of the Kalamazoo River (site 19), which is located 1 mi downstream from the Morrow Lake Dam. An exception occurred in the spring and summer of 1988 when the newly built Morrow Lake well field was put into operation. The well field, located 100 ft south of Morrow Lake, produces about 2,400 gal/min of water. The hydrograph of well 31, approximately 900 ft away, indicates that the water levels declined for more than 2 mo (months). Allen and others (1972) reported that the siltation of Morrow Lake limits the rate at which induced infiltration can occur.

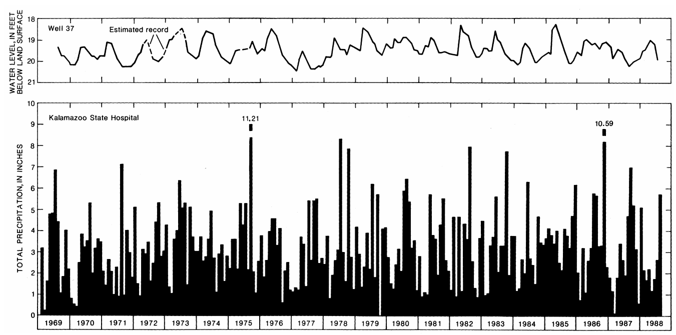


Figure 15.--Hydrograph of well 37 and monthly record of precipitation, 1969-88.

Water levels also were measured seasonally at 65 observation wells in the county during a 2-yr period (pl. 1). The maximum depth to water was 97 ft (well 1); however, one well (well 27) flowed at land surface. Based on water-level measurements and well-log data, there seems to be a correlation between water levels and the type of geologic materials. Wells in the upland moraine had the greatest depth to water (about 35 ft) and the least fluctuation. Wells in the downcut glacial drainage channels had the shallowest depth to water (about 11 ft) and the greatest fluctuation.

Recharge

In Kalamazoo County, because of the permeable sands and gravels, a close interconnection between surface- and ground-water systems exits. During drier periods, flow of streams is almost entirely maintained by ground-water inflow. During wet periods, stored runoff in lakes and marshes help recharge the aquifers. Some streams in the uplands lose water to aquifers as they flow over sand and gravel. Some streams lose water in areas where pumping has lowered water levels thereby allowing additional induced recharge into the aquifers.

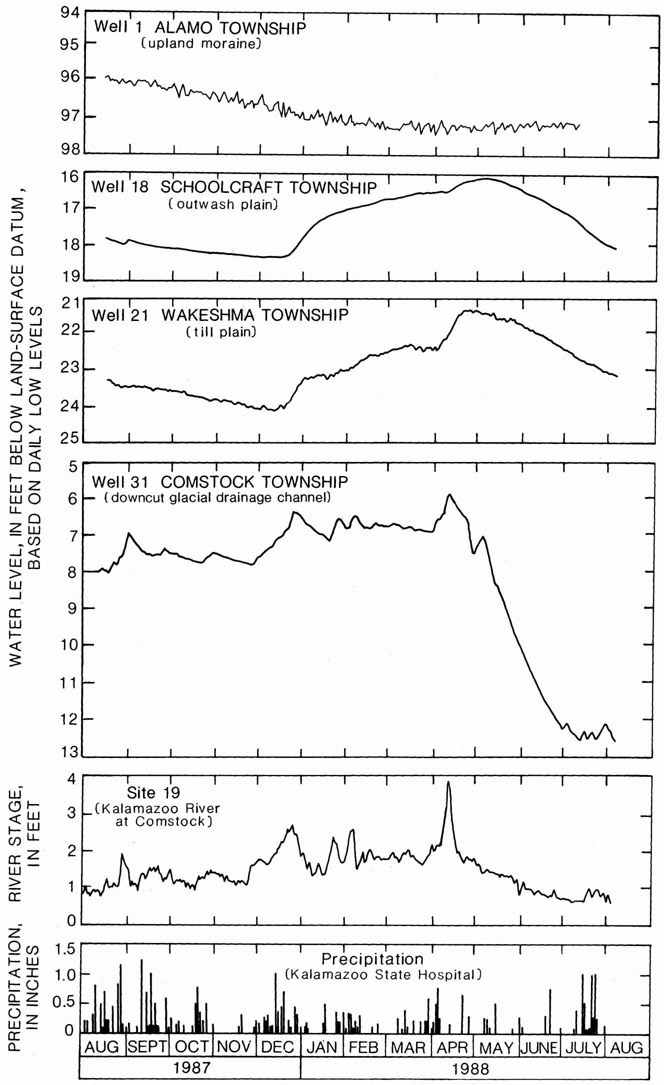


Figure 16.--Hydrographs of selected wells, the Kalamazoo River, and daily precipitation, August 1987 through August 1988.

Recharge to the aquifers from infiltration of precipitation occurs during periods of greater precipitation and lesser evapotranspiration, generally from November through May. Some recharge may occur during any month following intense rainfall events. The quantity of ground-water recharge can be estimated if ground-water runoff can be determined. This accounting, which includes precipitation, total runoff, and water loss, is commonly referred to as a hydrologic budget. Precipitation and total runoff can be determined from long-term records. Water loss can be computed as the difference between precipitation and total runoff. Water loss includes evapotranspiration, storage, subsurface underflow, and ground-water withdrawals. Allen and others (1972) estimated storage and subsurface underflow to be minimal over the long term, but they indicated that ground-water evapotranspiration and withdrawals in some areas may be substantial. Therefore, ground-water recharge estimated by this method may be considered minimum recharge.

In Kalamazoo County, ground-water recharge rates, for different geologic settings, were estimated from ground-water runoff to the streams (table 6). Stream discharge was separated into its components of surface- and ground-water runoff. Ground-water runoff was determined for each station by using a hydrograph separation technique described by Freeze and Cherry (1979, p 225 to 226). This method uses base-flow recession curves that show the rate of streamflow decline during periods of little or no precipitation.

Hydrograph separations were done on four surface-water records for three different calendar years. An average ground-water recharge value was computed using the low-, median-, and high-precipitation years (1971, 1977, and 1985, respectively) for the period 1969 to 1988, for each major surficial material type. Augusta Creek near Augusta (site 16), used to calculate ground-water recharge in the outwash plain area (60.3 percent of the county), had the greatest average recharge rate (10.86 in/yr). West Fork Portage Creek at Kalamazoo (site 24), which was used to calculate ground-water recharge to the upland moraine area (17.9 percent), had the least average recharge rate (5.87 in/yr). The Kalamazoo River at Comstock (site 19), used to calculate ground-water recharge to the downcut glacial drainage channels (12.1 percent), had an average recharge rate of 8.79 in/yr. Nottawa Creek near Athens (site 1), used to calculate ground-water recharge to the till plain (9.6 percent), had an average recharge rate of 6.89 in/yr. Based on the preceding rates, a countywide weighted average ground-water recharge rate was estimated to be 9.32 in/yr, which is similar to the 9 in/yr estimated by Allen and others (1972).

Table 6.--Estimated ground-water recharge rates based on ground-water runoff to streams located in different geologic settings

[Site location shown on plate 1. Average value given in parenthesis. in/yr, inches per year]

Site number	U.S. Geological Survey Station number, name, and geologic setting	Year	Precipi-tation (in/yr)	Water loss (in/yr)	Total runoff: Surface-water (in/yr)	Total runoff: Ground-water (in/yr)
1	04096900	1971	32.10	23.56	2.41	6.13
	Nottawa Creek	1977	37.42	30.18	2.20	5.04
	near Athens	1985	45.81	29.85	6.45	9.51
	(till plain)		(38.44)	(27.86)	(3.69)	(6.89)
16	04105700	1971	32.10	19.97	2.57	9.56
	Augusta Creek	1977	37.42	24.46	3.20	9.76
	near Augusta	1985	45.81	27.07	5.48	13.26
	(outwash)		(38.44)	(23.83)	(3.75)	(10.86)
19	04106000	1971	32.10	21.96	2.73	7.41
	Kalamazoo River at	1977	37.42	27.86	2.36	7.20
	Comstock (downcut	1985	45.81	28.47	5.57	11.77
	glacial drainage		(38.44)	(26.10)	(3.55)	(8.79)
	channels)					
24	04106400	1971	32.10	24.11	1.31	6.68
	West Fork Portage	1977	37.42	31.33	1.38	4.71
	Creek at Kalamazoo	1985	45.81	37.82	1.77	6.22
	(upland moraine)		(38.44)	(31.09)	(1.49)	(5.87)

WATER QUALITY

Quality of Precipitation, Surface Water, and Ground Water

In this section of the report, information on the physical and chemical characteristics of water is discussed. The results of analyses for data collected on atmospheric deposition, surface-water, and ground-water quality samples are tabulated and included at the back of this report. Some of these analyses also have been published in the annual series of U.S. Geological Survey hydrologic data reports (U.S. Geological Survey, 1987, 1988).

Precipitation

Rainfall, snow, and dry-fallout data were collected at two locations geographically aligned in the direction of prevailing winds, which is southwest to northeast. The stations, located at Schoolcraft in the southwestern corner of the county and at Galesburg in the northeastern part of the county (pl. 1), were operated from October 1986 through October 1987, by using automatic samplers. The quantity, values of specific conductance and pH of rainfall or snow were measured immediately following significant precipitation events. Analyses of nitrogen, phosphorus, and sulfate concentrations were made periodically. Analyses of common inorganic substances were sampled once at each site.

Sixty-one measurements of specific conductance and pH were made. Figure 17 is a plot of all measurements at both stations. Specific conductance of rainfall ranged from 4.3 to 80.9 µS/cm (microsiemens per centimeter at 25 degrees Celsius). The mean value was 34 µS/cm, and the median value was 31.5 µS/cm. The pH of rainfall ranged from 3.9 to 5.4; the median value was 4.3. In general, the lesser the pH of rainfall and snow, the greater the specific conductance. Specific conductance and pH values are slightly larger than median values found at two stations in Van Buren County (Cummings and others, 1984), which were 24 µS/cm and 4.1.

Nitrogen, phosphorus, and sulfate analyses of rainfall and snow at both stations were made at or about 2-month intervals, after major precipitation events (table 7). Data in table 8 indicate the maximum, minimum, and mean concentrations of these substances in rainfall and snow.

Concentrations of nitrogen, phosphorus, and sulfate in precipitation are similar to that indicated in other studies within southwestern Michigan. In a study of the upper St. Joseph River basin, Cummings (1978) reported the mean concentrations of the following: Ammonia, 0.48 mg/L (milligrams per liter); organic nitrogen, 0.41 mg/L; nitrite, 0.01 mg/L; nitrate, 0.58 mg/L; total nitrogen, 1.5 mg/L; orthophosphorus, 0.02 mg/L; and total phosphorus, 0.05 mg/L. In a study of Van Buren County, Cummings and others (1984) reported these mean concentrations as follows: Ammonia, 0.39 mg/L; organic nitrogen, 0.12 mg/L; nitrite, 0.01 mg/L; nitrate, 0.59 mg/L; total nitrogen, 1.0 mg/L; orthophosphorus, 0.01 mg/L; total phosphorus, 0.02 mg/L; and dissolved sulfate, 2.5 mg/L. The preceeding data indicates that these substances in precipitation do not differ appreciably across this area of the State.

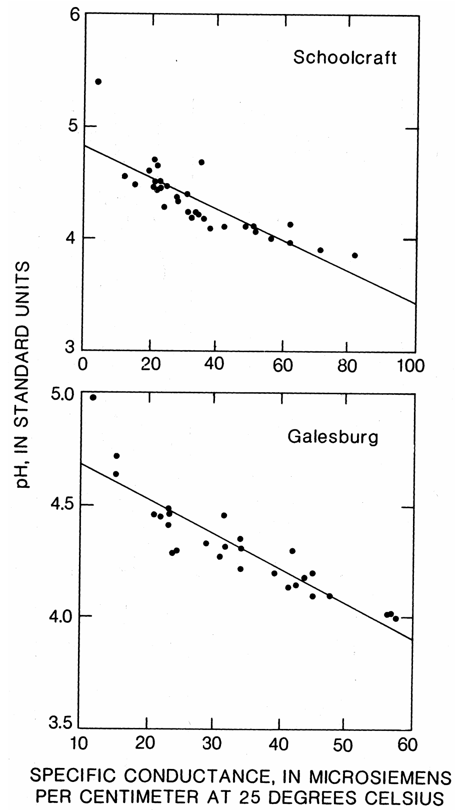


Figure 17.--Relation of specific conductance to pH of rainfall and snow at Schoolcraft and Galesburg.

Table 7.--Physical and chemical characteristics of precipitation at Galesburg and Schoolcraft

[Analyses by U.S. Geological Survey. --, no data collected; <, less than; µg/cm, micrograms per centimeter; mg/L, milligrams per liter]

421803085235701--Precipitation Gage at Galesburg, Michigan

Date of sample	Precipitation inches: Rain	Precipitation inches: [1]Snow	Specific conductance (µS/cm)	pH (standard units)	Sulfate dissolved (mg/L as SO_4)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen total (mg/L as N)	Phosphorus, ortho, total (mg/L as P)	Phosphorous total (mg/L as P)
Nov. 27, 1986	0.80	--	25	4.30	2.1	0.200	<0.010	0.29	0.20	0.70	0.020	0.020
Jan. 10, 1987	--	0.70	12	4.98	2.7	.270	<.010	.39	.13	.80	.010	<.010
Mar. 13, 1987	--	.45	42	4.30	4.1	1.20	<.010	1.69	1.2	4.10	.080	.080
May 18, 1987	.40	--	23	4.46	2.7	.370	<.010	.39	.43	1.20	<.010	<.010
June 21, 1987	3.10	--	26	--	4.0	.480	<.010	.39	.52	1.40	.010	.230
July 29, 1987	1.20	--	32	4.32	3.1	.520	<.010	.29	.08	.90	<.010	.010
Sep. 10, 1987	1.55	--	57	4.02	6.5	.930	<.010	.69	.0	1.40	<.010	.021

420717085394201--Precipitation Gage at Schoolcraft, Michigan

Date of sample	Precipitation inches: Rain	Precipitation inches: [1]Snow	Specific conductance (µS/cm)	pH (standard units)	Sulfate dissolved (mg/L as SO_4)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen organic total (mg/L as N)	Nitrogen total (mg/L as N)	Phosphorus, ortho, total (mg/L as P)	Phosphorous total (mg/L as P)
Nov. 27, 1986	0.30	--	15	4.50	1.3	0.110	<0.010	0.19	1.1	1.40	<0.010	0.010
Jan. 10, 1987	--	0.40	28	4.39	2.9	.420	<.010	.490	0.28	1.20	<.010	<.010
Mar. 13, 1987	--	.35	35	4.70	--	1.00	<.010	1.59	.40	3.00	.021	.010
May 18, 1987	.60	--	23	4.46	2.3	.370	<.010	.39	.33	1.10	<.010	<.010
July 29, 1987	.85	--	31	4.42	3.9	.620	<.010	.490	1.10	2.20	<.010	<.010
Sep. 10, 1987	.70	--	56	4.02	6.5	.840	<.010	.69	.0	1.50	<.010	<.010

[1]Water equivalent.

Table 8.--Maximum, minimum, and mean concentrations of nitrogen, phosphorus, and sulfate in rainfall and snow

[Analyses by the U.S. Geological Survey. Concentrations are in milligrams per liter]

Constituent	Concentration (mg/L)		
	Maximum	Minimum	Mean
Dissolved sulfate, as SO_4	6.5	1.3	3.5
Total ammonia, as N	1.2	.20	.56
Total organic nitrogen, as N	1.2	.00	.44
Total nitrite, as N	<.01	.00	<.01
Total nitrate, as N	1.7	.19	.61
Total nitrogen, as N	4.1	.70	1.6
Total orthophosphorus, as P	.08	.00	.01
Total phosphorus, as P	.23	.00	.03

Analysis of a single sample collected at each station indicates that a wide range of substances are present in rainfall. Data in table 9 list the results of these analyses. A comparison of data collected at each station indicates that the chemical characteristics of precipitation did not differ appreciably in the county.

Nitrogen, phosphorous, and sulfate deposition by precipitation in Kalamazoo County have been estimated using precipitation data collected at two long-term stations operated by the National Oceanic and Atmospheric[2], Administration, and at the two U.S. Geological Survey precipitation stations operated during this study (table 7). From October 1986 to October 1987, mean precipitation at the two long-term stations was 33 in., about 2 in. less than the long-term mean for the county. Deposition by rainfall and snow was estimated by using a mean annual precipitation of 33 in. and the mean concentrations indicated in table 8. Data in table 10 indicate these deposition rates. These deposition values were in reasonable agreement with values reported in neighboring Van Buren County by Cummings and others (1984).

[2]Stations are at the Kalamazoo State Hospital, at Kalamazoo, and at the Gull Lake Biological Station, at Gull Lake.

A two-bucket automatic sampler that opened and closed in response to rain and snow was used to collect samples of dry fallout at Schoolcraft and at Galesburg. Buckets containing dry material were removed at intervals ranging from 2 to 3 month. Dry fallout was removed by washing the bucket with 500 milliliters of distilled water, allowing the dry fallout to remain in contact with the water for 24 hours, and then filtering. The material collected on the filter paper was dried and weighed; the leachate was analyzed for nitrogen, phosphorus, and sulfate compounds (table 11).

The average quantity of filterable dry material collected at both stations was 0.041 gram per month, a rate that is similar to the 0.024 gram per month reported by Cummings and others (1984) in Van Buren County, and the 0.030 gram per month reported by Grannemann (1984) in Marquette County. The nitrogen, phosphorus, and sulfate leached by the above mentioned method did not differ significantly from one station to the other. Based on the preceding data, the quantity of leachable nutrients from dry fallout in Kalamazoo County was estimated (table 12).

Table 9.--Analyses of rainfall at Galesburg and Schoolcraft

[Analyses by U.S. Geological Survey. mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no analysis made]

Constituent	Concentration	
	At Galesburg (June 21, 1987)	At Schoolcraft (June 20, 1987)
Acidity as H+ (mg/L)	0.1	0.1
Alkalinity as $CaCO_3$ (mg/L)	<1.0	<1.0
Aluminum, total (µg/L)	10	<10
Arsenic, total (µg/L)	<1	<1
Barium, total (µg/L)	<100	<100
Boron, total (µg/L)	<10	<10
Calcium, dissolved (mg/L)	.12	.22
Chloride, dissolved (mg/L)	.3	.2
Chromium, total (µg/L)	20	70
Cobalt, total (µg/L)	<1	4
Copper, total (µg/L)	3	12
Cyanide, total (mg/L)	<.01	<.01
Fluoride, dissolved (mg/L)	<.1	<.1
Iron, dissolved (µg/L)	<3	<6
Iron, total (µg/L)	70	20
Lead, total (µg/L)	<5	<5
Magnesium, dissolved (mg/L)	<.01	<.01
Manganese, dissolved (µg/L)	<1	3
Manganese, total (µg/L)	<10	<10
Nickle, total (µg/L)	<1	<1
Potassium, dissolved (mg/L)	<.1	<.1
Silica, dissolved (mg/L)	0	0
Sodium, dissolved (mg/L)	<.2	<.2
Solids, residue, dissolved (mg/L)	3	3
Strontium, total (µg/L)	<10	<10
Zinc, total (µg/L)	10	10
Phenols, total (µg/L)	3	--

Table 10.--Nitrogen, phosphorus, and sulfate deposition by rainfall and snow

[Units are pounds per acre per year, [(lb/acre/)/yr] and tons per square mile per year, [(ton/mi²)/yr]]

Constituent	Nitrogen (as N), Phosphorus (as P), and Sulfate (as SO_4) deposition	
	(lb/acre)/yr	(ton/mi²)/yr
Dissolved sulfate	26.1	8.25
Total ammonia	4.22	1.35
Total organic nitrogen	3.37	1.08
Total nitrite	.075	.024
Total nitrate	4.60	1.47
Total nitrogen	12.1	3.86
Total orthophosphorus	.120	.038
Total phosphorus	.240	.076

Combining the dry fallout deposition with that estimated for rainfall and snow (table 10), total deposition of sulfate, nitrogen, and phosphorus from atmospheric sources is 30.7, 13.2, and 0.3 (lb/acre)/yr, respectively. For nitrate the corresponding value is 1.68 (ton/mi²)/yr or 5.24 (lb/acre)/yr.

Table 11.--Chemical characteristics of dry fallout at Galesburg and Schoolcraft

[Analysis by U.S. Geological Survey. mg/L, milligrams per liter; --, no data collected; <, less than]

421803085235701--Dry fallout gage at Galesburg, Michigan

Period of data collection From	Period of data collection To	Sulfate dissolved (mg/L as SO_4)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, Nitrate dissolved (mg/L as N)	Nitrogen, organic dissolved (mg/L as N)	Nitrogen total dissolved (mg/L) as N	Phosphorous ortho, dissolved (mg/L as P)	Phosphorous dissolved (mg/L as P)
10-23-86	01-05-87	22	2.00	<0.010	3.79	0.60	6.40	0.020	0.110
01-12-87	02-26-87	10	1.10	<.010	2.69	.60	4.40	<.010	<.010
02-26-87	05-18-87	29	.310	.010	3.19	1.6	5.10	.130	.170
05-18-87	08-10-87	23	[1].81	<.010	.93	[1].17	[1]1.14	[1].54	.720
08-10-87	10-06-87	18	1.30	<.010	1.49	1.1	3.90	.150	.200

420717085394201--Dry fallout gage at Schoolcraft, Michigan

Period of data collection From	Period of data collection To	Sulfate dissolved (mg/L as SO_4)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, Nitrate dissolved (mg/L as N)	Nitrogen, organic dissolved (mg/L as N)	Nitrogen total dissolved (mg/L) as N)	Phosphorous ortho, dissolved (mg/L as P)	Phosphorous dissolved (mg/L as P)
10-22-86	01-05-87	23	4.30	<0.010	5.59	0.10	10.0	0.070	0.130
01-05-87	02-26-87	9.8	2.10	<.010	2.89	.30	5.30	<.010	<.010
02-26-87	05-18-87	22	.240	<.010	3.19	1.1	4.50	.070	.100
05-18-87	08-10-87	23	[1].51	<.010	1.29	[1].42	[1]1.80	[1].55	.850
08-10-87	10-06-87	13	.630	<.010	1.59	.63	3.30	.220	.340

[1] Estimated data.

Table 12.--Nitrogen, phosphorus, and sulfate deposition by dry fallout

[Units are pounds per acre per year, [(lb/acre/)/yr] and tons per square mile per year, [(ton/mi²)/yr]]

Constituent	Dry fallout (lb/acre)/yr	Dry fallout (ton/mi²)/yr
Dissolved sulfate, as SO_4	4.63	1.48
Ammonia, as N	.32	.10
Organic nitrogen, as N	.16	.051
Nitrite, as N	.0024	.0008
Nitrate, as N	.64	.21
Nitrogen, total dissolved, as N	1.10	.35
Orthophosphorus, as P	.042	.013
Phosphorus, as P	.063	.020
Filterable dry material	47.2	15.1

Surface Water

From July 1986 to September 1987, measurements of streamflow as well as physical and chemical characteristics of water were made on four occasions at 27 of the 31 surface-water sites (fig. 11 and pl. 1). Sampling periods were selected to represent conditions at one high base flow, one median base flow, and two low base flow periods.

Each time a sample was collected, field measurements of specific conductance, dissolved oxygen, pH, and temperature were measured. Samples of water for nitrogen, phosphorus, sulfate, and sediments also were collected. Measurements of specific conductance, dissolved oxygen, pH, and temperature were made more frequently at the eight surface-water streamflow-gaging stations in the county.

In July and August 1986, samples for common inorganic substances were collected at all sites during a period of median base flow. In June 1987, water samples were collected for analyses of pesticides and phenols at selected sites.

Physical characteristics

Specific conductance, dissolved oxygen, pH, and temperature were measured from four to nine times at each site (table 13 and 14 in "Tables of Data" section at the back of report). Generally, specific conductance is slightly greater during periods of low flow when ground-water inflow comprises a larger percentage of total streamflow. It is lesser during periods of high flow, when much of the water is precipitation and surface runoff. Urban, industrial, or agricultural runoff to streams can alter this pattern and often cause variable specific conductance values.

Specific conductance ranged from 281 µS/cm at Bear Creek at Fulton (site 2) during a period of high flow to 1,330 µS/cm at Arcadia Creek at Kalamazoo (site 27) during a period of median base flow. The countywide mean, of all streams, was 484 µS/cm (table 13). The larger values observed in Arcadia Creek are indicative of urban/industrial runoff.

Dissolved oxygen and temperature are closely related properties of water. As temperature increases, the solubility of oxygen decreases. Both properties are important to aquatic life and may become a limiting factor in their propagation.

Mean concentrations of dissolved oxygen ranged from 4.6 mg/L (milligrams per liter) at Gourdneck Creek near Vicksburg (site 8), to 10.6 mg/L at Kalamazoo River at Comstock (site 19). In general, streams with the greatest percentage of ground-water inflow have the lowest summer temperatures and the largest dissolved oxygen concentrations.

Mean values of pH of water ranged from 7.5 at Gourdneck Creek (sites 7 and 8) to 8.2 at Kalamazoo River at Comstock (site 19). These values do not differ greatly from the mean pH values of 7.3 to 8.3 reported in Van Buren County (Cummings and others, 1984).

Major inorganic constituents

Water of streams and rivers in Kalamazoo County is predominately of a calcium bicarbonate type, although sulfate concentrations are slightly larger in streams in the southeastern and northwestern corners of the county (table 15 in "Tables of Data" section in the back of report). Allen and others (1972) indicate that these larger concentrations of sulfate may be attributed to solution of gypsum or anhydrite in the sandy clay till that is at or near the land surface.

The water of most streams is hard to very hard,[3] which is common in glaciated areas of the State. Concentrations of chloride in streams draining urban-industrial areas (sites 19-27) are slightly larger than at other locations. Salt applied to roads to control ice is one possible source.

Table 16, based on all analysis of water in table 15 lists mean concentrations of some of the physical properties and dissolved substances measured.

[3]The U.S. Geological Survey (Durfor and Becker, 1964) has classified the hardness of water as follows: 60 mg/L or less, soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; and 181 mg/L pr greater, very hard.

Table 16.--Mean concentrations of selected characteristics of streams

[Concentrations are in mg/L (milligrams per liter)]

Property, dissolved solid, or constituent	Mean concentration (mg/L)	Property, dissolved solid, or constituent	Mean concentration (mg/L)
Silica (SiO_2)	11.5	Sulfate (SO_4)	31
Calcium (Ca)	63	Chloride (Cl)	19
Magnesium (Mg)	20	Fluoride (F)	.15
Sodium (Na)	9.9	Hardness (as $CaCO_3$)	240
Potassium (K)	2.0	Dissolved solids (sum)	279

Nutrients

In many areas, the concentrations of nitrogen and phosphorus in streams increase as streamflow increases. This increase in concentrations is due primarily to overland runoff of nutrients from fertilizers and decaying vegetation being washed into the streams.

From 1986 to 1987, more than 100 measurements for nitrogen and phosphorus compounds were made at 27 stream sites throughout the county. The results of these analyses are reported in table 13. Mean total nitrogen concentration (ammonia + organic N + nitrite + nitrate as N), based on all sites, was 1.46 mg/L. This mean concentration is similar to the 1.7 mg/L reported in the upper St. Joseph River basin, located in neighboring Calhoun, Branch, and Hillsdale Counties (Cummings, 1978), and 1.5 mg/L reported in Van Buren County streams (Cummings and others, 1984). However, areal differences in nitrogen concentrations do occur within the county. The largest mean total nitrogen concentrations were detected in water of Little Portage Creek at site 3 (2.57 mg/L) and at site 4 (3.75 mg/L). The smallest concentration (0.65 mg/L) was detected in water of West Fork Portage Creek at site 24.

Trace elements

A one-time sampling of the 27 stream sites, during median base flow conditions, indicated that none of the trace elements exceeded maximum contaminant levels (MCL's) for drinking water established by USEPA (table 17). However, concentrations of iron and manganese in water in many streams, did exceed the USEPA secondary maximum contaminant levels (SMCL's). Total recoverable iron ranged from 20 to 4,000 µg/L (micrograms per liter).

Pesticides and total phenols

In June 1987, samples were collected for the analysis of pesticides and phenols. At 12 sites, on streams that drain major rural-agricultural basins, samples were collected for the analysis of pesticides. At 13 sites, on streams that drain urban-industrial basins, samples were collected for the analysis of total phenols. Basin selection was based on population centers and land-use data. Some basins were considered representative of both categories. And sampling was duplicated. Data in figure 18 indicates locations of basins and sampling sites.

Table 17.--Maximum and secondary maximum contaminant levels of the U.S. Environmental Protection Agency

[Concentrations are in mg/L (milligrams per liter) and µg/L (micrograms per liter). --, no level set, U.S. Environmental Protection Agency, 1986a and b]

Contaminant	Maximum contaminant levels for inorganic chemicals	Secondary maximum contaminant levels
Arsenic (As)	50 µg/L	--
Barium (Ba)	1,000 µg/L	--
Cadmium (Cd)	10 µg/L	--
Chloride (Cl)	--	250 mg/L
Chromium (Cr)	50 µg/L	--
Color (units)	--	15 units
Copper (Cu)	--	1 mg/L
Fluoride (F)	4 mg/L	2 mg/L
Iron (Fe)	--	300 µg/L
Lead (Pb)	50 µg/L	--
Manganese (Mn)	--	50 µg/L
Mercury (Hg)	2 µg/L	--
Nitrate (NO_3 as N)	10 mg/L	--
pH (units)	--	6.5 to 8.5 units
Selenium (Se)	10 µg/L	--
Silver (Ag)	50 µg/L	--
Sulfate (SO_4)	--	250 mg/L
Zinc (Zn)	--	5 mg/L
Total dissolved solids	--	500 mg/L

Pesticide analyses were made for the following compounds:

Alachlor, total	Methoxychlor, total
Aldrin, total	Methyl Parathion, total
Ametryne, total	Methyl Trithion, total
Atrazine, total	Mirex, total
Chlordane, total	Metribuzin, total
Cyanazine, total	Parathion, total
DDD, total	Perthane, total
DDE, total	PCB, total
DDT, total	PCN, total
[4]Diazinon, total	Perthane, total
Dieldrin, total	Prometone, total
Endrin, total	Prometryne, total
Endosulfan, total	Propazine, total
Ethion, total	Silvex, total
Ethyltrithion, total	Simazine, total
Heptachlor, total	Simetryne, total
Heptachlorepoxide, total	Toxaphene, total
Lindane, total	Trifluralin, total
Malathion, total	2,4,5-T, total
2,4-D, total	2,4-DP, total

Of the 40 pesticide, polychlorinated biphenyl, and polychlorinated napthalene compounds analyzed, only five pesticides were detected in water from Kalamazoo County streams. They were Alachlor, Atrazine, Diazinon, Simazine, and 2,4-D. Data in table 18 indicate the location of sites and concentrations of the five detected pesticides. The largest concentration of pesticide detected was that of Simazine (0.60 µg/L) in water of the Portage River (site 5). The compound 2,4-D was the most commonly detected pesticide and was present in water from 9 of the 12 sites sampled. Concentrations of 2,4-D ranged from a maximum of 0.30 µg/L in water of the Portage River (site 5) to nondetected at 3 of the 12 sites sampled. Diazinon and Simazine were detected at three sites, Atrazine at two sites, and Alachlor at one site. These results compare closely to those determined from analyses of water samples collected in Van Buren County streams, where stream samples had four of the same compounds present, but at slightly larger concentrations (Cummings and others, 1984).

An analysis for total phenols includes a wide variety of phenolic compounds, some of which are naturally occurring. Some phenols do pose health risk to humans and may be indicators of urban-industrial pollution. The mean concentration of total phenols in water from streams was 4 µg/L (table 13). A maximum concentration of 8 µg/L was detected in water of Portage Creek (site 21), and a minimum concentration of 2 µg/L was detected in water of Gull Creek (site 17).

[4]The use of brand names in this report is for identification only, and does not constitute endorsement of products by the U.S. Geological Survey, nor impute responsibilty for any present or potential effects on the natural resources.

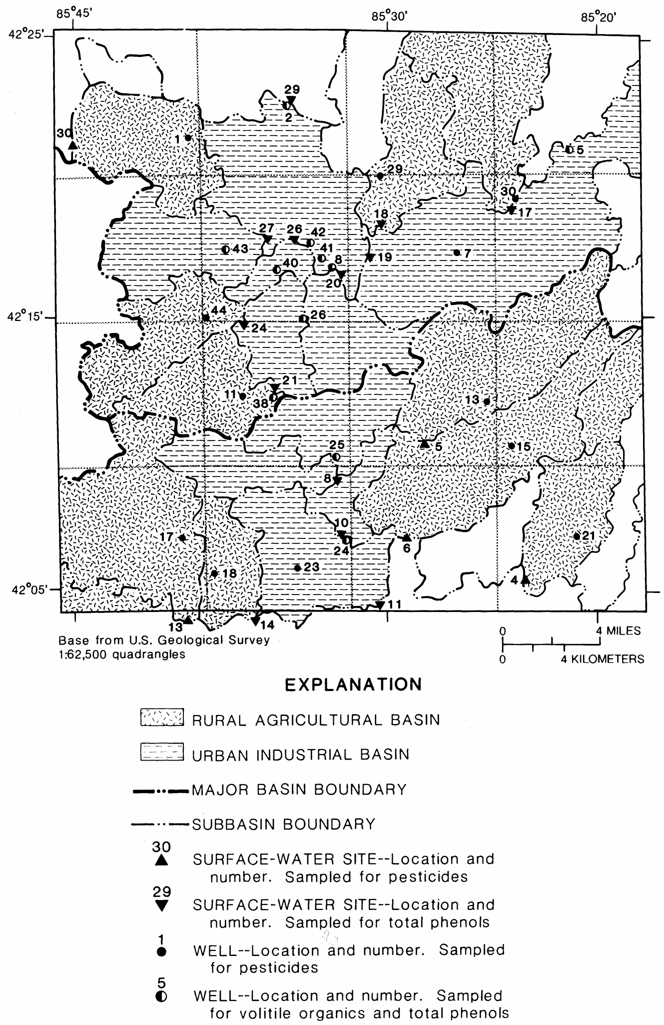


Figure 18.--Location of major rural-agricultural and urban-industrial basins.

Table 18.--Pesticide concentrations of streams, 1987

[Analyses by U.S. Geological Survey. µg/L, micrograms per liter; <, less than]

Site number	Stream name	Alachlor total (µg/L)	Atrazine total (µg/L)	Diazinon total (µg/L)	Simazine total (µg/L)	2,4-D total (µg/L)
4	Little Portage Creek	<0.10	<0.10	<0.01	<0.01	0.01
5	Portage River	<.10	<.10	<.01	.60	.30
6	Portage River	<.10	<.10	<.01	.50	.10
13	Flowerfield Creek	<.10	<.10	<.01	<.01	<.01
14	Spring Creek	.20	.20	<.01	<.01	<.01
17	Gull Creek	<.10	<.10	<.01	<.01	.02
18	Comstock Creek	<.10	<.10	.01	<.01	.09
19	Kalamazoo River	<.10	.20	.02	.10	.04
21	Portage Creek	<.10	<.10	.01	<.01	.08
24	West Fork Portage Creek	<.10	<.10	<.01	<.01	.19
26	Portage Creek	<.10	<.10	<.01	<.01	.03
30	Sand Creek	<.10	<.10	<.01	<.01	<.01

Ground Water

Physical and chemical characteristics of ground water were measured in water from 11 existing wells and 35 wells that were installed for this study during 1987. Locations of these wells are shown on plate 1; analyses are reported in table 19 in the "Tables of Data" section at the back of report. Well locations were selected to have one or two wells in each surface-water basin—preferably one well in the head waters and one downgradient. Although surface-water and ground-water divides are not exactly the same in Kalamazoo County, drainage in the shallow unconfined sand and gravel ground-water system does not differ greatly from surface-water drainage.

Physical and chemical characteristics

Ground water in the surficial aquifers is of a calcium bicarbonate type, although sodium, sulfate, and chloride are predominant ions at some locations. In general, ground-water quality of Kalamazoo County is good, and does not differ appreciably from statewide natural ground-water quality. Data in table 20 compare median values found in Kalamazoo County ground water with values found by Cummings (1989) in a statewide survey of natural ground-water quality.

Specific conductance, hardness, and dissolved-solids concentration are slightly larger than statewide averages. Dissolved-solids concentrations range from 74 to 2,700 mg/L; the largest concentrations are in areas where ground-water contamination seems more likely.

Concentrations of sodium and chloride exceeding those common in most natural ground waters, were detected in water from six wells. The wells were located next to major highways, and these larger concentrations may be the result of contamination from road salting during winter.

The median concentration of nitrate (0.19 mg/L) in ground water in Kalamazoo County is larger than the statewide median of 0.01 mg/L. A maximum concentration of 27 mg/L of nitrate was detected in water from well 18 in Schoolcraft Township; the mean concentration of water from 46 wells was 3.64 mg/L. Six of the 46 wells yielded water that had a nitrate concentration greater than 10.0 mg/L. The USEPA (1986a) regulations limit concentrations in drinking water to 10.0 mg/L.

The pH of ground water ranged from 6.60 to 8.24; the median was 7.3. Ground-water temperatures ranged from 9.0 °C to 14.0 °C; the mean was 11.0 °C.

Most trace-element concentrations did not differ greatly from statewide median valued, although at some locations unusually large concentrations were detected. For example, water from well 35, near Richland, contained 10,000 µg/L of chromium, 1,500 µg/L of zinc, and 600 µg/L of nickel. This well is located near a site where the Michigan Department of Natural Resources detected contaminated ground water.

Pesticides, volatile organics, and total phenols

In July and August 1987, selected wells were sampled for pesticides; other selected wells were sampled for volatile organics and total phenols. Data in figure 18 show locations of sampling sites for both well types. Well selection was based on the same general criteria used for surface-water sampling. Pesticides were sampled in major rural-agricultural areas, and volatile organics and phenols were sampled in major urban-industrial areas. Some wells represented both land-use types, and those wells were sampled for both categories.

The 12 wells in agricultural areas were sampled for the 40 pesticide, polychlorinated biphenyl, and polychlorinated napthalene compounds selected for surface-water analysis. Pesticides were detected in water from only one well. Water from well 11, located in the city of Portage, had 0.17 µg/L of 2,4-D.

Table 20.--Comparison of physical and chemical characteristics of ground water in Kalamazoo County with statewide ground-water quality

[Analyses by U.S. Geological Survey: µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; °C, degrees Celsisus]

Property, dissolved solids, or constituent	Median concentration	
	[1]Statewide	Kalamazoo County
Alkalinity (mg/L as $CaCO_3$)	155	212
Arsenic, total (µg/L as As)	1	<1
Cadmium, total recoverable (µg/L as Cd)	<1	<10
Calcium, dissolved (mg/L as Ca)	50	81
Chloride, dissolved (mg/L as Cl)	4.4	11
Chromium, total recoverable (µg/L as Cr)	<20	<10
Cobalt, total recoverable (µg/L as Co)	<1	<50
Copper, total recoverable (µg/L as Cu)	5	<10
Cyanide, dissolved (mg/L as CN)	.00	<.01
Fluoride, dissolved (mg/L as F)	.1	.1
Hardness, total (mg/L as $CaCO_3$)	200	310
Iron, total recoverable (µg/L as Fe)	560	540
Lead, total recoverable (µg/L as Pb)	5	<100
Manganese, total recoverable (µg/L as Mn)	22	50
Magnesium, dissolved (mg/L as Mg)	17	25
Mercury, total recoverable (µg/L as Hg)	<.50	<.1
Nickel, total recoverable (µg/L as Ni)	2	<100
Nitrogen, total (mg/L as N)	.29	.63
Nitrogen, ammonia, total (mg/L as N)	.05	.04
Nitrogen, nitrate, total (mg/L as N)	.01	.19
Nitrogen, nitrite, total (mg/L as N)	<.01	<.01
Nitrogen, organic, total (mg/L as N)	.13	.23
pH (units)	7.7	7.34
Phenols (mg/L)	<1	4.0
Phosphorus, total (mg/L as P)	<.01	.01
Phosphorus, ortho, total (mg/L as P)	<.01	<.01
Potassium, dissolved (mg/L as K)	1.4	1.0
Selenium, total (µg/L as Se)	<1	<1
Silica, dissolved (mg/L as SiO_2)	11	12
Silver, total recoverable (µg/L as Ag)	<1	<1
Sodium, dissolved (mg/L as Na)	6.8	5.1
Solids, residue at 180 °C, dissolved (mg/L)	244	346
Solids, sum of constituents, dissolved (mg/L)	240	293
Specific conductance (microsiemens at 25 °C)	426	587
Strontium, total recoverable (µg/L as Sr)	150	100
Sulfate, dissolved (mg/L as SO_4)	13	32
Zinc, total recoverable (µg/L as Zn)	60	100

[1] Cummings (1989)

Samples of water collected from the 12 wells located in urban-industrial areas were analyzed for the following volatile organics:

Benzene
Bromoform
Carbon Tetrachloride
Chlorobenzene
Chlorodibromomethane
Chloroethane
2-Chloroethylvinylether
Chloromethane
Chloroform
m-Dichlorobenzene
o-Dichlorobenzene
p-Dichlorobenzene
Dichlorobromomethane
Dichlorodifluromethane
1.1-Dichloroethane
1.2-Dichloroethane
1,1-Dichloroethylene
1,2-(trans)Dichloroethylene
1,2-Dichloropropane
1,3-Dichloropropene
Ethyl benzene
1,2-Dibromoethylene
Methylbromide
Methylene chloride
Styrene
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
1,1,1-Tri chloroethane
1,1,2-Chloroethane
Trichlorofluoromethane
Xylenes

Water from five wells contained volatile organics. Water from well 40, located at the city of Kalamazoo's Stockbridge well field, had 8.3 µg/L of tetrachloroethylene. Water from well 43, located at the city of Kalamazoo's Kendall well field, had 3.3 µg/L of 1,2-dichloroethane. Methylene chloride was detected in the following four wells: well 5 (11.0 µg/L) in Ross Township, well 25 (3.5 µg/L) and well 38 (14.0 µg/L) in the city of Portage, and well 40 (4.0 µg/L) in the city of Kalamazoo.

Of the preceding volatile organics only 1,2-dichloroethane is listed in the USEPA (1986a) drinking-water regulations. The 3.3 µg/L of 1,2-dichloroethane detected is below U.S. Environmental Protection Agency's maximum contaminant level of 5 µg/L.

Total phenols were detected in water from all 12 wells. A maximum concentration of 11 µg/L was in water of well 24 in Schoolcraft Township, and a minimum concentration of 1 µg/L was in water of well 38 in the city of Portage. The mean concentration in ground water was 4 µg/L (table 19). The mean total phenol concentration of surface water in these areas also was 4 µg/L. It is not surprising that concentrations are similar, because the surface-water samples were collected during periods of low flow, when most of the water in the stream is ground-water inflow. It is probable that the presence of phenols in surface and ground water of Kalamazoo County are the result of natural processes and not pollution of human origin. Cummings (1989) reported that 10 percent of the natural ground water sampled had total phenol concentrations equal to or exceeding 5 µg/L.

These data indicate there is no evidence of an extensive organic contamination of the ground water of Kalamazoo County. However, the Michigan Department of Natural Resources (1988) has identified sites in the county where organic contamination has occurred. Effects on the quality of ground water, however, are localized.

Selected chemical characteristics

For a number of years, the Kalamazoo County Health Department has collected samples from wells throughout the county. Approximately 12,000 analyses were available in county files, from 7,000 wells. Analyses were made by the Michigan Department of Public Health for the following seven substances: Iron, sodium, nitrate, hardness, specific conductance, chloride, and fluoride.

For this study, 706 of these analyses were used. Partial chemical analyses were matched to well logs, which gave the necessary location, well depth, and general lithology. To reflect current ground-water quality conditions, only wells sampled between 1984 to 1987 were used. Data in table 21 summarizes mean concentrations computed from these partial chemical analyses, by township.

Table 21.--Mean values of physical and chemical properties of ground water, by township

[Analyses by Michigan Department of Public Health--1984-87. mg/L, milligrams liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than]

Township	Iron (mg/L)	Sodium (mg/L)	Nitrate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Specific Conductance (µS/cm)	Chloride (mg/L)	Fluoride (mg/L)
Alamo	0.42	7.65	1.97	251	457	14.4	0.10
Brady	1.17	2.65	1.66	225	376	<10.0	<.10
Charleston	.33	1.79	2.11	267	469	<10.0	<.10
Climax	.81	2.56	2.76	262	447	<10.0	.10
Comstock	.72	6.65	3.05	280	531	16.2	.15
Cooper	.49	5.69	2.69	264	495	12.6	<.10
Kalamazoo	1.50	33.3	2.86	376	830	82.0	<.10
Oshtemo	.36	9.75	1.92	258	472	29.0	<.10
Pavilion	.58	13.0	1.77	234	462	<10.0	<.10
Portage (City)	.53	20.1	2.51	250	520	29.7	<.10
Prairie Ronde	.92	9.55	3.78	278	470	<10.0	.11
Richland	.49	25.1	4.97	289	625	31.4	.13
Ross	.42	26.0	2.10	231	493	32.4	<.10
Schoolcraft	.62	6.42	3.00	230	426	15.3	<.10
Texas	.44	5.61	2.59	197	359	<10.0	<.10
Wakeshma	.21	8.30	7.19	279	502	17.2	.16

Concentrations of specific conductance, hardness, fluoride, and iron do not differ greatly throughout the county. An exception occurs in Kalamazoo Township, where specific conductance, hardness, and iron are substantially larger. Concentrations of sodium, chloride, and nitrate varied substantially from one township to the next.

The partial chemical analyses also were analyzed by generalized ground-water drainage units. These units are based on surface-water divides and assumed to be representative of the shallow ground-water system. Data in figure 19 indicate the location and number of the ground-water units. These units cover approximately 93 percent of the county. Some of the smaller ground-water units have been combined due to insufficient data in the unit and are designated by a lower-case "a" on the figure. Data in table 22 indicate mean concentrations in ground water grouped by drainage units.

These data indicate that sodium and chloride concentrations in ground water are largest in the more urban-industrial basins. Concentrations are substantially smaller than the drinking-water regulations of USEPA, however.

Skinner (1966), and Allen and others (1972), reported no evidence to indicate a nitrate problem in ground water. Partial chemical analyses of water from wells collected by the Kalamazoo County Health Department, however, indicate concentrations of nitrate have been increasing in rural areas for the last two decades. Data indicate that concentrations of nitrate in ground water are now substantially larger than in the past in the rural-agricultural basins. Mean nitrate concentration in drainage unit A1 (figure 19) was 11.8 mg/L, which exceeds USEPA drinking-water regulations of 10.0 mg/L. The mean concentration of nitrate in ground water in two other drainage units, A10 (8.80 mg/L) and C3 (5.58 mg/L), approach the drinking-water limit.

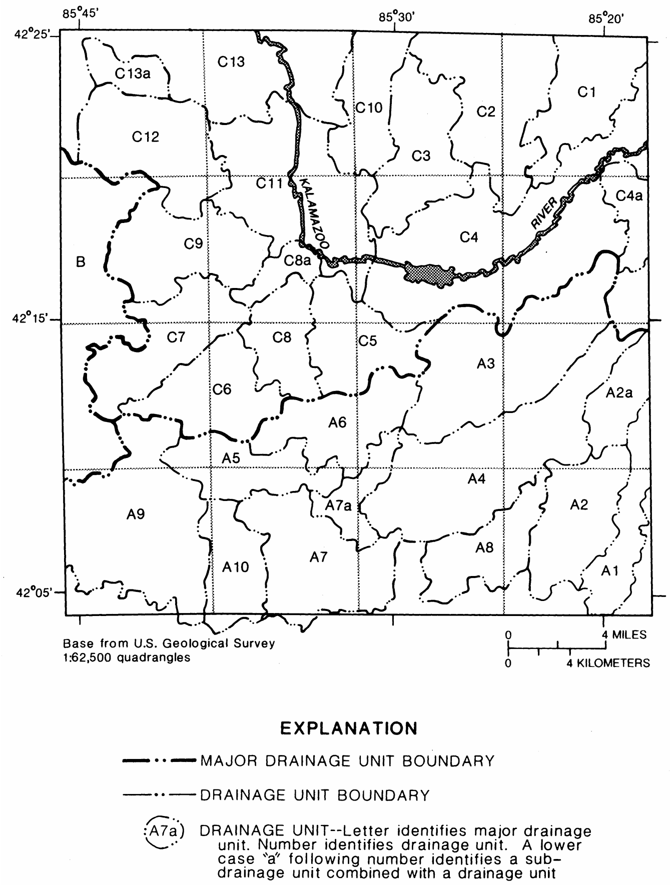


Figure 19.--Generalized ground-water drainage units based on surface-water divides.

Table 22.--Mean values of physical and chemical properties of ground water, by drainage unit

[Analyses by Michigan Department of Public Health--1984-87. mg/L, milligrams liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; mi², square miles]

Drainage unit	Area (mi²)	Iron (mg/L)	Sodium (mg/L)	Nitrate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Specific conductance (µS/cm)	Chloride (mg/L)	Fluoride (mg/L)
A1	10.1	0.06	<0.05	11.8	236	400	<10.0	0.11
A2	24.2	.09	9.86	4.93	296	533	23.2	.13
A3	32.8	.86	13.6	3.06	249	489	10.8	<.10
A4	35.4	.86	2.55	1.90	240	411	<10.0	<.10
A5	13.1	.56	12.8	3.12	230	481	23.1	<.10
A6	15.6	.59	18.1	3.31	229	500	14.4	<.10
A7	21.1	.96	1.27	1.35	231	394	<10.0	<.10
A8	13.1	.76	8.86	1.32	271	478	<10.0	.13
A9	33.5	.91	9.02	2.93	269	461	<10.0	.11
A10	9.4	.27	10.3	8.80	252	424	27.0	<.10
B	27.9	.51	2.51	1.47	227	389	12.0	<.10
C1	15.2	.50	36.3	.63	207	439	36.3	<.10
C2	24.3	.42	33.5	2.62	257	561	32.8	.15
C3	18.3	.39	14.8	5.58	295	623	30.0	.16
C4	54.7	.53	5.37	2.00	261	475	12.5	<.10
C5	15.2	.98	22.0	1.17	289	550	40.0	.10
C6	16.5	.26	13.6	3.52	204	414	18.4	<.10
C7	18.7	.43	3.47	1.60	209	366	12.3	<.10
C8	16.0	.34	28.4	2.18	329	691	54.4	<.10
C9	20.0	.30	10.1	2.86	318	540	37.7	<.10
C10	12.9	.43	6.40	2.55	263	490	14.9	<.10
C11	28.0	.99	12.5	3.19	307	627	26.7	<.10
C12	21.2	.39	12.2	2.07	255	496	26.0	.11
C13	36.4	.55	2.90	1.76	244	431	<10.0	<.10

Effects of Land Use on Ground-Water Quality

Geologic and hydrologic conditions determine the effect of land use on ground-water quality. Chemicals spilled, applied to the land, or discharged from waste or storage areas are carried to the water table by runoff or direct infiltration. Information on chemical inputs from urban-industrial areas, farms, animal feedlots, septic tanks, atmospheric deposition, and land use is necessary to determine the relation and significance of each input on the ground-water system.

General Land Use

In 1981, the Kalamazoo County Planning Department and the Geography Department of Western Michigan University, updated existing land-use maps. Data from various sources were assembled, analyzed, and verified by aerial photography. For this study, seven major land-use categories have been identified from these maps. A brief definition of these categories is as follows:

(1) Agricultural - All agricultural zoned lands. Includes active and nonactive farmland; croplands, hay, rotation and permanent pasture that produces grasses for animal consumption; confined feeding operations primarily beef-cattle feedlots, poultry, and hogs. Also includes commercially operated orchards, vineyards, bush fruits, vegetables, bedded plants, and ornamental horticulture.

(2) Vacant and wooded lands - Recreational parks and open space; brushland, coniferous and deciduous forest land.

(3) Commercial and public services - Central business districts, shopping centers, strip developments, and neighborhood business districts. Medical, governmental, institutional, and religious centers, including cemeteries.

(4) Rivers, lakes, and marshes

(5) Industrial - Industry, utilities, transportation, communications, and surface mining.

(6) Housing - Urban and rural homes, multiple family, and mobile-home parks.

(7) Highway, streets, and roads - Public right of ways.

Data in table 23 indicate the quantity and percentage of each land use, by township. About 40 percent of the land is used for agriculture. A combination of agricultural and vacant and wooded lands comprise nearly 80 percent of the county. Housing, urban and rural, is the next largest land-use category (6.6 percent), followed by highways and roads (3.4 percent), by industrial (2.0 percent), and by commercial and public services (1.9 percent).

Effects of Chemical Inputs on the Hydrologic System

Degradation of water resources within the county can result from various activities. In the past, poor land-use practices or accidental spills within sensitive areas have caused ground-water-quality problems, often resulting in costly cleanup efforts. Potential sources of contamination are numerous and discussion of each is beyond the scope of this report. However, some of the more common land-use practices and their potential for allowing chemicals to enter the hydrologic system have been considered.

Table 23.--General land-use data in Kalamazoo County

[mi^2, square miles]

Township	Size of area (mi^2)	Agricultural		Vacant and wooded lands		Commercial and public services		Rivers, lakes, and marshes		Industrial		Housing		Highways, streets, and roads	
		mi^2	percentage of total area	mi^2	percentage of total area	mi^2	percentage of total area	mi^2	percentage of total area	mi^2	percentage of total area	mi^2	percentage of total area	mi^2	percentage of total area
Alamo Township	36.0	14.2	39.4	18.0	50.0	0.07	0.19	0.38	1.1	0.81	2.2	1.4	3.9	1.1	3.1
Brady Township	36.0	18.7	51.9	8.5	23.6	.17	.47	5.9	16.4	.40	1.1	1.4	3.9	1.0	2.8
Charleston Township	36.0	10.8	30.0	21.4	59.4	1.0	2.8	.58	1.6	.37	1.0	.90	2.5	.94	2.6
Climax Township	36.0	19.8	55.0	12.9	35.8	.08	.22	1.2	3.3	.13	.36	1.02	2.8	.87	2.4
Comstock Township	36.0	12.9	35.8	14.6	40.6	.59	1.6	2.4	6.7	1.6	4.4	2.4	6.7	1.5	4.2
Cooper Township	36.0	13.6	37.8	17.5	48.6	.17	0.47	.32	.90	.86	2.4	2.4	6.6	1.2	3.3
Kalamazoo Township	36.0	3.1	8.6	5.5	15.2	6.1	16.9	2.0	5.6	3.9	10.8	12.8	35.6	2.6	7.2
Oshtemo Township	36.0	8.2	22.8	23.4	65.0	.51	1.4	.41	1.1	.22	.61	2.1	5.9	1.2	3.3
Pavilion Township	36.0	19.4	53.9	11.1	30.8	.08	.23	2.7	7.6	.47	1.3	1.4	3.9	.84	2.3
Prairie Ronde Township	36.0	21.8	60.5	7.5	20.9	.02	.06	4.7	13.1	.31	.9	.73	2.0	.87	2.5
Portage (city of)	36.0	12.6	34.9	12.5	34.7	.76	2.1	3.3	9.3	1.4	3.8	3.7	10.2	1.8	5.0
Richland Township	36.0	17.7	49.2	11.9	33.0	.12	0.33	3.1	8.6	.68	1.9	1.5	4.2	1.0	2.8
Ross Township	36.0	6.1	16.9	23.3	64.7	.53	1.5	3.0	8.3	.16	.44	1.8	5.0	1.2	3.3
Schoolcraft Township	36.0	18.5	51.4	9.0	25.0	.29	.81	5.2	14.4	.38	1.06	1.7	4.7	.92	2.6
Texas Township	36.0	11.8	32.7	18.6	51.7	.24	.68	2.0	5.6	.05	.13	1.9	5.2	1.4	4.0
Wakeshma Township	36.0	23.1	64.1	10.9	30.2	.01	.04	.34	1.0	.01	.02	.85	2.4	.87	2.4
Total	576	232	40.3	226.5	39.3	10.7	1.9	37.5	6.5	11.8	2.0	38.2	6.6	19.3	3.4

Municipal and industrial inputs

The Michigan Department of Natural Resources (1988) has identified sites where ground-water contamination has or is thought to have occurred. A listing of these sites, which includes location, possible source of contamination, and potential effects on the resource, is prepared each year. In Kalamazoo County, 44 sites have been identified. Many of the compounds contaminating ground water are chlorinated hydrocarbons, fuel substances, and plating wastes, because of improper handling or accidental spills.

Agricultural and rural residential inputs

The most common ground-water problem affecting the rural-agricultural areas is the increasing nitrate concentrations in the local ground-water systems. According to the Kalamazoo Health Department, nitrate concentrations in the 20 to 30 mg/L range are no longer uncommon in some areas. The maximum concentration measured during this study was 27 mg/L in water of well 18 in Schoolcraft Township.

Data in figure 20 indicate mean concentrations of nitrate in ground water of each drainage unit. The mean concentrations range from less than 1.0 to 11.8 mg/L. The ground water from wells in drainage units AI (in Wakeshma Township), A10 (in Schoolcraft Township), and C3 (in Richland Township) had mean concentrations of nitrate 11.8, 8.80, and 5.58, respectively (table 22). In each of these units, there are a number of wells that yield water having a nitrate concentration exceeding the USEPA maximum contaminant level of 10.0 mg/L (fig. 20).

Surface or near-surface nitrogen inputs in the county largely are fertilizers, animal wastes, septic tanks and precipitation. Total nitrogen input from each of these sources are now discussed:

Animal wastes.--Estimates of the amount of nitrogen deposited on land in Kalamazoo County by animals are based on a 1983 survey by the Kalamazoo County Planning Department, which indicates the approximate number and type of animals, and on estimates of the daily production of nitrogen by animals (Miner and Willrich, 1970). The survey identified 450 beef cattle, 1,000 dairy cattle, 3,000 hogs, 200 sheep, and 20,000 chickens and other poultry. Data in table 24 indicate estimates of the yearly quantity of nitrogen deposited by animals, by township. Countywide average deposition of nitrogen from animals is 0.25 [(ton/mi^2)/yr] or 0.78 (lb/acre)/yr. Most animal feedlots are in Pavilion, Comstock, and Climax Townships.

Septic-tank discharges.--Estimates of the quantity of nitrogen discharged by septic tanks were calculated for each township. These estimates were based on the population of nonsewered areas and on studies of nitrogen discharge from septic tanks by Winneberger (1982). Winneberger reported that the average home septic-tank discharges 24 lb of nitrogen per year. Using these data, estimates of nitrogen discharge by septic tanks are listed in table 25. Countywide, an average of 0.47 (ton/mi^2)/yr of nitrogen is discharged from septic tanks. Discharge is greatest in Portage and Kalamazoo Townships.

Fertilizer applications.--Estimates of the quantity of nitrogen deposited on land by agricultural fertilizers are based on a 1983 agricultural crop survey by the Kalamazoo County Planning Department and on fertilizer application rates for different crops provided by the Kalamazoo County Extension Office. Data in table 26 list fertilizer application rates for different crop types within Kalamazoo County.

Using the multiplication of total acreage of each crop (table 27) and the fertilizer suggested application rates (table 26), an estimated 6,500 tons of commercial fertilizers are applied in the county annually. Of this total, 2,700 tons (42 percent) is nitrogen.

Data in table 27 indicate total tons of nitrogen fertilizer applied in each of the 24 drainage units. Countywide average application of nitrogen from agricultural fertilizers is 5.12 (ton/mi^2)/yr or 16.0 (lb/acre)/yr. Application rates vary, however. Application rates, in the St. Joseph River basin, are two to three times those in the Paw Paw and Kalamazoo River basins. These greater application rates are consistent with larger concentrations of nitrate found in ground water within these areas. Concentration of nitrate in ground water, in the St. Joseph River basin, is about twice that determined in the Paw Paw and Kalamazoo River basins (table 22).

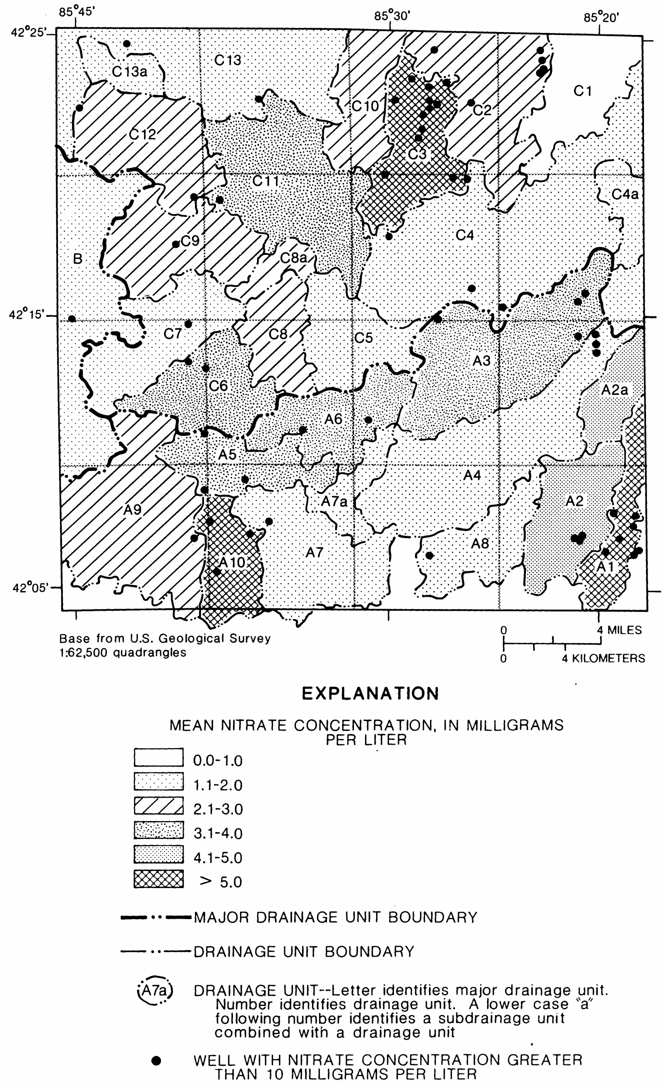


Figure 20.--Mean concentrations of nitrate as nitrogen in ground water, by drainage unit.

Table 24.--Nitrogen deposited by animals, by township

Township	Nitrogen deposited (as N) Pounds per acre per year	Tons per square mile per year
Alamo	0.87	0.28
Brady	.75	.24
Charleston	.79	.25
Climax	1.66	.53
Comstock	1.78	.57
Cooper	"a"	"a"
Kalamazoo	"a"	"a"
Oshtemo	.48	.15
Pavilion	1.98	.63
Portage (City)	"a"	"a"
Prairie Ronde	.48	.15
Richland	.95	.30
Ross	.34	.11
Schoolcraft	1.03	.33
Texas	.24	.08
Wakeshma	1.19	.38

"a" Insignificant number of animals identified during survey.

Table 25.--Nitrogen discharge by septic tanks, by township

Township	Nitrogen deposited (as N) Pounds pre acre per year	Tons per square mile per year
Alamo	0.82	0.26
Brady	.71	.23
Charleston	.26	.08
Climax	.94	.30
Comstock	2.00	.64
Cooper	2.38	.76
Kalamazoo	3.51	1.12
Oshtemo	1.87	.60
Pavilion	1.41	.45
Portage (City)	3.76	1.20
Prairie Ronde	.33	.11
Richland	1.23	.39
Ross	1.00	.32
Schoolcraft	1.62	.52
Texas	1.29	.41
Wakeshma	.39	.12

Table 26.--Fertilizer application within Kalamazoo County

[Data from Kalamazoo County Extension Office-1988.]

Crop or fruit	Fertilizer application Pounds per acre Nitrogen (as N)	Phosphorus (as P)	Potassium (as K)
Row crops			
Corn	150	60	120
Soybeans	15	30	90
Wheat	60	40	40
Oats	40	40	40
Hay	20	60	120
Tree and bush fruits			
Apples	100	20	60
Grapes	80	0	120
Blueberries	120	20	60
Strawberries	80	80	80
Vegetable crops			
Asparagus	80	40	80
Peppers	120	60	120
Pickles	100	60	120
Tomatoes	120	60	120

Table 27.--Nitrogen fertilizer application rates, by drainage unit

[Drainage unit locations shown in fig. 19. mi², square miles; (lb/acre)/yr, pounds per acre per year; (ton/mi²)/yr, tons per square mile per year]

Drainage unit	Area (mi²)	[1] Nitrogen fertilizer (as N) applied [(lb/acre)/yr]	[(ton/mi²)/yr]	[2] Total nitrogen fertilizer applied by crop type: Corn (tons)	Soy bean (tons)	Wheat and oats (tons)	Hay (tons)	Orchards, bush-fruits, and vine-ards (tons)	Other fruit and veget-ables crops (tons)
A1	10.1	30.6	9.8	78.8	4.5	13.6	0.3	0.0	1.5
A2	24.2	27.2	8.7	161.1	9.4	38.0	2.3	.0	.4
A3	32.8	20.3	6.5	155.6	10.6	45.3	2.9	.0	.4
A4	35.4	16.6	5.3	140.0	9.2	36.2	3.3	.0	.3
A5	13.1	14.1	4.5	34.2	9.1	14.0	.0	.0	1.6
A6	15.6	28.8	9.2	104.2	6.6	25.2	1.4	3.7	2.1
A7	21.1	35.9	11.5	183.7	8.6	47.2	2.4	.0	.4
A8	13.1	25.0	8.0	88.7	3.4	10.5	1.0	.0	1.7
A9	33.5	34.4	11.0	305.0	15.9	46.0	2.0	.5	.5
A10	9.4	24.1	7.7	48.2	6.3	16.0	.2	.0	1.3
B	27.9	6.7	2.1	44.6	.2	3.3	3.3	5.4	.9
C1	15.2	7.5	2.4	29.0	.6	4.5	2.3	.0	.6
C2	24.3	13.4	4.3	83.6	1.6	16.2	1.4	.0	2.0
C3	18.3	7.5	2.4	29.1	1.6	11.1	.1	.0	1.2
C4	54.7	11.2	3.6	158.0	5.0	24.3	8.7	.6	3.1
C5	15.2	16.9	5.4	63.0	4.0	11.1	.8	2.2	1.4
C6	16.5	13.8	4.4	37.2	3.3	17.6	.7	12.2	1.6
C7	18.7	6.9	2.2	32.2	1.0	3.9	1.1	2.9	.6
C8	16.0	2.5	.8	9.0	.3	1.5	.3	.0	1.8
C9	20.0	6.2	2.0	37.7	.0	.4	1.0	.0	.4
C10	12.9	7.2	2.3	19.2	1.0	6.2	2.5	.1	1.1
C11	28.0	6.6	2.1	51.3	1.9	4.0	.3	.0	.8
C12	21.2	12.5	4.0	74.5	3.1	5.8	.9	.0	1.5
C13	36.4	13.8	4.4	136.5	6.9	9.4	5.2	.4	2.5

[1] Nitrogen application rates were derived by summing tons of nitrogen applied to crops and dividing by drainage unit area.

[2] Tons of nitrogen applied to crops were derived by summing total acreage of each crop grown and multiplying by the recommended application rate indicated in table 26.

Based on fertilizer application rates, septic tank discharges, animal deposition, and atmospheric deposition, the mean total nitrogen input from these sources is 10.0 (ton/mi^2)/yr in the county. Data in table 28 list the percentage composition of the nitrogen input.

Table 28.--Percentage composition of nitrogen input

Source	Nitrogen input: Tons per square mile per year	Percent
Precipitation and dry fallout	4.21	41.9
Septic tanks	.47	4.7
Animal wastes	.25	2.5
Fertilizers	5.12	50.9

Potential nitrogen inputs are 41.9 percent from precipitation and dry fallout, 4.7 percent from septic tanks, 2.5 percent from animal wastes, and 50.9 percent from fertilizers. Based on these percentage compositions of nitrogen input (table 28), fertilizers are the greatest source of nitrogen in the county. However, in some areas where fertilizer applications are heavy, only moderate nitrate concentrations occur in ground water. This occurrence indicates that fertilizers are not the only factor involved. A study in neighboring Van Buren County reported that the number of acres irrigated, and thus the volume of water applied, may be equally important in increasing concentrations of nitrate in ground water. The study also indicated that a well yielding water from a depth of 40 ft is likely to have a nitrate concentration about twice that of one yielding water from a depth of 90 ft (Cummings and others, 1984).

Data in figure 21 show plots of mean nitrate concentrations, by drainage units as compared to the quantity of fertilizer applied, percent of area irrigated, and average well depth. Although the data are inconclusive, mean nitrate concentrations tend to increase as fertilizer application increases and as the percent of area irrigated increases. Mean nitrate concentrations seem to decrease as well depths increase.

Geohydrologic Factors Affecting Susceptibility of Ground Water to Contamination

In recent years, a number of supply wells in Kalamazoo County have been shut down because of ground-water contamination. The cost of replacing these wells is expensive, as is cleaning up the contamination. The possibility of future contamination of aquifers could be mitigated if their relative susceptibility to contamination were known when making land-use decisions.

Within the last 20 years, many different systems for evaluating pollution potential have been developed (Aller and others, 1985). Most systems are designed to be site-specific and are not suitable for countywide comparisons. For this study, a generalized map of ground-water susceptibility to contamination in Kalamazoo County has been developed (pl. 3) by using the USEPA Agricultural DRASTIC system (Aller and others, 1985). (An explanation of the Agricultural DRASTIC system is included in the appendix.) The use of this system does not imply that it is the best or only system available. However, this system does use a standardized method for evaluating ground-water pollution potential based on geohydrologic settings. Agricultural DRASTIC is designed to be used where the activity of concern is the application of herbicides and pesticides to an area (Aller and others, 1985). However, because most of the county is underlain by unconfined aquifers, the movement of any other potential contaminants to the shallow system are probably similar.

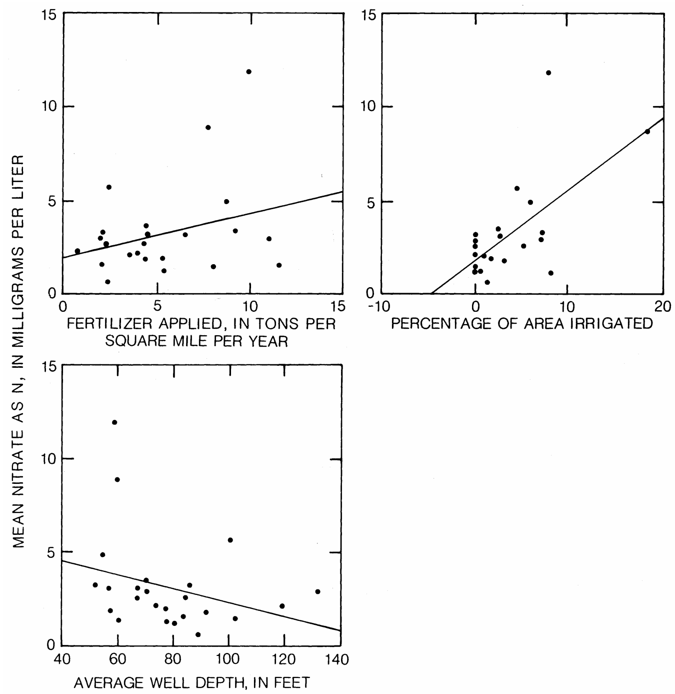


Figure 21.--Graph showing relation of mean concentrations of nitrate as nitrogen to quantity of fertilizer applied, percentage of area irrigated, and average well depth, by drainage unit.

Geohydrologic factors that affect and control ground-water movement were delineated on seven DRASTIC index maps. These maps depict depth to water, net recharge, aquifer media, soil media, topography, unsaturated zone, and hydraulic conductivity of the aquifer. All seven geohydrologic factors had some effect on countywide susceptibility, but the most important factors are those that dealt with the composition of the materials above the aquifer and the depth to water. A composite of these seven maps form a generalized map of the susceptibility of ground water to contamination. Each of the seven geohydrologic maps and their resulting composite map are described in the following sections:

Depth to Water

In Kalamazoo County, where water quality and availability in the unconfined aquifer are of greatest concern, the depth to water is the depth, in feet, between land surface and water table. Depth to water determines the quantity of unsaturated material through which a contaminant must travel before reaching an aquifer. It is one control of time of travel and provides an opportunity for decomposition of the contaminant (Aller and others, 1985). The longer the time of travel, or the greater the depth to water, then the lesser the potential for ground-water contamination as reflected in the DRASTIC ratings below:

Depth to water (ft)	DRASTIC value
< 5	50
5 to 29	40
30 to 49	25
50 to 74	15
75 to 100	10
> 100	5

A map of DRASTIC values for depth to water based upon the map of depth to the water table is shown on plate 3.

Net Recharge

Net recharge is defined as "the amount of water per unit area of land which penetrates the ground surface and reaches the water table" (Aller and others, 1985). The quantity of recharge reflects the availability of water for transporting contaminants vertically to the water table and horizontally within the aquifer. In addition, the quantity of recharge also indicates the volume of water available for dispersion and dilution in the vadose zone (the unsaturated zone between the land surface and aquifer), as well as within the saturated zone as described by Alter and others (1985). Therefore, the greater the recharge, the greater the potential for contaminants to reach the water table. The quantity of net recharge in Kalamazoo County was determined for each of the five surficial geologic deposits present. Recharge rates varied from 5.87 in/yr for the upland moraines to 10.86 in/yr for the outwash. The DRASTIC values associated with the quantity of net recharge in Kalamazoo County are listed below:

Net recharge (in.)	DRASTIC value
> 10	36
7 to 10	32
< 7	24

A map of DRASTIC values for net recharge based upon recharge rates in different geologic deposits is shown on plate 3.

Aquifer Media

The aquifer media "exerts the major control over the route and path length which a contaminant must follow" (Aller and others, 1985). The "path length" affects attenuation processes such as sorption, reactivity, and dispersion as well as the quantity of surface area of materials contacted in the aquifer by a contaminant (Aller and others, 1985). In general, the larger the grain size, the greater the permeability and the lesser the attenuation capacity. The result is a DRASTIC rating of greater susceptibility to ground-water contamination.

The aquifer media in Kalamazoo County are glacial deposits, all within the DRASTIC category "sand and gravel". "Sand and gravel" DRASTIC values vary between 18 and 27, depending on how "clean" the sand and gravel is, or how much fine material are associated with the deposit. The "cleaner" deposits, or those with a minimum of fine material, do not retard contaminants readily and thus have higher ratings in the DRASTIC system, as shown below:

Aquifer media (sand and gravel)	DRASTIC value
Outwash	27
Glacial Drainage Channel Deposits	24
Till or Outwash over Till	21
Moraine	18

A map of DRASTIC values for aquifer media based upon the five glacial deposits in Kalamazoo County is shown on plate 3.

Soil Media

The soil media is the "uppermost portion of the vadose zone characterized by significant biological activity" (Aller and others, 1985). The soil media affects the quantity of recharge that can penetrate the surface and, therefore, the vertical movement of contaminants into the unsaturated zone. Soil also affects attenuation processes such as filtration, biodegradation, sorption, and volatization (Aller and others, 1985). The most important aspect of the soil is the type of clay present, the shrink/swell potential of the clay, and the grain size of the soil. In general, the more clay shrinks and swells, and the larger the grain size of the soil, the more likely ground water can be contaminated. Eight soil types in Kalamazoo County, described by the U.S. Department of Agriculture, were grouped into two DRASTIC categories. Six soil types were categorized as sandy loam, and two soil types were categorized as loam. The DRASTIC values for soil media in Kalamazoo County are as follows:

Soil media (Drastic categories)	DRASTIC value
"Sandy Loam"	30
"Loam"	25

A map of DRASTIC values for soil media based upon general soil types is shown on plate 3.

Topography

In the DRASTIC system, topography refers to the slope variability of the land surface. The degree of slope of land controls how long a contaminant will remain at one location. According to Aller and others (1985), the greater the degree of slope, the less infiltration, and therefore, the smaller the potential for ground-water contamination. The percent slope in Kalamazoo County was determined from slope data published by the U.S. Department of Agriculture for each soil type in the county soil survey. The DRASTIC values for the percent slope in Kalamazoo County are as follows:

Percent slope	DRASTIC value
< 2	30
2 to 6	27
7 to 12	15

A map of DRASTIC values for topography based upon percent slope in different soil types of the county is shown on plate 3.

Impact of the Unsaturated Zone

The unsaturated zone is defined as “that zone above the water table which is unsaturated” (Aller and others, 1985). The type of media in the unsaturated zone affects attenuation processes that occur in the zone (biodegradation, neutralization, and dispersion) as contaminants move vertically down to the aquifer. The unsaturated zone media also "controls the path length and route, thus affecting the time available for attenuation and the quantity of material encountered" (Aller and others, 1985). In general, the larger the grain size in the unsaturated zone media, the greater the permeability and the lesser the attenuation capacity. The greater permeability results in a greater DRASTIC value of susceptibility of ground water to contamination. The unsaturated zone media data, similar to the aquifer media data, were obtained from information shown on the glacial deposits map by Monaghan and others (1983) and verified by well logs when possible (fig. 9). All five glacial deposits in the county are classified within the DRASTIC unsaturated media category "sand and gravel” which has a value between 24 and 36, depending on the quantity of fine-grained material. The DRASTIC values for the unsaturated media in Kalamazoo County are as follows:

Unsaturated zone media (sand and gravel)	DRASTIC value
Outwash	36
Glacial Drainage Channel deposits or Outwash over Till	32
Moraine or Till	24

A map of DRASTIC values for impact of the unsaturated zone based upon the five glacial deposits in Kalamazoo County is shown on plate 3.

[5]The U.S. Environmental Protection Agency classifies the unsaturated zone above the water table as the "vadose zone".

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity is defined as "the ability of the aquifer materials to transmit water which, in turn, controls the rate at which ground water will flow under a given hydraulic gradient” (Aller and others, 1985). The horizontal hydraulic conductivity effects the rate of movement of a contaminant from the point at which the contaminant was introduced into the aquifer. The greater the hydraulic conductivity, the greater the DRASTIC value or potential for ground-water contamination. The hydraulic conductivity was obtained from a transmissivity map of the upper unconfined aquifer by Allen and others (1972) and applied to the DRASTIC values, as follows:

Hydraulic conductivity gallons per day per foot	DRASTIC value
>2000	20
1000 to 2000	16
700 to 999	12
300 to 699	8
100 to 299	4
<100	2

A map of DRASTIC values for horizontal hydraulic conductivity based upon the hydraulic conductivity map is shown on plate 3.

Each of the seven Agricultural DRASTIC index maps were digitized, gridded, and contoured using a data-base system described by Kontis and Handle (1980). Two-dimensional grids of each map were generated. The seven gridded data sets were overlaid and summed forming a composite grid of DRASTIC index values. The composite grid was contoured to produce a map of susceptibility of ground water to contamination. The resulting contour map (pl. 3), showing DRASTIC index values ranging from less than 125 to greater than 200, reflects areas that are most likely to be susceptible to ground-water contamination. The larger index values represent areas that have greater susceptibility. It is emphasized that the DRASTIC index composite map provides only a relative evaluation tool. The map does not show areas that will be contaminated or areas that cannot be contaminated. The map is compiled from generalized countywide information, and therefore cannot be used for any site-specific purpose. It is useful only as a comparison from one area of the county to the other and should not be compared to values generated in other areas or studies.

SUMMARY

Three surface-water basins drain Kalamazoo County. The Kalamazoo River basin (in the northern part of the county), drains 54 percent of the county. The remaining 46 percent is the St. Joseph River basin, of which 5 percent (in the western part of the county) forms the headwaters of the Paw Paw River basin, a major subbasin of the St. Joseph River system. The largest river in the county is the Kalamazoo River, which has an average discharge of 861 ft^3/s. The maximum discharge observed was 6,910 ft^3/s in April 1947; the minimum discharge observed was 119 ft^3/s in May 1958.

An estimated 217,200 people lived in Kalamazoo County in 1985. These people used approximately 20 Mgal/d of ground water for domestic water use. An additional 45 to 50 Mgal/d of ground water was used by industrial and commercial facilities. Almost all of this supply is produced from the glacial sand and gravel aquifer systems of the county. These glacial deposits, from 50 to 600 ft thick, overlie the Coldwater Shale of Mississippian age. The shale is a poor source of ground water; yields are small, and the water is greatly mineralized. The Coldwater Shale grades upward into the Marshall Formation in a small part of the northeastern corner of the county, but the sandstone is thin and only useful as a local supply to domestic wells.

Most wells completed at depths less than 75 ft have yields adequate for private domestic uses. Wells yielding adequate amounts of water for industry, public supply, and irrigation (1,000 gal/min or more) usually are completed at depths from 100 to 200 ft deep. Of the glacial deposits, the outwash plains contain the most productive aquifers within the county.

Ground-water recharge rates for four geologic settings were estimated from ground-water runoff to streams. Hydrograph separations for four streamflow-gaging stations indicated ground-water recharge of 10.86 in/yr in the outwash plains, 8.79 in/yr in the downcut glacial drainage channels, 6.89 in/yr in the till plain, and 5.87 in/yr in the upland moraines. Based on the above rates, a countywide average recharge rate of 9.32 in/yr was estimated.

Chemical analyses indicated presence of a wide range of substances in rainfall and snow. Specific conductance of rainfall ranged from 4.3 µS/cm to 80.9 µS/cm and averaged 34 µS/cm. The pH of rainfall ranged from 3.9 to 5.4, with a median value of 4.3. In general, the smaller the pH value of precipitation, the larger the value of the specific conductance.

Streams and rivers of Kalamazoo County are predominately of the calcium bicarbonate type, although concentrations of dissolved sulfate are slightly larger in streams in the southeastern and northwestern corners of the county. Specific conductance values ranged from 281 µS/cm at Bear Creek at Fulton to 1,330 µS/cm at Arcadia Creek at Kalamazoo. Mean concentrations of dissolved oxygen ranged from 4.6 mg/L at Gourdneck Creek near Vicksburg to 10.6 mg/L at Kalamazoo River at Comstock. Mean values of pH ranged from 7.5 at Gourdneck Creek to 8.2 at Kalamazoo River at Comstock. The water of most streams is considered hard to very hard and contains substantial quantities of total recoverable iron. Concentrations of dissolved chloride in streams draining urban-industrial areas are slightly larger than at other locations. Concentrations of total nitrogen and total phosphorus in streams increase as streamflow increases. Except for large concentrations of total recoverable iron, none of the trace elements in streams exceeded maximum contaminant levels for drinking water established by the U.S. Environmental Proctection Agency. Twelve surface-water sites were sampled for the presence of pesticides. The pesticide compound 2,4-D was detected in water at nine sites, Diazinon and Simazine, at three sites, Atrazine, at two sites, and Alachlor at one site.

Physical and chemical characteristics of ground-water samples were measured in water from 46 wells in Kalamazoo County. In general, ground-water quality is good, and measurements at most locations indicated no evidence of contamination. However, some ground-water quality problems do exist. Concentrations of specific conductance, hardness, and dissolved-solids are slightly larger then statewide averages. Concentrations of dissolved sodium and dissolved chloride, exceeding those common in most natural ground waters of the State, were detected in six wells. Six of the 46 wells sampled had nitrate as nitrogen levels greater than 10.0 mg/L. Larger concentrations of total recoverable chromium, copper, manganese, nickel, and zinc indicate ground-water contamination at a few sites. Samples from one well indicated the presence of the pesticide 2,4-D. Water samples from five wells contained volatile organics.

Results from partial chemical analysis from 706 wells indicated that ground-water concentrations of values of specific conductance, hardness, total recoverable iron, and dissolved fluoride are fairly uniform throughout the county. Concentrations of dissolved sodium, dissolved chloride, and total nitrate as nitrogen in ground water differed among townships. Concentrations of dissolved sodium and dissolved chloride in ground water are slightly larger in urban-industrial areas. Concentrations of total nitrate as nitrogen are substantially larger in rural-agricultural areas.

Potential nitrogen inputs are 41.9 percent from precipitation and dry fallout, 4.7 percent from septic tanks, 2.5 percent from animal wastes, and 50.9 percent from fertilizers. Studies of the relations among mean concentrations of total nitrate (as N) by drainage units, in respect to quantity of fertilizer applied, percentage of area irrigated, and average well depth were inconclusive. However, the trend was that mean concentrations of total nitrate (as N) increase as fertilizer application increases and percentage of area irrigated increases. Mean concentrations of total nitrate (as N) decrease as well depths increase.

A map of susceptibility of ground water to contamination in Kalamazoo County was developed using the United States Environmental Protection Agency's Agricultural DRASTIC system. Seven geohydrologic factors that affect and control ground-water movement are mapped, including depth-to-water table, net recharge, aquifer media, soil media, topography, impact of the unsaturated zone, and hydraulic conductivity of the aquifer.

SELECTED REFERENCES

Allen, W.B., Miller, J.B., and Wood, W.W., 1972, Availability of water in Kalamazoo County, Michigan: U.S. Geological Survey Water-Supply Paper 1973, 129 p.

Aller, Linda, Bennett, T., Lehr, J.H., and Petty, R.J., 1985, DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings: U.S. Environmental Protection Agency, 600/2-85/018, 163 p.

Austin, G.R., 1979, Soil Survey of Kalamazoo County, Michigan: U.S. Department of Agriculture, Soil Conservation Service, 102 p.

Bedell, D.J., and Van Til, R.L., 1979, Irrigation in Michigan, 1977: Michigan Department of Natural Resources, Water Management Division, 37 p.

Cummings, T.R., 1978, Agricultural land use and water quality in the upper St. Joseph River Basin, Michigan: U.S. Geological Survey Open-File Report 78-950, 106 p.

Cummings, T.R., 1989, Natural ground waters in Michigan: 1974-1987: U.S. Geological Survey Open-File Report 89-259, 50 p.

Cummings, T.R., Twenter, F.R., and Holtschlag, D.J., 1984, Hydrology and land use in Van Buren County, Michigan: U.S. Geological Survey Water-Resources Investigations Report 84-4112, 124 p.

Deutsch, Morris, Vanlier, K.E., and Giroux, P.R., 1960, Ground-water hydrology and glacial geology of the Kalamazoo area, Michigan: Michigan Geological Survey Progess Report 23, 122 p.

Durfor, C.N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962, U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, Inc., 603 p.

Grannemann, N.G., 1984, Hydrogeology and effects of tailings basins on the hydrology of Sands Plain, Marquette County, Michigan: U.S. Geological Survey Water-Resources Investigations Report 84-4114, 98 p.

Humphreys, C.R., and Green, R.F., 1962, Michigan lake inventory: Michigan State University Department of Resources Development Bulletin 39, p. 39A-39C.

Kontis, A.L., and Mandle, R.J., 1980, Data-base system for northern midwest regional aquifer-system analysis: U.S. Geological Survey Water-Resources Investigations Report 80-104, 23 p.

Leverett, Frank, and Taylor, F.B., 1915, The Pleistocence of Indiana and Michigan and the history of the Great Lakes: U.S. Geological Survey, Monongraph 53, 529 p.

Martin, H.M., 1958, Outline of the geologic history of Kalamazoo County: Michigan Department of Conservation Geological Survey Division, 17 p.

Michigan Department of Natural Resources, 1988, Michigan sites of environmental contamination: Proposed priority lists, ACT 307: November 1986 for fiscal year 1988, 211 p.

Miner, J.R., and Willrich, T.L., 1970, Livestock operations and field-spread manure as sources of pollutants, in Willrich. T.L., and Smith, G.E., eds., Agricultural Practices and Water Quality: Ames, Iowa, Iowa University Press, p. 231-240.

Monaghan, G.W., Larson G.J., Forstat, D.W., and Sorensen, H.O., 1983, Selected geologic maps of Kalamazoo County, Michigan: County geologic map series - Kalamazoo: Kalamazoo, Michigan Department of Natural Resources Geological Survey Division, 5 pl, scale 1:100,000.

National Oceanic and Atmospheric Administration, 1986, Climatological data - Michigan annual summary: Asheville, N.C., National Climatic Center v. 101, no. 13, 26 p.

Passero, R.N., (ed.), 1978, Kalamazoo County—Geology and the environment: Western Michigan University Department of Geology, 143 p.

-----1983, Information for the evaluation of location criteria for sanitary landfills--Kalamazoo County solid waste management plan: Kalamazoo County Solid Waste Management Planning Committe, 79 p.

Rosen, L.S., 1985, Population projections for Michigan to the year 2010, Summary report: Michigan Department of Management and Budget, Office of Revenue and Tax Analysis, 15 p.

Skinner, E.L., 1966, Quality of water in Kalamazoo County, Michigan: U.S. Geological Survey Interim Report, 29 p.

Straw, W.T., 1976, Guidebook for a field trip on some aspects of the glacial geology of the Kalamazoo area: Kalamazoo, Western Michigan University Department of Geology, 27 p.

U.S. Bureau of Census, 1982, 1980 Census of population, number of inhabitants-Michigan: U.S. Bureau of Census, v. 1, Chapter A, part 24.

U.S. Environmental Protection Agency, 1986a, Maximum contaminant levels (subpart B of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulation, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 524-528, 567-568.

-----1986b, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking-water regulations): U.S. Code of Federal Regulations, Title 40. parts 100 to 149, revised as of July 1, 1986, p. 587-590.

U.S. Geological Survey, 1987, Water resources data - Michigan, water year 1986: U.S. Geological Survey Water-Data Report MI-86-1, 353 p.

-----1988, Water resources data - Michigan, water year 1987: U.S. Geological Survey Water-Data Report MI-87-1, 281 p.

Winneberger, J.H.T., 1982, Nitrogen, public health, and the environment--Some tools for critical thought: Ann Arbor, Michigan, Ann Arbor Science Publishers, p. 20.

DEFINITION OF TERMS

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow. The discharge entering stream channels as inflow from ground water or other delayed sources; sustained or fair weather flow of streams.

Bedrock. Designates consolidated rocks, which in Kalamazoo County underlie glacial deposits.

Concentration. The weight of dissolved solids or sediment per unit volume of water expressed in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Contour. An imaginary line connecting points of equal altitude, whether the points are on the land surface, water-table surface, or bedrock surface.

Cubic feet per second. A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

Discharge. The rate of flow of a stream; reported in cubic feet per second (ft^3/s).

Dissolved solids. Substances present in water that are in true chemical solution.

Divide. A line of separation between drainage systems. A topographic divide delineates the land from which a stream gathers its water; a ground-water divide is a line on a potentiometric or water-table surface on each side of which the potentiometric surface slopes downward away from the line.

Dry fallout. Particulate matter transported by air circulation and deposited during periods when no condensed water is falling.

Elevation. Vertical distance of a point or line above or below the National Geodetic Vertical Datum of 1929. The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929." In this report, all elevations are above NGVD of 1929.

Evapotranspiration. Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plant transpiration, no attempt being made to distinguish between the two.

Ground water. Water that is in the saturated zone from which wells, springs, and ground-water inflow to streams are supplied.

Ground-water runoff. Ground water that has discharged into stream channels by seepage from saturated earth materials.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In general terms, hydraulic conductivity is the ability of a porous medium to transmit water.

Hydrograph. A graph showing the variations of stage, flow, velocity, discharge, or other aspect of water with respect to time.

NGVD of 1929. See Elevation.

Permeability. A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium alone, and is independent of the nature of the fluid and of the force field.

Recharge. The process by which water is infiltrated and is added to the zone of saturation. It is also the quantity of water added to the zone of saturation.

Runoff. That part of precipitation that appears in streams; the water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Specific conductance. A measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm) [formerly termed micromhos (µmhos)]. Because the specific conductance is related to amount and type of dissolved material, it is used for approximating the dissolved-solids concentration of water. For most natural waters the ratio of dissolved-solids concentration (in milligrams per liter) to specific conductance (in microsiemens) is in the range 0.5 to 0.8.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Water table. That surface in an unconfined water body at which the pressure is atmospheric. It is defined by levels at which water stands in wells. No water table exists where the upper surface of the water body is confined by low permeability materials.

TABLES OF DATA

Table 13.--Physical and chemical characteristics of streams, 1986-87

[Analyses by U.S. Geological Survey. Site location shown on plate 1. <, less than; --, no analysis made; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Site number	Station number and name	Date of sample	Time of sample	Stream-flow, instan-taneous (ft³/s)	Spe-cific con-duct-ance (µS/cm)	Water Temper-ature (°C)	pH (stand-ard units)
2	04096950	07-15-86	1200	31	323	22.5	7.50
	Bear Creek at	10-07-86	1445	52	281	11.5	7.50
	44th Street, near Fulton	06-15-87	1230	2.8	470	28.0	8.10
		09-10-87	1000	4.4	450	18.5	7.90
3	04097040	07-15-86	1000	11	474	18.0	7.80
	Little Portage Creek	10-07-86	1045	27	445	10.0	7.80
	at TS Avenue, near	06-15-87	1050	1.9	544	20.0	8.20
	Climax	09-10-87	1130	2.4	545	17.0	8.10
4	04097060	07-15-86	1400	28	491	19.0	8.00
	Little Portage Creek	10-08-86	1015	60	479	11.5	7.90
	at 38th Street, near	06-15-87	1505	8.0	566	20.0	8.10
	Fulton	09-09-87	1345	11	543	16.5	8.00
5	04097120	07-15-86	1115	37	431	19.0	8.00
	Portage River at	10-08-86	1345	69	421	12.0	7.60
	S Avenue, near	06-15-87	1100	15	489	20.0	7.80
	Scotts	09-09-87	1100	16	506	16.0	7.70
6	04097170	07-30-86	1355	63	377	25.0	7.80
	Portage River	10-08-86	1515	169	375	14.5	7.70
	near Vicksburg	06-17-87	1045	21	424	24.5	7.20
		09-09-87	1500	34	394	23.0	7.90
8	04097205	07-15-86	1400	16	360	25.0	7.70
	Gourdneck Creek	10-07-86	1715	37	359	15.0	7.50
	near Vicksburg	06-15-87	1545	7.3	394	28.0	7.50
		09-09-87	1430	14	366	21.5	7.20
9	04097207	07-15-86	1600	1.4	483	19.5	8.00
	Austin Lake Outlet	10-08-86	0910	14	337	12.0	7.80
	at TU Avenue, near	06-15-87	1830	.69	479	19.5	7.90
	Vicksburg	09-09-87	1245	.52	503	15.5	7.70
10	04097210	07-29-86	1700	28	370	27.0	8.00
	Portage Creek at	10-08-86	1420	65	343	14.5	7.90
	W Avenue, at	06-17-87	0930	4.7	370	24.0	8.00
	Vicksburg	09-09-87	0930	11	336	21.5	8.10
11	04097240	07-30-86	1140	64	365	25.0	7.90
	Portage Creek	10-09-86	1330	137	392	14.5	8.00
	near Mendon	06-16-87	1410	30	401	28.0	8.40
		09-09-87	1100	45	369	21.0	7.80
12	04097330	07-15-86	1530	12	485	21.0	7.90
	Bear Creek	10-08-86	1200	49	452	11.5	7.60
	near Vicksburg	06-16-87	1545	3.1	525	23.5	8.30
		09-09-87	1215	3.7	534	16.5	8.10
13	04097370	07-29-86	1200	24	488	20.0	8.00
	Flowerfield Creek	10-09-86	1100	54	414	12.5	8.00
	at Flowerfield	06-16-87	0955	8.7	500	17.0	8.00
		09-08-87	1300	14	511	18.5	8.10
14	04097380	07-29-86	1435	7.8	426	22.0	7.80
	Spring Creek	10-09-86	0930	9.1	377	11.5	7.70
	near Flowerfield	06-16-87	1110	6.3	444	20.0	8.80
		09-08-87	1500	7.0	420	16.5	7.90
15	04105671	08-01-86	1030	7.5	373	23.0	8.00
	Eagle Lake Drain	10-07-86	1225	16	372	14.5	8.00
	near Augusta	06-15-87	1120	5.1	417	20.5	7.50
		09-09-87	1100	6.4	395	20.0	8.10
16	04105700	08-01-86	0900	39	428	20.5	8.20
	Augusta Creek	10-07-86	1015	104	367	10.5	8.00
	near Augusta	06-15-87	1215	27	483	21.0	7.70
		09-09-87	1245	28	487	18.0	8.30
17	04105800	07-31-86	1300	47	354	27.0	8.20
	Gull Creek	10-07-86	1445	102	344	15.5	8.00
	near Galesburg	06-15-87	1420	15	410	27.0	7.60
		09-09-87	1430	31	391	24.0	8.30
18	04105990	07-31-86	1100	7.6	343	25.5	8.20
	Comstock Creek	10-07-86	1650	19	367	17.0	8.00
	near Kalamazoo	06-15-87	1530	4.5	371	30.0	7.70
		09-09-87	1550	6.2	379	25.0	8.10
19	04106000	07-31-86	1120	778	542	26.0	8.40
	Kalamazoo River	10-09-86	1000	3,100	441	13.5	8.20
	at Comstock	06-17-87	1000	580	561	27.0	8.20
		09-11-87	0945	762	551	22.0	8.20
20	04106050	07-31-86	1400	6.4	588	20.5	8.10
	Davis Creek at	10-08-86	1700	[1]13	566	15.0	7.90
	Olmstead Road, at	06-16-87	1830	4.5	762	23.0	8.00
	Kalamazoo	09-10-87	1500	[1]3.3	648	19.0	8.20
21	04106180	08-01-86	0800	23	450	17.0	8.10
	Portage Creek	10-07-86	1315	25	421	12.0	7.90
	at Portage	06-16-87	0830	13	437	15.0	7.80
		09-09-87	1630	14	437	18.0	7.90
24	04106400	07-31-86	1630	6.8	420	28.0	8.20
	West Fork Portage	10-07-86	1050	17	429	13.5	7.80
	Creek at Kalamazoo	06-16-87	1100	3.9	476	25.5	7.80
		09-10-87	0845	4.5	450	19.0	7.40
25	04106500	07-31-86	1030	39	564	20.0	8.20
	Portage Creek	10-09-86	1530	125	576	14.0	8.10
	at Kalamazoo	06-16-87	1500	30	584	25.0	8.00
		09-10-87	1120	33	571	18.5	7.80
26	04106512	08-01-86	1230	44	637	22.5	8.10
	Portage Creek	10-09-86	1300	--	614	14.0	8.00
	at Michigan Avenue,	06-17-87	1400	38	654	23.0	7.50
	at Kalamazoo	09-10-87	1315	40	632	19.0	7.90
27	04106513	07-31-86	0900	3.8	774	19.0	8.10
	Arcadia Creek	10-08-86	1535	6.2	1330	16.0	7.90
	at Kalamazoo	06-16-87	1415	3.4	--	19.5	7.40
		09-10-87	0945	4.1	774	17.0	8.00
28	04106750	07-15-86	1915	20	550	18.0	8.30
	Spring Brook	10-08-86	1345	30	444	12.5	8.20
	near East Cooper	06-16-87	1550	18	--	17.5	7.70
		09-10-87	1035	20	523	13.0	8.20
29	04106770	07-15-86	1700	1,420	566	26.5	8.30
	Kalamazoo River	10-09-86	1300	2,980	455	13.5	8.00
	near Cooper	06-17-87	1130	482	691	26.5	7.40
	Center	09-11-87	1115	955	541	22.0	8.30
30	04107710	07-15-86	1315	16	494	16.5	8.00
	Sand Creek	10-08-86	1155	30	502	12.5	7.90
	near Alamo	06-16-87	1220	9.3	511	14.0	7.50
		09-10-87	1330	12	535	14.0	8.10
31	04107750	07-15-86	1100	15	480	22.5	8.20
	Rupert Lake	10-08-86	1015	31	475	14.0	7.80
	Outlet near	06-16-87	1015	8.3	536	20.5	7.60
	Plainwell	09-10-87	1215	10	519	19.0	8.20

Table 13.--Physical and chemical characteristics of streams, 1986-87--Continued

Site number	Oxygen, dis-solved (mg/L)	Nitro-gen, ammonia total (mg/L as N)	Nitro-gen, nitrite total (mg/L as N)	Nitro-gen, nitrate total (mg/L as N)	Nitro-gen, organic total (mg/L as N)	Phos-phorous, ortho, total (mg/L as P)	Phos-phorous total (mg/L as P)	Sedi-ment, sus-pended (mg/L)	Phenols total (µg/L)
2	3.8	0.050	<0.010	0.09	1.2	0.080	0.100	2	--
	4.0	.040	<.010	.09	.86	.040	.070	1	--
	5.8	.100	.020	.180	1.4	.090	.150	18	--
	7.0	.060	.010	.190	.94	.140	.110	7	--
3	7.7	.110	.030	1.57	1.6	.050	.150	--	--
	11.2	.090	.020	1.68	1.9	.030	.080	15	--
	8.0	.100	.050	.850	.80	.020	.090	14	--
	9.8	.030	.020	1.08	.37	.020	.030	31	--
4	7.9	.080	.020	2.48	1.0	.050	.070	8	--
	8.6	.070	.020	2.38	1.5	.040	.060	8	--
	8.3	.060	.030	2.57	1.6	.020	.050	4	--
	8.7	.030	.020	2.48	.57	.020	.030	49	--
5	6.0	.130	.030	.570	.97	.020	.060	17	--
	5.7	.060	.020	.480	1.7	.010	.040	2	--
	7.6	.070	.020	.480	.53	<.010	.040	8	--
	8.0	.040	.010	.590	1.1	<.010	<.010	<1	--
6	5.8	.040	<.010	.190	.56	.010	.020	8	--
	4.6	.060	.020	.180	1.2	.010	.030	5	--
	6.1	.050	.010	.190	.55	<.010	.040	4	--
	6.8	.020	<.010	.190	.38	<.010	<.010	5	--
8	4.5	.030	<.010	.090	.97	.020	.030	1	--
	4.6	.030	<.010	.090	.47	<.010	.020	1	--
	5.3	.070	.010	.090	.63	.020	.060	3	5
	4.3	<.010	<.010	.090	.79	<.010	<.010	2	--
9	5.7	.170	.040	.460	.53	.020	.050	12	--
	9.4	.070	<.010	.090	.73	<.010	.020	7	--
	5.2	.040	.020	.380	.66	<.010	.040	6	--
	6.6	.040	.010	.390	.26	<.010	.020	9	--
10	7.3	.030	<.010	.090	.57	<.010	.020	3	--
	8.4	.060	.020	1.58	1.2	.040	.090	1	--
	5.1	.050	<.010	.090	.35	<.010	.050	5	3
	7.7	.030	<.010	.090	.37	<.010	<.010	3	--
11	6.1	.050	.020	.580	.45	.010	.020	4	--
	6.8	.040	.020	.480	1.4	.010	.040	5	--
	9.1	.080	.020	.680	1.3	<.010	.040	19	3
	5.8	.020	.010	.290	.58	<.010	<.010	4	--

Table 13.--Physical and chemical characteristics of streams, 1986-87--Continued

Site number	Oxygen, dis-solved (mg/L)	Nitro-gen, ammonia total (mg/L as N)	Nitro-gen, nitrite total (mg/L as N)	Nitro-gen, nitrate total (mg/L as N)	Nitro-gen, organic total (mg/L as N)	Phos-phorous, ortho, total (mg/L as P)	Phos-phorous total (mg/L as P)	Sedi-ment, sus-pended (mg/L)	Phenols total (µg/L)
12	6.6	0.080	0.020	1.58	1.2	0.050	0.080	8	--
	4.8	.050	<.010	.090	.45	<.010	.020	1	--
	10.0	.030	.030	2.77	.77	.020	.060	14	--
	9.3	.030	.020	2.18	.17	.020	.040	34	--
13	8.2	.040	.020	1.38	.76	.030	.040	12	--
	9.0	.040	<.010	.79	.86	.020	.040	6	--
	7.6	.030	.020	1.88	.17	<.010	.040	44	--
	7.7	.030	.010	1.19	.37	<.010	<.010	33	--
14	8.4	.060	.020	1.28	.94	.010	.030	6	--
	7.2	.170	.030	1.37	.93	.010	.050	16	--
	10.8	.040	.020	1.08	.46	<.010	.040	8	3
	8.8	.080	.020	.980	.12	<.010	<.010	31	--
15	6.1	.100	<.010	.090	.70	.010	.040	15	--
	8.2	.070	.010	.090	.73	<.010	.030	12	--
	6.1	.050	.010	.090	.95	<.010	.040	42	--
	7.5	.020	<.010	.090	.18	<.010	<.010	18	--
16	7.8	.050	<.010	.090	.55	.010	.040	35	--
	8.9	.040	<.010	.49	1.1	.010	.050	7	--
	7.9	.030	<.010	1.29	.37	<.010	.050	44	--
	10.0	.010	<.010	1.09	.19	<.010	<.010	45	--
17	8.4	.040	<.010	.090	.46	<.010	.020	6	--
	9.9	.040	.010	.090	.26	<.010	.020	3	--
	7.1	.030	<.010	.090	1.6	<.010	.040	8	2
	9.2	.010	<.010	.090	.29	<.010	<.010	5	--
18	9.1	.040	<.010	.090	.56	<.010	.010	3	--
	7.5	.090	.010	.190	.71	<.010	.020	3	--
	6.9	.060	<.010	.190	.84	<.010	.040	5	4
	8.1	.030	<.010	.090	.27	<.010	<.010	1	--
19	9.9	.060	.020	.580	.74	.020	.060	8	--
	9.8	.050	.010	.690	1.2	.030	.070	7	--
	11.7	.030	.020	.280	.57	<.010	.080	11	5
	10.6	.020	.040	.560	.58	<.010	<.010	39	--
20	9.4	.360	.070	.830	.44	.080	.110	5	--
	8.5	.440	.050	.750	1.1	.040	.070	17	--
	7.1	.160	.090	.810	.34	.020	.070	8	3
	13.9	.210	.090	.910	.44	.010	.010	48	--
21	7.6	.080	.020	.780	.42	<.010	.020	4	--
	8.2	.140	.020	.780	.86	<.010	.030	6	--
	8.2	.100	.020	.780	1.1	<.010	.030	11	8
	9.0	.080	.020	.880	.12	<.010	<.010	20	--

Table 13.--Physical and chemical characteristics of streams, 1986-87--Continued

Site number	Oxygen, dis-solved (mg/L)	Nitro-gen, ammonia total (mg/L as N)	Nitro-gen, nitrite total (mg/L as N)	Nitro-gen, nitrate total (mg/L as N)	Nitro-gen, organic total (mg/L as N)	Phos-phorous, ortho, total (mg/L as P)	Phos-phorous total (mg/L as P)	Sedi-ment, sus-pended (mg/L)	Phenols total (µg/L)
24	5.8	0.030	<0.010	0.090	0.57	<0.010	0.020	<1	--
	6.1	.070	.020	.080	.83	.010	.020	1	--
	8.5	.030	<.010	.090	.57	<.010	.040	3	4
	5.1	.030	<.010	.090	.27	<.010	.020	7	--
25	8.0	.140	.020	.480	.56	.030	.040	38	--
	9.6	.110	.030	.670	.69	.030	.080	60	--
	8.4	.070	.020	.380	.63	.010	.050	23	--
	9.0	.040	.020	.480	.56	<.010	.020	67	--
26	7.6	.100	.020	.580	.40	.030	.090	60	--
	7.8	.070	.020	.580	.93	.020	.090	32	--
	7.1	.090	.020	.480	.81	.020	.050	44	3
	10.0	.040	.020	.480	.16	<.010	.010	45	--
27	8.6	.080	.010	1.100	.22	.050	.080	11	--
	9.2	.230	.030	.970	.97	.020	.130	60	--
	7.6	.070	.020	.980	.63	.050	.260	110	4
	8.6	.020	<.010	1.19	1.8	.050	.070	2	--
28	8.9	.030	<.010	1.69	.87	.010	.030	23	--
	10.9	.030	<.010	1.49	.57	.010	.030	24	--
	8.9	.020	<.010	1.79	.78	<.010	.030	45	--
	10.0	<.010	<.010	1.69	.19	<.010	<.010	30	--
29	9.4	.050	.020	1.08	.95	.030	.090	14	--
	9.0	.070	.020	.880	1.5	.030	.080	9	--
	7.5	.130	.030	1.27	.27	.020	.080	13	5
	7.8	.080	.040	.860	.52	.020	.020	30	--
30	8.8	.050	.010	.290	.45	<.010	.020	5	--
	7.2	.090	.020	.380	.41	<.010	.030	45	--
	--	.030	<.010	.390	.47	<.010	.040	36	--
	8.3	.020	.010	.390	.28	<.010	<.010	42	--
31	8.2	.090	.010	.290	.51	<.010	.020	5	--
	4.2	.230	.040	.460	1.1	.010	.060	7	--
	6.3	.050	<.010	.290	.75	<.010	.030	33	--
	8.0	.040	<.010	.190	.46	<.010	<.010	32	--

[1] Downstream from diversion channel.

[2]Not measureable. Site is under backwater from the Kalamazoo River at higher stages.

Table 14.--Maximum, mean, and minimum values of specific conductance, dissolved oxygen, and pH of streams, 1986-87

[Analyses by U.S. Geological Survey. Site locations shown on plate 1. Mean pH from antilog average. µS/cm, microsiemens per centimeter at 25 degrees Celsisus; mg/L, milligrams per liter]

Site number	Number of analysis		Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (units)
		Maximum	450	7.0	8.1
2	4	Mean	381	5.2	7.8
		Minimum	281	3.8	7.5
		Maximum	545	11.2	8.2
3	4	Mean	502	9.2	8.0
		Minimum	445	7.7	7.8
		Maximum	566	8.7	8.1
4	4	Mean	520	8.4	8.0
		Minimum	479	7.9	7.9
		Maximum	506	8.0	8.0
5	4	Mean	462	6.8	7.8
		Minimum	421	5.7	7.6
		Maximum	477	10.9	8.1
6	9	Mean	429	6.4	7.7
		Minimum	375	4.6	7.2
		Maximum	444	11.0	8.0
7	5	Mean	343	8.9	7.5
		Minimum	395	6.7	6.8
		Maximum	394	5.3	7.7
8	4	Mean	370	4.6	7.5
		Minimum	359	4.3	7.2
		Maximum	503	9.4	8.0
9	4	Mean	450	6.7	7.8
		Minimum	337	5.2	7.7
		Maximum	370	8.4	8.1
10	4	Mean	355	7.1	8.0
		Minimum	336	5.1	7.9
		Maximum	401	9.1	8.4
11	4	Mean	382	7.0	8.0
		Minimum	365	5.8	7.8

Table 14.--Maximum, mean, and minimum values of specific conductance, dissolved oxygen, and pH of streams, 1986-87--Continued

Site number	Number of analysis		Specific conductance (µS/cm)	Oxygen dissolved (mg/L)	pH (units)
		Maximum	534	10.0	8.3
12	4	Mean	499	7.7	8.0
		Minimum	452	4.8	7.6
		Maximum	511	9.0	8.1
13	4	Mean	478	8.1	8.0
		Minimum	414	7.6	8.0
		Maximum	444	10.8	8.8
14	4	Mean	417	8.8	8.0
		Minimum	377	7.2	7.7
		Maximum	417	8.2	8.1
15	4	Mean	389	7.0	7.9
		Minimum	372	6.1	7.5
		Maximum	487	11.8	8.5
16	9	Mean	454	9.6	8.0
		Minimum	367	7.8	7.6
		Maximum	410	9.9	8.3
17	4	Mean	375	8.6	8.0
		Minimum	354	7.1	7.6
		Maximum	379	9.1	8.2
18	4	Mean	365	7.9	8.0
		Minimum	343	6.9	7.7
		Maximum	589	11.7	8.4
19	9	Mean	552	10.6	8.2
		Minimum	441	9.8	7.7
		Maximum	762	13.9	8.2
20	4	Mean	641	9.7	8.0
		Minimum	566	7.1	7.9
		Maximum	485	9.9	8.1
21	9	Mean	445	8.5	7.8
		Minimum	421	7.5	7.3

Table 14.--Maximum, mean, and minimum values of specific conductance, dissolved oxygen, and pH of streams, 1986-87--Continued

Site number	Number of analysis		Specific conductance (µS/cm)	Oxygen dissolved (mg/L)	pH (units)
		Maximum	594	11.0	8.0
22	5	Mean	590	9.7	7.8
		Minimum	582	8.5	7.4
		Maximum	450	11.6	8.1
23	5	Mean	432	8.7	7.6
		Minimum	417	6.2	7.0
		Maximum	529	11.0	8.3
24	9	Mean	476	8.1	7.8
		Minimum	472	5.1	7.4
		Maximum	609	10.2	8.2
25	8	Mean	586	8.9	7.9
		Minimum	564	8.0	7.4
		Maximum	654	10.0	8.1
26	4	Mean	634	8.1	7.9
		Minimum	614	7.1	7.5
		Maximum	1,330	9.2	8.1
27	4	Mean	910	8.5	7.8
		Minimum	761	7.6	7.4
		Maximum	550	10.9	8.3
28	4	Mean	504	9.7	8.1
		Minimum	444	8.9	7.7
		Maximum	691	9.4	8.3
29	4	Mean	563	8.4	8.0
		Minimum	455	7.5	7.4
		Maximum	535	8.8	8.1
30	4	Mean	510	8.1	7.9
		Minimum	494	7.2	7.5
		Maximum	536	8.2	8.2
31	4	Mean	502	6.7	8.0
		Minimum	475	4.2	7.6

Table 15.--Common dissolved substances and trace elements of streams

[Analyses by U.S. Geological Survey. Stream location shown on plate 1. mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; <, less than; --, no analysis made]

Site number	Date of sample	Time of sample	Turbidity (NTU)	Hardness (mg/L as $CaCO_3$)	Alkalinity lab (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 °C dissolved (mg/L)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
2	07-15-86	1200	2.0	180	170	206	234	51	13
3	07-15-86	1000	--	270	216	297	339	78	18
4	07-15-86	1400	2.5	280	215	310	348	79	20
5	07-15-86	1115	2.0	250	197	276	297	68	19
6	07-30-86	1355	2.3	200	170	231	247	54	17
8	07-15-86	1400	8.0	180	164	209	212	43	18
9	07-15-86	1600	1.6	240	203	278	288	64	19
10	07-29-86	1700	1.5	180	169	214	223	46	16
11	07-30-86	1140	1.7	190	159	210	220	47	17
12	07-15-86	1530	3.5	290	225	315	343	82	20
13	07-29-86	1200	1.5	260	241	287	301	68	23
14	07-29-86	1435	2.5	230	184	257	266	62	18
15	08-01-86	1030	4.0	210	191	220	225	56	17
16	08-01-86	0900	4.0	240	224	265	272	65	20
17	07-31-86	1300	1.7	190	171	215	215	43	21
18	07-31-86	1100	1.0	190	161	217	222	43	20
19	07-31-86	1120	2.5	270	232	332	345	75	21
20	07-31-86	1400	3.5	270	238	365	362	77	20
21	08-01-86	0800	1.2	210	186	247	255	55	17
24	07-31-86	1630	1.5	170	162	239	234	36	20
25	07-31-86	1030	2.7	280	227	341	331	73	23
26	08-01-86	1230	8.0	290	242	370	381	77	24
27	07-31-86	0900	1.0	330	273	430	430	83	29
28	07-15-86	1915	2.2	260	226	277	278	67	22
29	07-15-86	1700	5.0	270	210	323	338	72	21
30	07-15-86	1315	1.5	280	231	294	298	71	24
31	07-15-86	1100	2.5	280	223	308	318	70	25

Table 15.--Common dissolved substances and trace metals of streams--Continued

Site number	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic total (µg/L as As)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)
2	2.9	1.3	12	7.2	0.10	17	4	<10	<10
3	4.4	1.1	43	11	.10	12	6	<10	<10
4	4.7	1.4	52	12	.10	12	3	<10	<10
5	4.2	1.6	43	9.8	.20	12	6	<10	<10
6	4.7	1.3	34	11	.10	7.2	2	<10	<10
8	7.9	.70	20	12	.20	9.3	1	<10	<10
9	8.2	1.6	35	18	.10	10	2	<10	<10
10	6.5	1.1	15	14	.10	14	2	<10	<10
11	6.9	.90	27	14	.10	6.6	2	<10	<10
12	6.4	2.0	39	16	.20	14	3	<10	<10
13	3.7	.90	22	9.9	.20	15	2	<10	<10
14	5.9	1.4	31	16	.20	12	1	<10	<10
15	4.1	.60	19	6.8	.10	6.8	2	<10	<10
16	4.7	.80	18	7.7	.10	14	1	<10	<10
17	5.8	.90	21	9.8	<.10	11	4	<10	<10
18	6.2	.80	27	11	<.10	12	<1	<10	<10
19	15	1.7	36	31	.20	13	2	<10	<10
20	20	22	33	38	.40	12	5	<10	<10
21	11	1.0	26	16	<.10	9.9	2	<10	<10
24	18	1.0	21	34	<.10	12	<1	<10	<10
25	21	1.4	36	38	.10	12	5	<10	<10
26	25	1.60	41	47	.20	11	4	<10	<10
27	36	1.7	31	69	.20	12	1	<10	<10
28	4.8	.90	27	8.7	.10	11	<1	<10	<10
29	19	2.0	40	32	.20	11	2	<10	<10
30	4.3	.90	36	7.4	.20	12	3	<10	<10
31	6.4	1.1	50	12	.20	9.8	3	<10	<10

Table 15.--Common dissolved substances and trace metals of streams--Continued

Site number	Cobalt, total recoverable (µg/L as Co)	Copper, total recoverable (µg/L as Cu)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Mercury total recoverable (µg/L as Hg)	Strontium, total recoverable (µg/L as Sr)	Zinc, total recoverable (µg/L as Zn)
2	<50	10	960	<100	120	<0.10	80	20
3	<50	10	4,000	<100	290	<.10	120	20
4	<50	10	860	<100	100	<.10	110	10
5	<50	10	1,200	<100	160	<.10	80	10
6	<50	<10	400	<100	80	.10	60	10
8	<50	10	400	<100	40	<.10	60	20
9	<50	<10	1,500	<100	100	<.10	50	10
10	<50	<10	90	<100	50	.10	40	<10
11	<50	<10	200	<100	40	.10	50	30
12	<50	10	1,200	<100	130	.10	100	10
13	<50	<10	690	<100	180	.10	60	20
14	<50	<10	840	<100	60	.10	60	90
15	<50	<10	460	<100	90	.10	60	<10
16	<50	<10	650	<100	100	.10	80	<10
17	<50	<10	160	<100	30	.10	50	<10
18	<50	<10	100	<100	20	.10	50	20
19	<50	<10	290	<100	70	.10	130	20
20	<50	<10	550	<100	80	.10	80	30
21	<50	<10	350	<100	50	.10	50	<10
24	<50	<10	20	<100	20	.10	40	<10
25	<50	<10	1,300	<100	130	.10	80	30
26	<50	10	1,200	<100	130	.10	100	10
27	<50	<10	30	<100	30	.10	90	20
28	<50	10	410	<100	30	<.10	90	10
29	<50	10	600	<100	80	<.10	120	20
30	<50	10	600	<100	60	<.10	100	10
31	<50	<10	400	<100	30	<.10	120	90

Table 19.--Physical and chemical characteristics of ground water in wells, 1987

[Analyses by U.S. Geological Survey. Well locations are shown on plate 1. µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, means no analysis made]

Well number	U.S. Geological Survey Station number	Date of sample	Time of sample	Depth of well, total (feet)	Specific conductance (µS/cm)	Water Temperature (°C)
1	422117085393001	July 29, 1987	1215	146.0	1,660	10.5
2	422232085344701	July 28, 1987	1400	37.9	758	10.0
3	422153085314701	July 28, 1987	1300	37.8	439	9.5
4	422328085285701	July 29, 1987	1400	46.7	539	11.0
5	422056085211701	July 29, 1987	1515	34.8	533	10.5
6	421942085190301	July 27, 1987	1100	39.1	489	14.0
7	421713085264601	July 27, 1987	1415	29.0	662	12.0
8	421630085322601	July 28, 1987	1045	35.4	1,180	11.5
9	421742085452501	July 30, 1987	0945	67.5	496	12.0
10	421312085432301	July 29, 1987	1515	29.0	202	11.0
11	421203085370401	July 29, 1987	1600	56.2	495	12.0
12	421208085283301	July 27, 1987	1600	37.5	902	9.5
13	421148085252101	July 28, 1987	1030	34.1	602	10.0
14	421358085195101	July 27, 1987	1130	38.2	532	10.5
15	421016085240601	July 27, 1987	1445	42.2	606	10.0
16	420858085432401	July 29, 1987	1410	56.0	837	11.5
17	420653085395401	July 29, 1987	1330	29.9	572	11.0
18	420533085381501	July 29, 1987	1130	48.2	730	11.5
19	420657085245501	July 28, 1987	1415	111.0	540	10.0
20	420653085190701	July 28, 1987	1145	38.0	730	10.0
21	420658085210401	July 28, 1987	1330	47.2	900	9.0
22	421107085185301	July 27, 1987	1330	38.0	516	10.5
23	420547085342301	July 28, 1987	1615	48.0	582	10.0
24	420657085320301	July 28, 1987	1520	39.0	858	9.5
25	420945085323301	July 29, 1987	0930	38.5	509	12.0
26	421445085335201	July 28, 1987	1635	86.0	1,550	12.0
27	422418085440201	July 28, 1987	1000	37.5	585	10.0
28	422006085353901	July 28, 1987	1130	55.0	587	11.0
29	422004085301801	July 28, 1987	1500	65.4	495	10.5
30	421908085240501	July 27, 1987	1245	27.5	535	11.0
31	421616085262801	July 27, 1987	1535	47.7	612	11.0
32-S	421435085353701	July 27, 1987	1430	36.4	813	12.0
32-D	421435085353702	July 29, 1987	1335	145.0	631	12.5
33	422227085213001	July 30, 1987	1100	75.7	477	11.0
34	422207085175501	July 30, 1987	1145	62.5	427	10.5
35	422228085260301	July 30, 1987	1000	68.0	3,310	13.0
36-S	421517085204501	July 29, 1987	0930	60.0	639	11.0
36-D	421517085204502	July 29, 1987	1030	100.0	394	13.0
37	420838085344501	July 29, 1987	1030	190.0	362	11.5
38	421151085351601	July 29, 1987	1200	102.0	726	13.5
39	421457085325802	Aug. 14, 1987	1500	190.0	504	11.0
40	421641085350602	Aug. 14, 1987	1115	162.0	831	12.5
41	421658085325901	July 28, 1987	1220	42.9	1,810	12.0
42	421731085332601	July 28, 1987	1425	90.0	1,680	12.5
43	421716085373701	July 30, 1987	1200	81.0	614	11.5
44	421448085383601	Aug. 14, 1987	1300	193.5	495	11.0

Table 19.--Physical and chemical characteristics of ground water in wells, 1987--Continued

Well number	pH (standard units)	Oxygen, dissolved (mg/L)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, No_2+No_3 total (mg/L as N)	Phosphorus, ortho, total (mg/L as P)	Phosphorous total (mg/L as P)	Phenols total (mg/L)
1	7.40	4.4	0.050	<0.010	3.39	0.55	3.40	<0.010	0.010	--
2	6.90	1.2	.030	<.010	.79	.37	.800	<.010	<.010	2
3	7.58	.1	.020	<.010	.09	.28	<.100	<.010	<.010	--
4	7.60	11.1	.010	<.010	9.69	1.2	9.70	<.010	.010	--
5	7.52	.1	<.010	<.010	.19	.19	.200	.041	.050	3
6	8.00	.1	.040	<.010	.09	.16	<.100	<.010	.020	--
7	7.10	7.8	.020	<.010	3.99	.18	4.00	<.010	.010	--
8	6.80	.1	.450	<.010	2.59	1.0	2.60	<.010	<.010	4
9	7.20	--	.380	<.010	.09	.22	<.100	<.010	.010	--
10	8.04	--	.060	<.010	.09	.44	<.100	<.010	.030	--
11	7.33	--	<.010	<.010	.09	.19	.100	<.010	.010	--
12	7.34	.1	.040	<.010	.09	.16	<.100	<.010	.010	--
13	7.50	0	.020	<.010	.29	.38	.300	<.010	.020	--
14	7.10	8.1	.020	<.010	12.00	2.4	12.0	<.010	.010	--
15	7.82	0	.040	<.010	.09	.26	<.100	<.010	.020	--
16	7.22	--	<.010	.020	5.28	.39	5.30	<.010	<.010	--
17	7.65	--	<.010	<.010	6.89	.19	6.90	<.010	.010	--
18	7.73	--	<.010	<.010	27.00	2.30	27.0	<.010	<.010	5
19	7.71	--	.080	<.010	.09	.52	<.100	<.010	.020	--
20	7.45	2.2	.030	<.010	16.00	1.9	16.0	<.010	.010	--
21	7.43	6.3	.040	<.010	21.00	2.9	21.0	.020	.080	--
22	7.61	.3	.030	.020	2.18	.77	2.20	<.010	.010	--
23	7.30	--	.020	<.010	.09	.48	<.100	<.010	<.010	--
24	7.03	--	.440	<.010	.09	.66	<.100	<.010	.030	11
25	7.59	0	1.20	<.010	.19	1.0	.200	<.010	.020	6
26	6.70	7.4	.040	<.010	2.39	.76	2.40	<.010	.010	3
27	7.48	.1	.040	<.010	.09	.46	<.100	<.010	.010	--
28	7.30	4.8	.020	<.010	1.69	.28	1.70	<.010	.010	--
29	7.55	9.6	.030	<.010	9.99	.97	10.0	<.010	.010	--
30	7.10	.1	.190	<.010	.09	.11	<.100	<.010	.010	--
31	7.40	5.8	.020	<.010	7.59	.98	7.60	.010	.010	--
32-S	6.70	.0	.210	<.010	.09	.19	<.100	<.010	.020	--
32-D	7.10	.1	.040	<.010	.09	.26	<.100	<.010	.010	--
33	6.90	.2	.120	<.010	.09	.18	<.100	<.010	.030	--
34	7.42	.1	<.010	<.010	.09	.19	<.100	<.010	.010	--
35	6.80	.4	.100	.880	16.10	1.9	17.0	<.010	.010	--
36-S	7.70	7.8	<.010	<.010	13.00	1.4	13.0	<.010	.010	--
36-D	7.60	.1	.100	<.010	.09	.30	<.100	<.010	.030	--
37	8.24	0	<.010	.020	.480	.49	.500	<.010	<.010	--
38	7.10	0	1.20	<.010	.09	.30	<.100	.020	.080	1
39	7.00	0	.300	<.010	.09	.30	<.100	.010	.160	--
40	6.80	8.3	.040	.020	.980	.26	1.00	<.010	.010	2
41	6.60	.1	.320	<.010	.09	.18	<.100	<.010	.150	4
42	6.60	.1	.110	.010	1.59	1.2	1.60	<.010	.490	4
43	7.00	.1	.090	<.010	.09	.21	<.100	<.010	.020	6
44	7.00	.1	.080	<.010	.09	.42	<.100	<.010	.041	--

Table 19.--Physical and chemical characteristics of ground water in wells, 1987--Continued

Well number	Hardness total (mg/L as $CaCO_3$)	Alkalinity Lab (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 °C dissolved (mg/L)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate dissolved (mg/L as So_4)
1	580	220	913	1,100	140	55	130	2.2	41
2	460	388	520	522	120	39	10	1.2	87
3	240	177	238	256	63	20	2.7	.60	31
4	290	199	259	310	74	26	2.5	.60	21
5	310	212	288	326	83	26	6.0	.90	26
6	250	254	274	280	71	18	4.8	.70	5.2
7	350	223	364	399	90	31	26	1.3	28
8	440	305	648	688	120	33	68	6.9	51
9	260	177	234	253	68	23	5.0	.90	9.0
10	73	61	81	74	18	6.7	1.2	.40	9.7
11	230	138	220	249	60	20	2.3	.60	38
12	360	249	373	406	100	27	4.1	1.5	72
13	270	177	264	283	74	20	5.1	.80	37
14	310	147	246	306	80	26	3.2	.90	27
15	360	220	359	377	97	28	4.5	1.1	69
16	400	244	329	427	100	37	2.7	1.1	17
17	280	203	263	282	69	27	2.7	.40	25
18	320	142	254	418	83	28	3.9	.60	29
19	230	217	265	259	61	20	6.8	.70	26
20	310	161	259	346	88	23	3.6	2.6	23
21	390	--	206	441	100	33	6.1	2.6	36
22	290	181	301	350	80	22	4.3	1.9	59
23	270	170	309	308	70	23	3.5	.70	91
24	320	245	359	391	91	23	19	3.0	31
25	200	172	234	241	54	16	14	1.5	12
26	630	292	793	919	160	56	100	1.9	33
27	310	233	320	330	81	27	3.9	1.1	51
28	320	204	293	342	81	28	4.3	.90	35
29	260	169	236	287	69	21	3.4	.80	18
30	280	267	313	302	80	20	4.6	.80	29
31	320	250	323	379	90	22	4.3	.90	32
32-S	410	316	495	516	130	21	11	1.7	110
32-D	290	169	--	354	73	25	24	1.4	36
33	250	235	266	274	62	22	8.4	1.1	7.8
34	250	197	255	261	68	20	3.0	.60	31
35	900	342	2,310	2,700	220	84	440	14	1,100
36-S	370	141	281	371	100	28	6.8	1.0	34
36-D	180	168	185	168	37	22	4.7	.90	7.3
37	330	252	379	386	89	26	6.5	1.0	86
38	260	238	399	415	70	21	51	1.1	35
39	260	190	255	280	63	24	13	1.1	9.0
40	340	264	440	472	88	28	40	2.3	36
41	930	364	1,160	1,340	250	75	61	2.7	440
42	650	243	886	1,050	190	43	97	3.5	130
43	330	211	330	411	82	30	5.4	1.0	63
44	250	186	249	274	60	24	5.0	.80	26

Table 19.--Physical and chemical characteristics of ground water in wells, 1987--Continued

Well number	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic total (µg/L as As)	Cyanide dissolved (mg/L as Cn)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Cobalt, total recoverable (µg/L as Co)	Copper, total recoverable (µg/L as Cu)
1	400	0.10	13	<1	<0.01	<10	<10	<50	<10
2	15	.10	15	<1	<.01	<10	<10	<50	<10
3	4.8	.20	9.5	1	--	<10	<10	<50	<10
4	5.4	.10	10	<1	<.01	<10	60	<50	<10
5	4.8	.10	14	8	<.01	<10	<10	<50	<10
6	6.4	.10	16	1	<.01	<10	20	<50	<10
7	43	.10	11	<1	<.01	<10	<10	<50	<10
8	170	.10	16	<1	<.01	<10	<10	<50	<10
9	11	.10	11	5	<.01	<10	50	<50	<10
10	.50	.10	8.3	3	<.01	<10	100	<50	<10
11	4.5	.10	12	5	<.01	<10	<10	<50	<10
12	10	.10	9.1	<1	<.01	<10	<10	<50	<10
13	10	.30	11	3	<.01	<10	<10	<50	<10
14	8.6	.10	12	<1	<.01	<10	90	<50	<10
15	11	.20	16	4	<.01	<10	<10	<50	<10
16	12	.20	13	<1	<.01	<10	<10	<50	<10
17	7.2	.10	9.8	<1	<.01	<10	<10	<50	<10
18	13	.40	11	<1	<.01	<10	70	<50	<10
19	6.2	.20	14	4	<.01	<10	<10	<50	<10
20	10	.20	12	<1	<.01	<10	<10	<50	<10
21	14	.20	14	<1	<.01	<10	<10	<50	<10
22	13	.20	12	<1	<.01	<10	<10	<50	<10
23	11	.20	7.6	<1	<.01	<10	10	<50	<10
24	33	.10	12	2	<.01	<10	<10	<50	<10
25	26	.40	7.3	<1	<.01	<10	<10	<50	<10
26	250	.10	17	<1	<.01	<10	100	<50	<10
27	5.9	.10	10	4	<.01	<10	<10	<50	<10
28	8.4	.20	13	<1	<.01	<10	20	<50	<10
29	11	.10	11	<1	<.01	<10	50	<50	<10
30	5.7	.20	13	3	<.01	<10	110	<50	<10
31	12	.10	12	<1	<.01	<10	<10	<50	<10
32-S	18	.20	14	3	<.01	<10	<10	<50	<10
32-D	--	.40	14	6	<.01	<10	<10	<50	<10
33	8.4	.20	15	<1	<.01	<10	40	<50	<10
34	3.3	.10	11	1	<.01	<10	<10	<50	<10
35	220	.10	29	<1	<.01	10	10,000	<50	<10
36-S	14	.10	13	<1	--	<10	40	<50	<10
36-D	2.9	.10	9.5	1	<.01	<10	<10	<50	<10
37	12	.10	7.2	<1	<.01	<10	100	<50	<10
38	68	.10	9.6	1	<.01	<10	130	<50	410
39	15	.30	16	2	<.01	<10	10	<50	10
40	74	.10	13	<1	<.01	<10	40	<50	20
41	100	.10	15	<1	<.01	<10	50	<50	10
42	260	.20	17	15	<.01	<10	40	<50	20
43	10	.20	12	5	<.01	<10	20	<50	<10
44	8.2	.20	13	4	<.01	<10	20	<50	10

Table 19.--Physical and chemical characteristics of ground water in wells, 1987--Continued

Well number	Iron, total recov-erable (µg/L as Fe)	Lead, total recov-erable (µg/L as Pb)	Manga-nese, total recov-erable (µg/L as Mn)	Mercury total recov-erable (µg/L as Hg)	Stron-tium, total recov-erable (µg/L as Sr)	Zinc, total recov-erable (µg/L as Zn)	Sele-nium, total (µg/L as Se)	Nickel, total recov-erable (µg/L as Ni)	Silver, total recov-erable (µg/L as Ag)
1	180	<100	30	<0.10	200	360	<1	<100	<1
2	190	<100	30	.10	140	450	<1	<100	<1
3	580	<100	130	.80	70	80	<1	<100	<1
4	190	<100	10	<.10	60	70	<1	<100	<1
5	1,700	<100	100	<.10	160	300	<1	--	<1
6	1,300	<100	<10	<.10	60	340	<1	<100	<1
7	160	<100	10	.20	90	100	<1	<100	<1
8	50	<100	30	.10	150	80	<1	<100	<1
9	1,700	<100	60	<.10	70	100	<1	<100	<1
10	30	<100	10	.10	30	30	<1	<100	<1
11	760	<100	70	<.10	70	60	<1	<100	<1
12	620	<100	130	.20	90	480	<1	<100	<1
13	900	<100	70	<.10	60	110	<1	<100	<1
14	50	<100	<10	.20	70	60	<1	<100	<1
15	990	<100	50	.20	110	260	<1	<100	<1
16	180	<100	30	<.10	100	70	<1	<100	<1
17	70	<100	10	<.10	70	60	<1	<100	<1
18	320	<100	10	<.10	70	90	<1	<100	<1
19	800	<100	190	<.10	250	350	<1	<100	<1
20	140	<100	20	<.10	80	80	<1	<100	<1
21	630	<100	20	<.10	120	320	<1	<100	<1
22	60	<100	<10	.30	100	120	<1	<100	<1
23	220	<100	140	.10	60	210	<1	<100	<1
24	2,800	<100	230	<.10	110	650	<1	<100	<1
25	1,100	<100	120	<.10	70	70	<1	<100	<1
26	390	<100	30	<.10	150	260	<1	<100	<1
27	920	<100	50	<.10	100	30	<1	<100	<1
28	80	<100	20	.10	100	70	<1	<100	<1
29	120	<100	20	<.10	80	110	<1	<100	<1
30	2,500	<100	260	.20	100	120	<1	<100	<1
31	110	<100	<10	<.10	100	30	<1	<100	<1
32-S	1,000	<100	250	.20	130	1,100	<1	<100	<1
32-D	480	<100	180	<.10	100	70	<1	<100	<1
33	1,300	<100	240	<.10	240	440	<1	<100	<1
34	440	<100	40	<.10	70	20	<1	<100	<1
35	40	<100	30	.10	230	1,500	<1	600	<1
36-S	50	<100	<10	<.10	80	230	<1	<100	<1
36-D	2,700	<100	50	.10	90	160	1	<100	<1
37	540	<100	70	<.10	100	80	<1	<100	<1
38	6,400	<100	140	<.10	90	60	<1	<100	<1
39	1,100	<100	70	<.10	540	<10	<1	<100	<1
40	340	<100	50	.10	220	<10	<1	<100	<1
41	8,000	<100	600	<.10	390	<10	<1	<100	<1
42	13,000	<100	1,700	<.10	420	<10	<1	<100	<1
43	29,000	<100	250	<.10	90	1,400	<1	<100	<1
44	880	<100	80	.10	220	130	<1	<100	<1

APPENDIX
Agricultural DRASTIC System

The Agricultural DRASTIC system, developed by the U.S. Environmental Protection Agency, uses seven factors to determine contamination potential: depth to water, net recharge, aquifer media, soil media, topography, unsaturated zone, and hydraulic conductivity. Each DRASTIC factor is assigned a relative weight ranging from 1 to 5 (table 29). The most significant factors have weights of 5, the least significant, a weight of 1. These weights are constants and cannot be changed; however, it should be noted that these weighting factors are not necessarily endorsed by the U.S. Geological Survey and that other methods for determining ground-water susceptibility are being considered.

Table 29.--Assigned weights for Agricultural DRASTIC factors

[Aller and others, 1985]

Factors	Weights
Depth to water table	5
Net recharge	4
Aquifer media	3
Soil media	5
Topography	3
Impact of the unsaturated zone	4
Hydraulic conductivity of the aquifer	2

Each DRASTIC factor is divided into either ranges or significant media types that have an effect on pollution potential (tables 30-36). Then, each range has been assigned a rating that varies between 1 and 10. The most significant factors have a rating of 10, the least significant, a rating of 1. Some ranges have varying ratings, and decisions based on differences in the geology and hydrology of the areas, have to be made.

The system allows the user to determine a numerical value for any geohydrologic setting by adding each of the seven DRASTIC factors for that particular area. The equation for determining the DRASTIC index is:

$$D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$$

= Pollution potential

Where

D = Depth to water table
R = net Recharge
A = Aquifer media
S = Soil media
T = Topography
I = Impact of the unsaturated zone
C = hydraulic Conductivity of the aquifer
r = rating
w = weight

The resulting total is considered to be the DRASTIC index of susceptibility to ground-water contamination.

Table 30.--Ranges and ratings for depth to water

[Aller and others, 1985]

Depth to water	
Range (feet)	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1
	Agricultural Weight: 5

Table 31.--Ranges and ratings for net recharge

[Aller and others, 1985]

Net Recharge	
Range (inches)	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
	Agricultural Weight: 4

Table 32.--Ranges and ratings for aquifer media

[Aller and others, 1985]

Aquifer Media Range	Rating
Massive Shale	1-3
Metamorphic/Igneous	2-5
Weathered Metamorphic/Igneous	3-5
Thin Bedded Sandstone, Limestone, Shale Sequences	5-9
Massive Sandstone	4-9
Massive Limestone	4-9
Sand and Gravel	6-9
Basalt	2-10
Karst Limestone	9-10
	Agricultural Weight: 3

Table 33.--Ranges and ratings for soil media

[Aller and others, 1985]

Soil Media Range	Rating
Thin or Absent	10
Gravel	10
Sand	9
Shrinking and/or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Nonshrinking and Nonaggregated Clay	1
	Agricultural Weight: 5

Table 34.--Ranges and ratings for topography

[Aller and others, 1985]

Topography Range (percent slope)	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1
	Agricultural Weight: 3

Table 35.--Ranges and ratings for impact of unsaturated zone media

[Aller and others, 1985]

Impact of Unsaturated Zone Media Range	Rating
Silt/Clay	1-2
Shale	2-5
Limestone	2-7
Sandstone	4-8
Bedded Limestone, Sandstone, Shale	4-8
Sand and Gravel with significant Silt and Clay	4-8
Metamorphic/Igneous	2-8
Sand and Gravel	6-9
Basalt	2-10
Karst Limestone	8-10
	Agricultural Weight: 4

Table 36.--Ranges and ratings for hydraulic conductivity

[Aller and others, 1985]

Hydraulic Conductivity Range [(gal/d)ft^2]	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
2000+	10
	Agricultural Weight: 2