Water-Supply Development and Management Alternatives for Clinton, Eaton, and Ingham Counties, Michigan

By K. E. VANLIER, W. W. WOOD, *and* J. O. BRUNETT

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ABSTRACT

The Tri-County region, consisting of Clinton, Eaton, and Ingham Counties, is an area of 1,697 square miles in Michigan's Lower Peninsula and has as its hub the Lansing metropolitan area. The land surface ranges in altitude from about 700 to about 1,000 feet. The region receives an average of about 31 inches of precipitation each year.

The population is nearing 400,000 and by 1990 will be near 600,000. Average daily water use is slightly more than 30 million gallons today; by 1980 it will be abcut 50 million gallons, and by 1990 it will probably be about 70 million gallons.

The Tri-County region is drained by seven river systems. The median annual 7-day mean low flows of the principal streams in these systems were measured at the point farthest downstream within the region. These values, in cubic feet per second, are as follows: Grand River, 180; Maple River, 34; Looking Glass River, 28; Red Cedar River, 30; Portage Creek, 15; Battle Creek, 20; and Thornapple River, 24—a total of 331 cubic feet per second or about 220 million gallons per day. The areal variance in 7-day low-flow runoff ranges from 0 to 0.15 cubic foot per second per square mile.

The principal source of ground water in the Tri-County region is a complex aquifer system composed of the Saginaw and Grand River Formations and some of the overlying glacial sediments. This aquifer yields between 300 and 700 gallons per minute to individual wells in much of the western half of Ingham County, in the eastern half of Clinton County, in a small area in southeastern Clinton County, and in northeastern Eaton County. In some parts of the region, the glacial sediments are favorable for development of moderate to large supplies of water. Minor aquifers in the region are the Bayport, Michigan, and Marshall Formations.

Providing water supplies in the future requires complete and comprehensive water-management programs. Such management programs involve determining which of several alternative water-development systems is the best. Some of the chief factors and methods that must be considered when planning these systems are combined use of ground and surface water, artificial recharge, treatment of wastes, use of storage reservoirs, and importation of water from the Great Lakes.

INTRODUCTION

The rapid economic growth and development anticipated in the Tri-County region will require an increasing amount of water.

Short- and long-term planning will be needed if water supplies are to be developed efficiently. Effective planning, however, demands an input of adequate information to insure that reliable estimates of total costs can be prepared and potential problems anticipated before decisions are made. The investigation of water resources described in this report was designed to provide the hydrologic data needed in long-range planning for development of the region's water supplies. The major emphasis is on the period 1969–90.

PURPOSE AND SCOPE

The purposes of this investigation were (1) to evaluate the water resources of the Tri-County region, (2) to determine if local resources could adequately serve the region in future decades, (3) to provide information on water-management practices needed for best development of the resources, and (4) to outline problems that may have to be resolved before the resources are developed. The study was designed to provide geologic, hydrologic, and other water-availability data needed by water users in planning for development and expansion of water-supply facilities.

This report summarizes the conclusions drawn and information gained during a 4-year study. It contains information on the availability of water in the region, on problems that may develop as the water resources are utilized in the future, on streamflow throughout the region, and on the chemical quality of ground and surface water. The report includes geologic and hydrologic maps of the various aquifers in the region. On the basis of this information it presents alternative methods of water-supply development available to the region and the kinds of water-management programs that may be needed to obtain adequate water supplies.

ACKNOWLEDGMENTS

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CHARACTERISTICS OF THE REGION

The Tri-County region—Clinton, Eaton, and Ingham Counties—covers 1,697 square miles in the south-central part of Michigan's Lower Peninsula (fig. 1). The Lansing metropolitan area (fig. 2) is the center of industrial and commercial activity in the region.

Most of the Tri-County region is drained by the Grand River and its tributaries, the Maple, Looking Glass, Red Cedar, and Thornapple Rivers. A small area in southeastern Ingham County drains east to the Huron River, and the southwestern part of Eaton County, about 93 square miles, is drained by Battle Creek.

The region has a continental semimarine climate. The marine effect, which is due to the influence of the Great Lakes, principally Lake Michigan, tends to moderate the temperature and to alter the patterns of humidity and precipitation. When the wind is from a southerly direction, the climate is predominantly continental.

Annual precipitation generally ranges from 19 to 48 inches but averages about 31 inches (fig. 3). The rate of precipitation is fairly uniform through the year. Precipitation in June, the month of maximum precipitation, is about 3.5 inches; in February, the month of minimum precipitation, it is about 1.6 inches. The maximum 24-hour rainfall in the region was 5.89 inches, recorded in Webberville on June 5–6, 1905.

Mean annual snowfall in Lansing is 47 inches. Measurable amounts of snow have been recorded in every month except June, July, August, and September, about 90 percent falling in the months of December through March.

The average annual temperature (fig. 4) is about 48°F. In July, the month of maximum temperature, the average is 72°F; in January, the month of minimum temperature, the average is 23°F. Extremes in temperature generally are 100°F in the summer and −30°F in the winter. The average growing season extends from the first week in May to the first week in October.

The land surface of the region generally is flat or gently rolling, a topography characteristic of the southern part of Michigan's

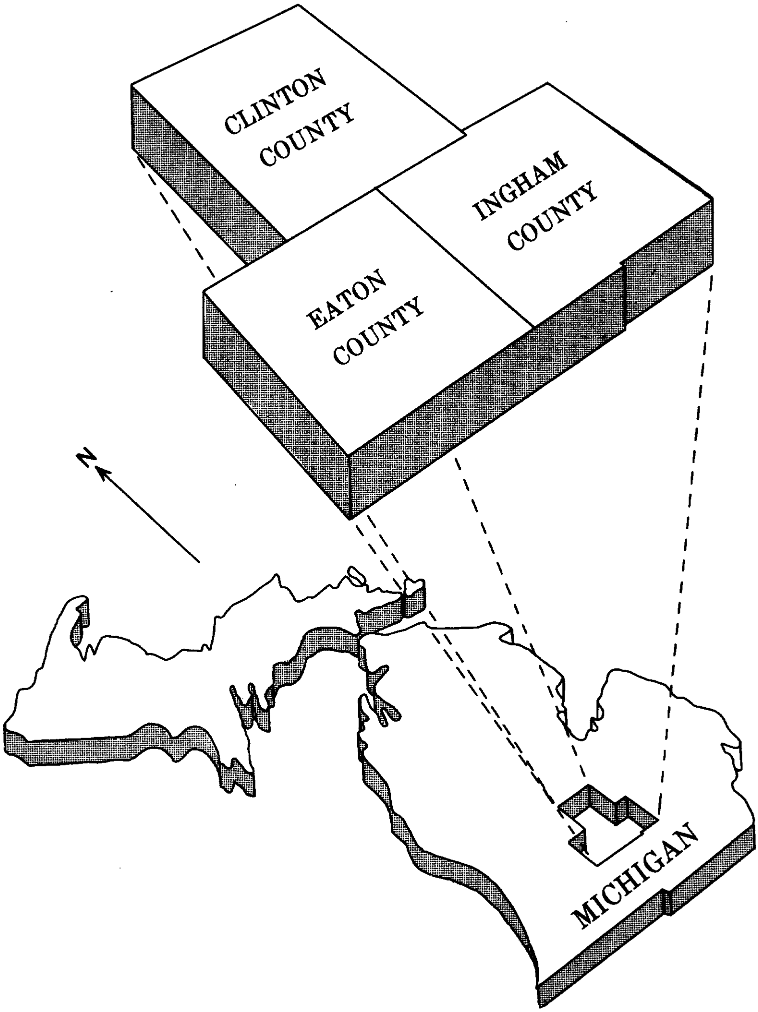


FIGURE 1.—The Tri-County region is near the center of the southern part of Michigan's Lower Peninsula.

Lower Peninsula. Although it is not readily evident to those traversing the area, the land surface on a regional scale slopes gently to the north and west. The highest areas in the region are hills in the southern part of Ingham County, which are above 1,000 feet in altitude (fig. 5). The lowest areas are along the Maple River where it flows out of the region in northwestern Clinton County.

The region contains about 24 natural lakes, only a few of which are large enough to provide for large-scale recreational needs. A

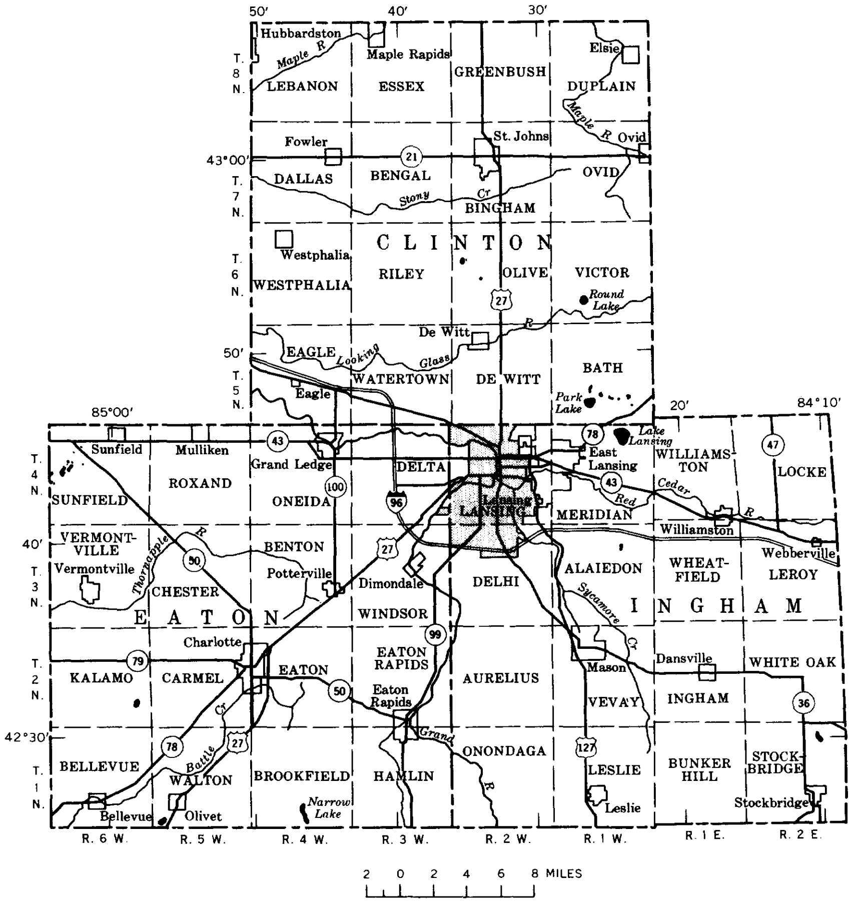


FIGURE 2.—The Lansing metropolitan area is the center of the Tri-County region.

significant part of the region is swampy or marshy; many wetland areas cover several square miles, mostly along glacial drainageways.

THE ECONOMIC BASE AND POPULATION

The Tri-County region has a broad economic base that includes industry, retail trade, banking, insurance, other commercial firms, State government, and educational institutions. The principal industry of the region is automobile manufacturing; however, metal fabricating and light industrial plants are important also. Michigan State University, one of the largest in the country, contributes significantly to the economic base as does the State government

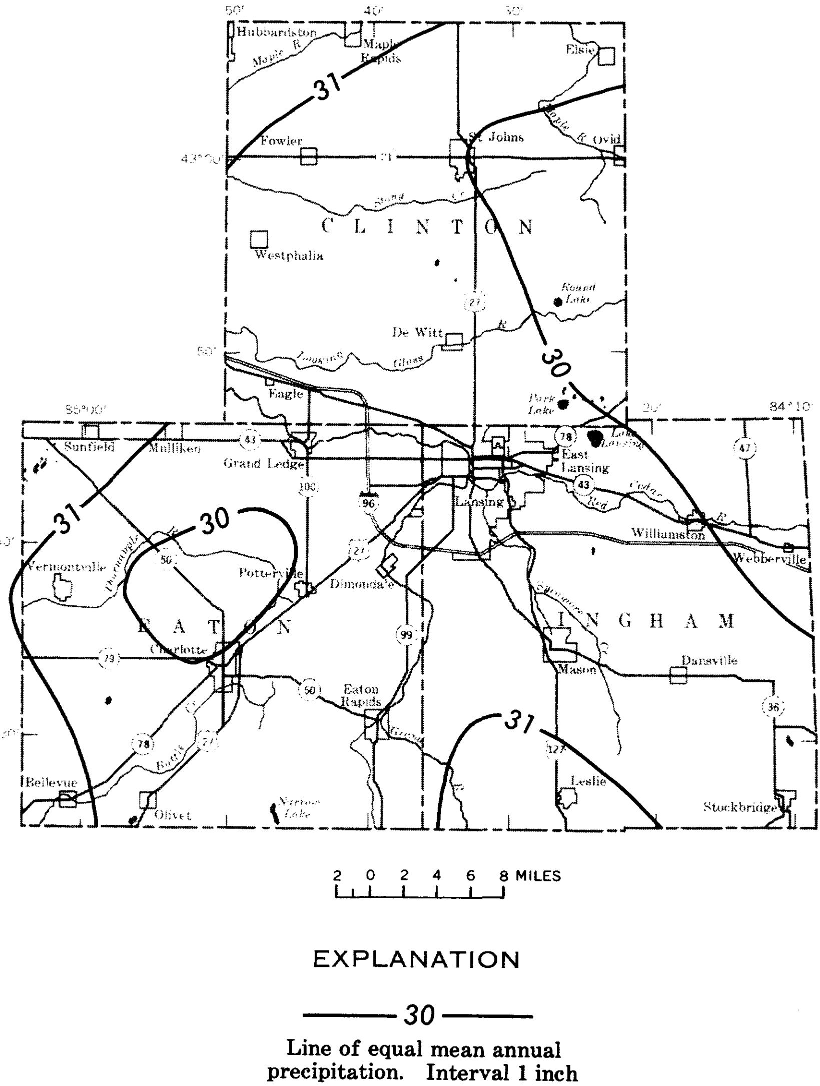
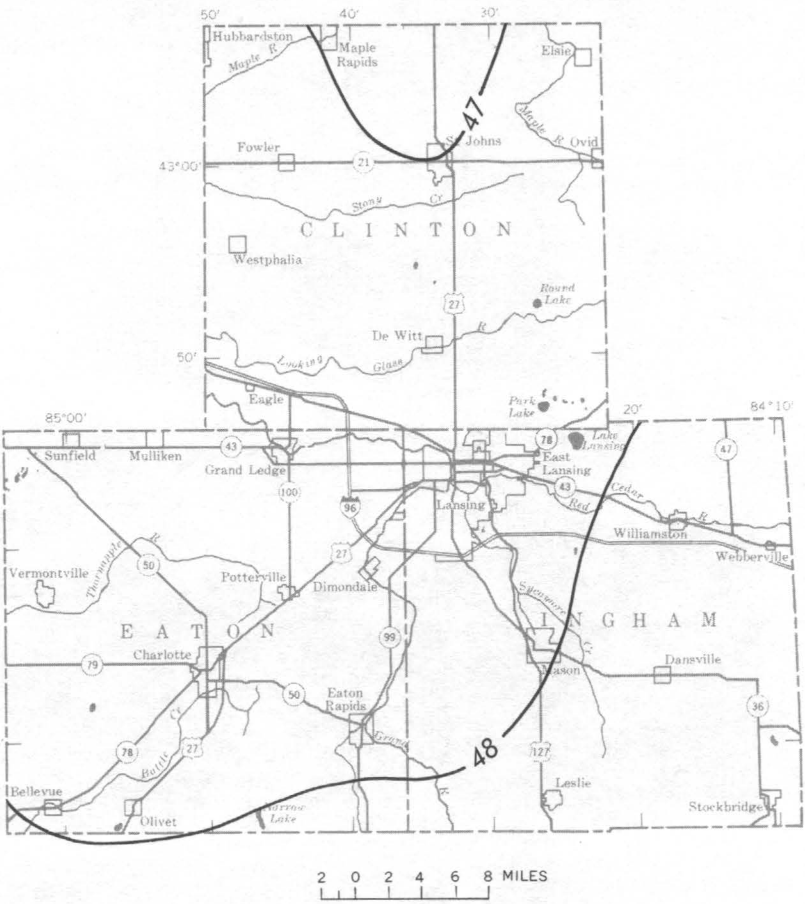


FIGURE 3.—Most of the Tri-County region receives an average of about 31 inches of precipitation each year.

which is centered in Lansing. Most industrial, commercial, governmental, and educational activity is concentrated in the Lansing metropolitan area. The outlying communities are supported principally by agriculture, light industry, and the residence of those who commute to work in the Lansing area.

Continued growth of the economic base may be anticipated on the basis of the type and diversity of the economic activity in the



EXPLANATION

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Line of equal mean annual temperature. Interval 1° F

FIGURE 4.—The mean annual temperature in the region is about 48°F.

area. The expected growth of the economic base indicates a continued rapid growth of population and services.

Population-growth rate in the region has been one of the highest in the State and is expected to continue to be one of the highest in the future (fig. 6), particularly in and adjacent to the Lansing metropolitan area. By 1990 about 600,000 people will live in the Tri-County region; most will live in the Lansing metropolitan area

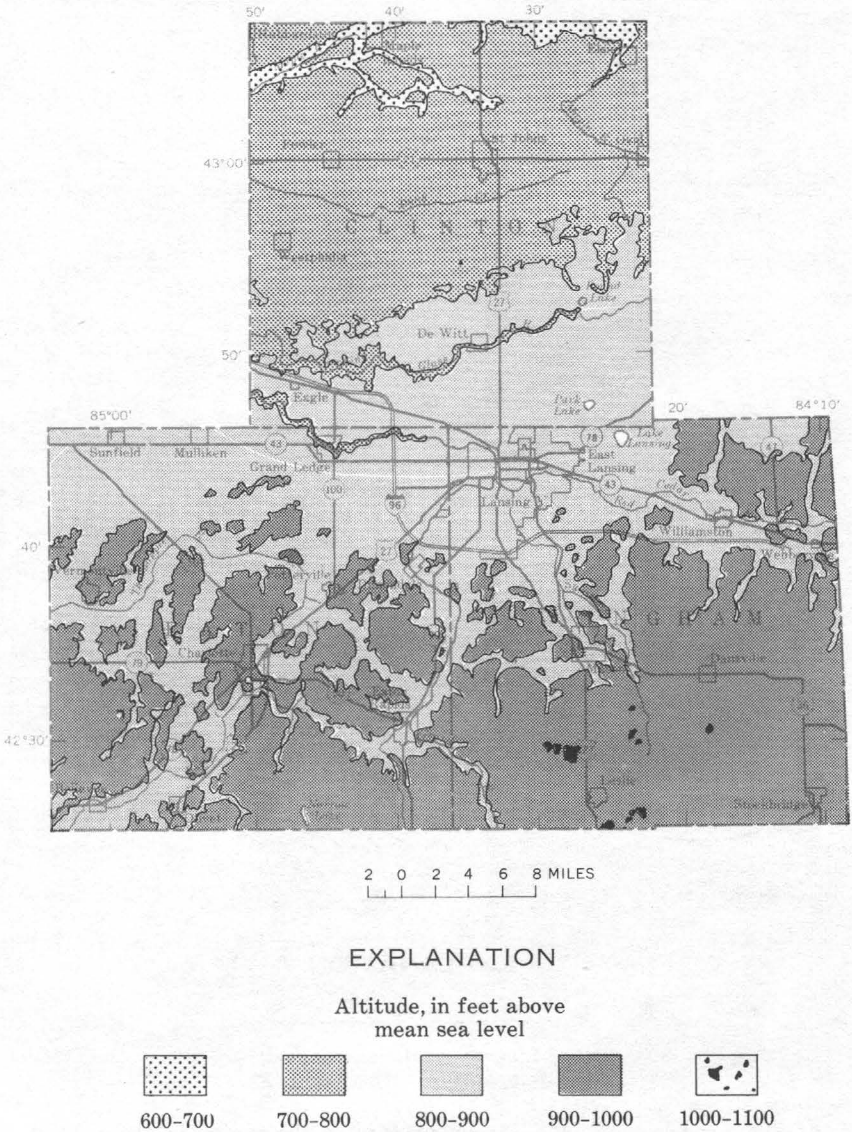

FIGURE 5.—The gently rolling land surface slopes to the north.

(data from Tri-County Regional Planning Commission, 1969). Population projections indicate that within two decades the Lansing metropolitan area may rank second to Detroit in State population. Population growth is anticipated to be slowest in those parts of the region most remote from the Lansing area, although the rate of growth also should be relatively high along the main transportation corridors.

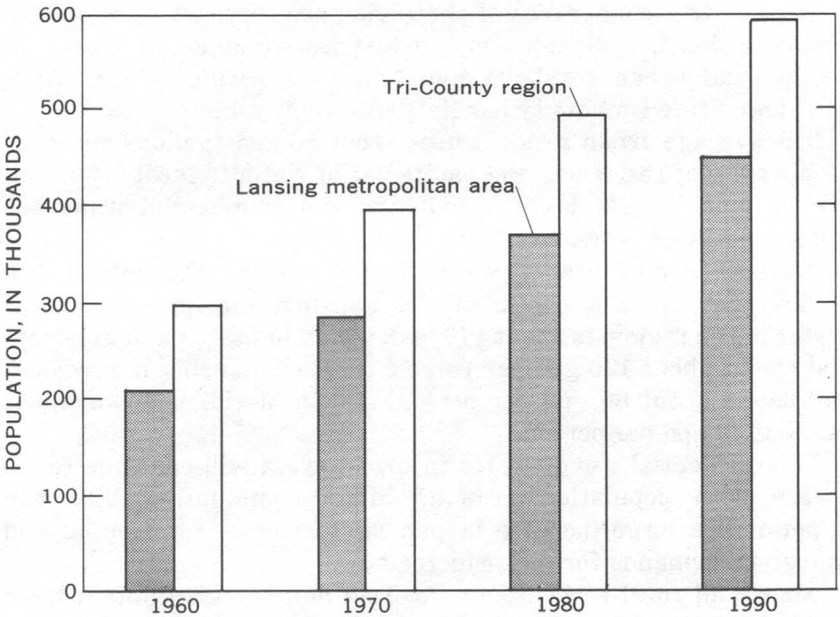

FIGURE 6.—The population is expected to increase by 1990, and most of the people in the Tri-County region will live in the Lansing metropolitan area.

WATER USE

WITHDRAWAL USES

Withdrawal uses include all uses where water is actually withdrawn from a stream, lake, or well. Such uses tend to degrade the water and conflict with other uses.

Large quantities of water are used for cooling of fuel-powered electrical generating plants, more water being withdrawn for this use in the region than for any other use. Two large plants in the city of Lansing use water from the Grand River. Both plants return the water to the river within quality standards established by the Michigan Water Resources Commission, and one plant has cooling towers to remove heat prior to returning the water. The cooling towers were installed to prevent possible thermal load on the river and are normally operated only during the summer months as required to meet the Water Resources Commission's standards. During cooling-tower operation, estimated evaporation loss is 1,000 gpm (gallons per minute), based on average loading and design conditions. Except for this loss, all water used for cooling at both plants is returned to the river.

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Most of the urban areas of the region are serviced by municipal water systems, although some industries, commercial establishments, and urban residents have their own water wells. Also, Michigan State University has its own water system.

The average urban resident uses about 50 gpd (gallons per day) at his place of residence. Per capita use of water in most communities is much larger because industry and commercial firms use large quantities of water.

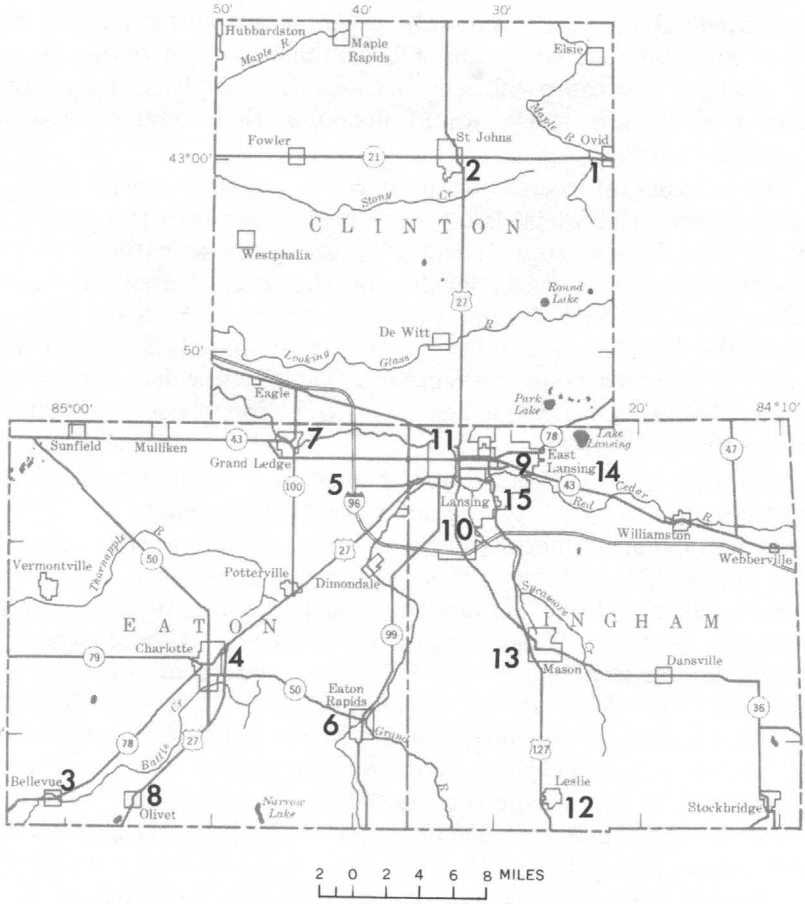
The per capita use of water varies greatly throughout the region (fig. 7). Per capita use in Lansing, the largest user of water in the region, is about 170 gpd, which indicates a nonresidential use of about 120 gpd per person. In East Lansing nonresidential use is about 60 gpd per person, and in Meridian Township it is about 32 gpd per person.

The residential use of water in urban areas will continue to increase with population growth. Many communities also will experience a large increase in per capita use as commercial and industrial demands for water increase.

Nearly all rural residents of the Tri-County region obtain their water from their own wells and use water only for household needs. Some farmers, however, also use water for livestock, irrigation of

Map No. (fig. 7)	Name	Total pumpage for 1967 (million gallons)	Per capita use (gallons per day)
	Clinton County		
1	Ovid	29	---
2	St. Johns	473	216
	Eaton County		
3	Bellevue	55	---
4	Charlotte	544	---
5	Delta Township	165	206
6	Eaton Rapids	302	---
7	Grand Ledge	187	99
8	Olivet	52	---
	Ingham County		
9	East Lansing	1,073	107
10	Lansing	7,801	171
11	Lansing Township	609	224
12	Leslie	69	---
13	Mason	188	114
14	Meridan Township	91	82
15	Michigan State University	1,874	128

crops, and other agricultural purposes. The reported quantity of water used for domestic purposes in rural areas is about 50 gpd per person. The use of water for agriculture is not large in relation to the total supply available, but the potential use for irrigation of farm crops is large. A much larger use of water for agriculture in the future can be anticipated in those parts of the region not being urbanized.



EXPLANATION

8

Location of pumping center

See table below

FIGURE 7.—Lansing is the biggest user of water in the Tri-County region.

NONWITHDRAWAL USES

Nonwithdrawal uses involve use of water in streams and lakes without removal of the water. Except for uses resulting in pollution, nonwithdrawal uses do not degrade the water and thus do not conflict with other uses.

Many of the streams and most lakes in the region are used for recreational and esthetic purposes. Areas where these uses are small generally are those where the quality of water has been degraded. Such uses commonly preempt withdrawal uses; most lakes and some streams cannot be extensively utilized as sources of water for withdrawal uses because the resultant lowering of lake and stream levels would decrease their recreational and esthetic values.

Some types of recreation may result in withdrawal. For example, several artificial lakes have been created in the region for real-estate development. Three of these lakes use water from wells for stabilization of water levels, and the level of another, Geneva Lake near De Witt, is maintained through withdrawal of water from the Looking Glass River. It is anticipated that more such lakes will be created in the region in the next few decades and that some of these lakes will depend on water from wells or streams to maintain their levels.

The flow of the Grand River is sometimes used for the generation of electricity at two small hydroelectric plants at Lansing, but the primary function of these plants under present operating procedures is to help regulate and otherwise maintain the present pond-level elevations behind the two dams for recreational and esthetic reasons. When producing electricity, the Moores Park Plant, which is about half a mile upstream from the confluence with the Red Cedar River, uses water at an average rate of 330 cfs (cubic feet per second), and the North Lansing Plant, which is about half a mile below the confluence with the Red Cedar River, uses water at an average rate of 230 cfs (U.S. Federal Power Commission, 1970, table 4). Use of water for hydroelectric power generally does not conflict with other uses.

Effluents from waste-treatment plants in and adjacent to the region are discharged to the Grand River, its tributaries, and other streams. Although nearly all wastes are treated to reduce their impact upon the quality of the streams, the treatment processes presently employed do not remove all undesirable characteristics. Through natural processes, the stream must recover from the undesirable effects of the waste, and the ability of a stream to assimilate waste is primarily a function of the quantity of water available to dilute the waste and the stream's dissolved oxygen content. As an example, wastes that enter the Grand River each year from Lansing disposal plants are of a quantity that requires about 1 million pounds of oxygen for assimilation. The dissolved oxygen content is controlled largely by temperature: the higher the temperature, the lower the dissolved oxygen content. The problem of waste assimilation is compounded by the fact that the temperature of the streams is highest and the dissolved oxygen content lowest during summer periods when streamflows are low.

SOURCES OF WATER

The average annual precipitation for the region is about 31 inches, or about 6,300 gpd per person in the region (1970 population estimates). Obviously only a fraction of this water becomes available for use, as most precipitation is used by plants or is returned directly to the atmosphere. Only about one-third of the precipitation runs off the surface and becomes streamflow or infiltrates into the ground to replenish the ground-water reservoirs. If this amount could be made available for withdrawal use, water adequate to meet the needs of the region would be assured for many decades.

THE HYDROLOGIC CYCLE

The condensation of vapor in the atmosphere into rain or snow is but one part of a never-ending hydrologic cycle. Water is continually moving through this cycle from atmosphere to earth and back again to the atmosphere. All the many and varied paths of the hydrologic cycle are followed by water as it moves through the Tri-County region (fig. 8).

The hydrologic cycle as applied to the Tri-County region can be discussed in terms of four major components: precipitation, evapotranspiration, surface runoff, and ground-water runoff. Of the total of 31 inches of precipitation, about 24 inches returns to the atmosphere through evaporation and transpiration from plants (fig. 9). Average surface runoff is about 7 inches, of which about 3 inches is direct surface runoff and about 4 inches is ground-water runoff—water that infiltrates into the ground, moves underground, and is discharged to the streams from seeps and springs.

The 4 inches of ground-water runoff is not the total amount of water that infiltrates to the ground-water reservoir. An additional amount infiltrates and moves underground to areas where it is taken up and discharged by trees and other vegetation or is evaporated directly from the soil. The rate of discharge directly

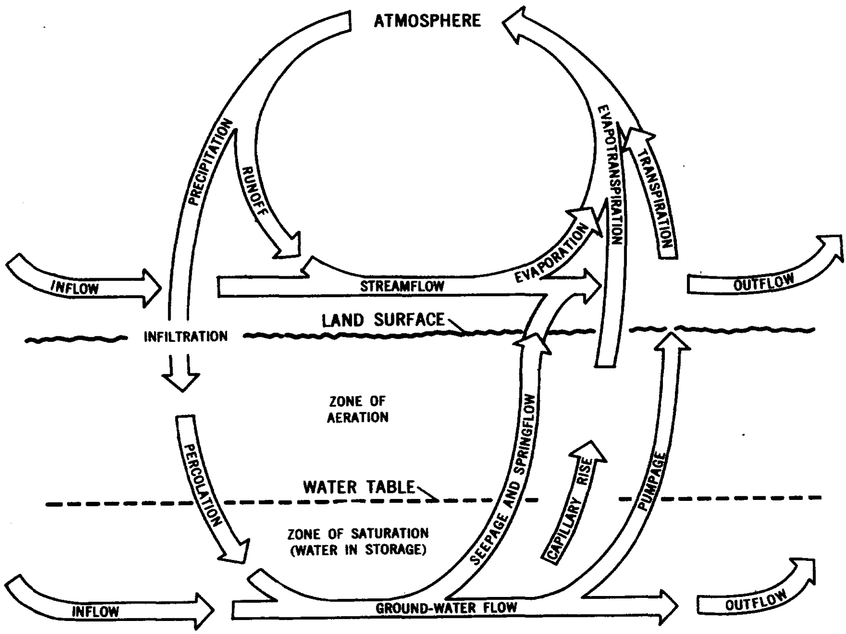


FIGURE 8.—Water moves in a never-ending cycle.

to the atmosphere from the ground-water reservoirs is not accurately known, although in the Tri-County region it is estimated to be about 2 inches per year. Studies in the Wichita, Kans., area (Robinson, 1963) reveal that nearly all the water yielded by municipal wells at Wichita would have been discharged from the ground-water reservoir by evaporation and transpiration if water levels were not lowered by pumping. The Wichita studies indicate that a large volume of ground water can be salvaged by reduction of evapotranspiration losses through ground-water development.

INTERRELATIONSHIP OF GROUND AND SURFACE WATERS

As it moves underground or flows in streams, water is a part of a single hydrologic system. Under natural conditions ground water migrates to and eventually discharges through springs and seeps to become part of surface runoff. In some areas this situation is reversed and water infiltrates into the ground from streams.

The rate of discharge of ground water to a stream is primarily a function of the permeability of the shallow sediments in the stream basin. Permeable sediments allow large quantities of precipitation to infiltrate into the ground and also transmit and discharge this water readily to the stream. The water in effect is stored and

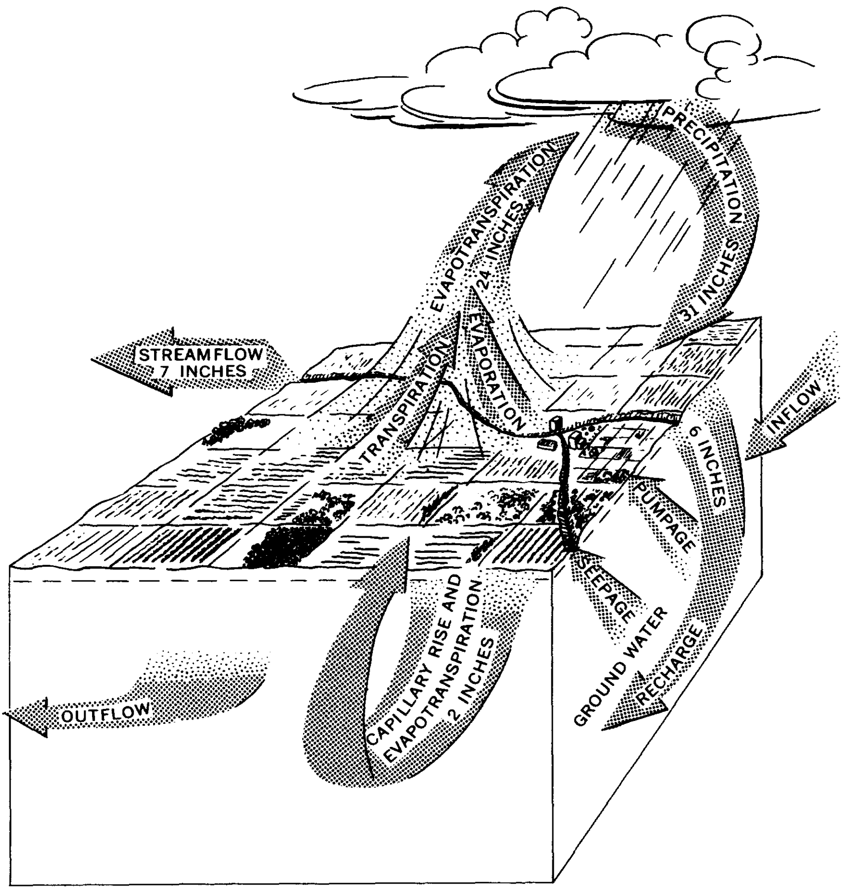


FIGURE 9.—Water from precipitation follows many paths.

gradually released. Thus, the streams in drainage basins underlain by permeable sediments have stable flows, as most of the precipitation and melting snow is able to infiltrate to the groundwater reservoir rather than run off directly to the stream. Such basins are less susceptible to flooding, and the stream continues to flow during dry periods as water stored in the ground continues to supply the stream. Conversely, streams in drainage basins underlain by sediments of low permeability have highly variable flow. They are susceptable to flooding from rapid runoff and dry up or have low sustained dry-weather flow because little ground water is supplied to them. Thus, the flow characteristics of a stream are an indication of the types of sediment underlying its drainage basin.

INDUCED RECHARGE

Under natural conditions ground-water levels in most areas are higher than adjacent stream levels. Withdrawal of water from wells commonly reverses this relationship and as a consequence water moves under the force of gravity from the stream into the ground. This process, called induced recharge, can significantly increase the yield of an aquifer. The increased yield, however, is obtained at the expense of the flow of the stream. Also, water induced from a stream containing water of poor chemical quality may contaminate the aquifer. Thus, development or use of one source of water commonly affects other sources within the same hydrogeologic system.

WATER IN STREAMS

Most of the Tri-County region is drained by the Grand River and four of its major tributaries (fig. 10). The remainder of the region is drained by Battle Creek and by tributaries of the Huron River.

Natural streamflow is composed of overland runoff and ground-water discharge. Although streams are major sources of water supply, their usefulness is limited by the variability of streamflow. The most restrictive factor in utilization of streamflow is that low flows usually occur at the times of greatest water demand. Low-flow data thus provide good indices of reliable supply.

LOW-FLOW CHARACTERISTICS

The runoff characteristics of a stream are determined primarily by climate, by the physiographic and geologic conditions of the drainage basins, and by the use of water and other stream-regulating effects of man. If basins are generally similar, their median and floodflow characteristics are similar also. The low-flow characteristics, however, are much more responsive to slight differences in physiography and geology, so the low-flow characteristics vary significantly in different parts of the region. The areal variance in dry-weather runoff ranges between 0 and 0.15 cfs per square mile; this is illustrated in figure 11.

Specific data on variation of streamflow in the seven major drainage areas of the region are presented in the following sections. Low-flow data are presented in terms of 7- and 30-day mean low flows, which are the lowest average flows occurring for 7 and 30 consecutive days during the year. These data are indices of dependable flow and reflect the adequacy of a stream for water supply. Also presented are flow-duration data, which indicate the percentage of time a given flow rate may be expected to be equaled

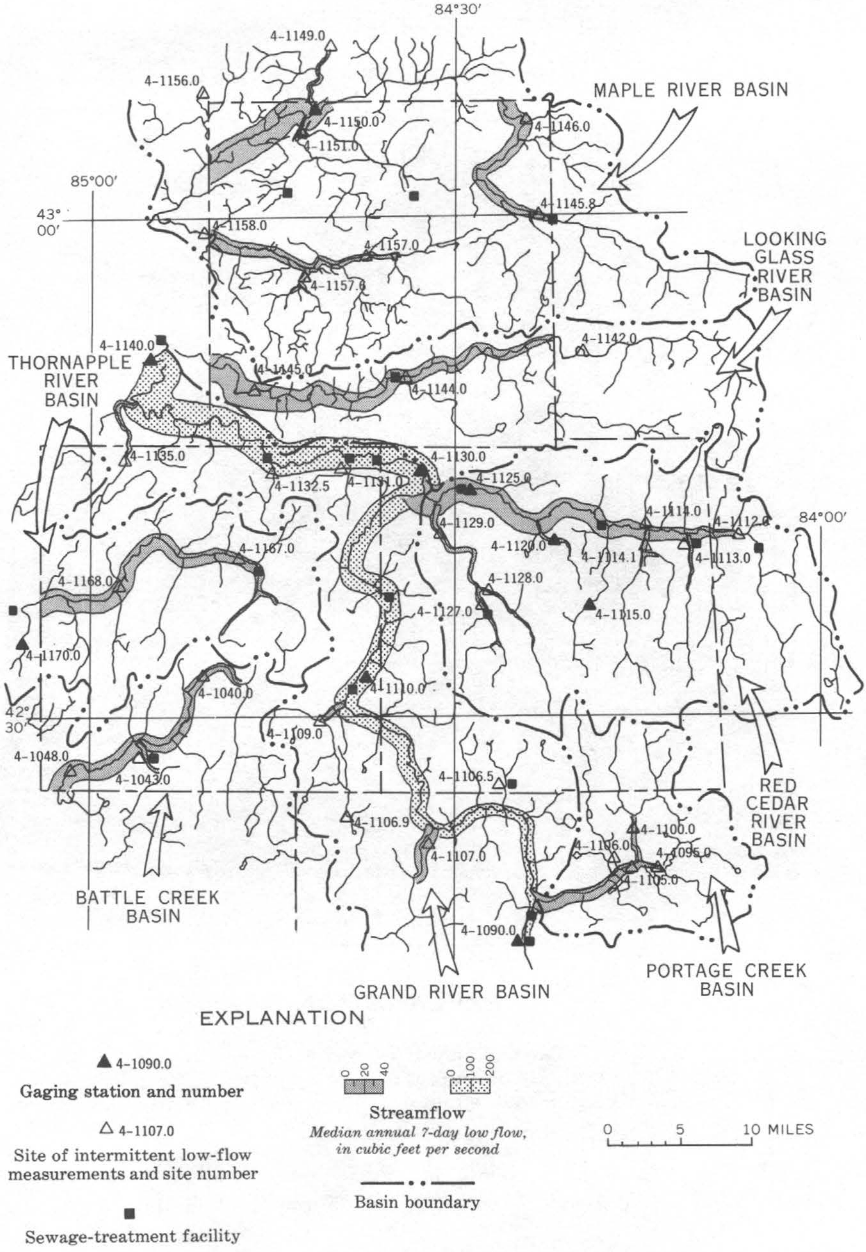


FIGURE 10.—Streams in seven drainage basins drain water from the Tri-County region.

or exceeded. This information provides a user with an estimate as to the percentage of time streamflow may be deficient for his needs.

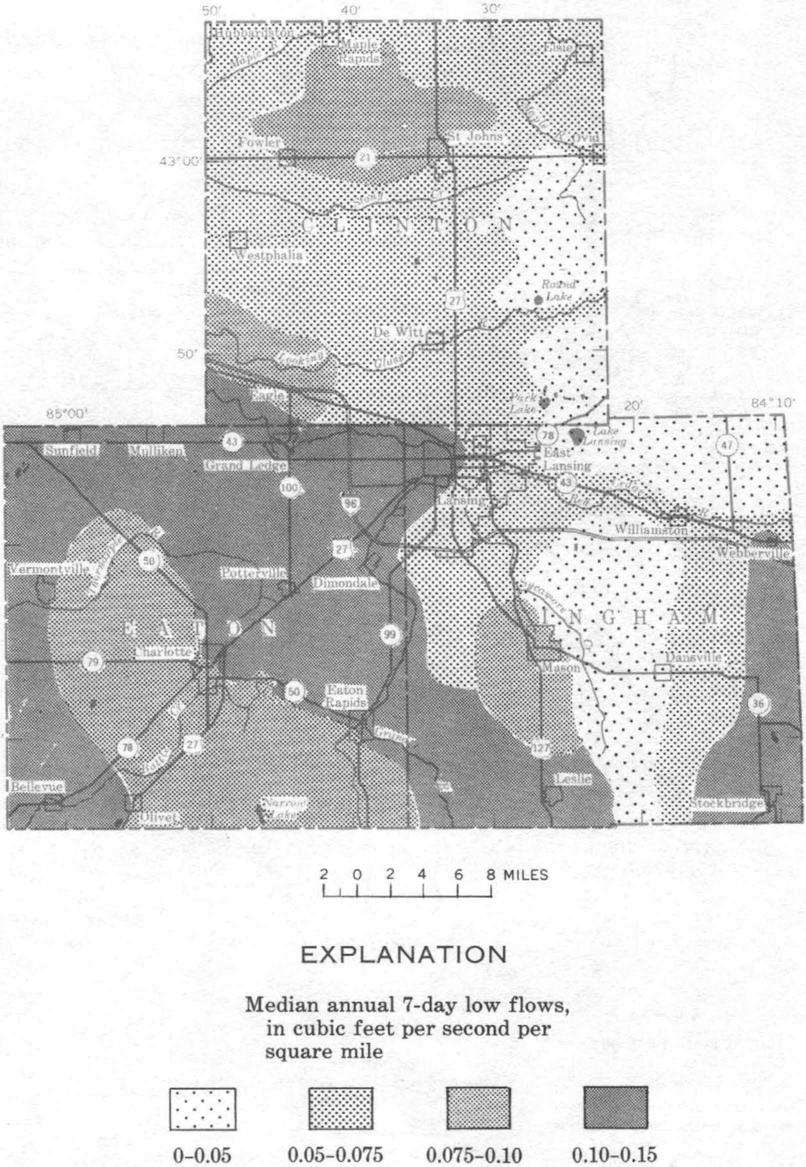


FIGURE 11.—Dry-weather runoff ranges between 0 and 0.15 cubic feet per second per square mile.

FLOODFLOWS

Floodflows result from snowmelt, intense or extended rains, or a combination of these events. Floods may occur at any time during the year, but most occur during the spring months. The major floods recorded at Lansing, in order of decreasing intensity, occurred in March 1904, March 1918, March 1908, April 1947, and March 1916. Lesser floods have occurred at more frequent intervals.

The time of occurrence of a flood cannot be predicted. It is possible, however, through analysis of past records, to estimate with reasonable reliability the frequency of floods of certain magnitudes. Such an analysis is contained in a comprehensive report on the magnitude and frequency of floods in the St. Lawrence River basin (Wiitala, 1965), and data from that report were used to prepare flood-frequency curves for the Tri-County region (fig. 12). As an example, by using the curves we can estimate the magnitude of a flood occurring on the average of once every 10 years at the gage on the Looking Glass River at Eagle. The drainage area of the river above the gage is 281 square miles (fig. 18, p. 35). The point of intersection of the lines representing a 281-square-mile drainage area and the 10-year flood, as shown in figure 12, indicates that a peak flow equal to or greater than 3,000 cfs would occur on an average of once every 10 years. Similarly, analyses can be made for other points on streams in the region to determine their peak flows for various frequencies of occurrence.

STORAGE OF STREAMFLOW

The average flow of streams in the region is about seven times larger than the low flow. This large difference between flows indicates that low flows can be increased significantly using water stored in reservoirs during periods of high flow. Major reservoirs could be used to provide storage that would be sufficient to withstand droughts of 2 or more years, but many such reservoirs are not economically feasible unless several uses or benefits are realized from the impoundment. Retention of floodwaters, recreational uses, and esthetic values are among the benefits which may be realized in a multiple-purpose reservoir.

Estimates of storage needed to maintain a desired dependable flow can be made by several methods. Owing to the limited streamflow data available, a regional analysis method appears to be best for estimating required storage in the Tri-County region. This method involves derivation of regional curves relating draft storage, computed from low-flow frequency curves, to an index of low

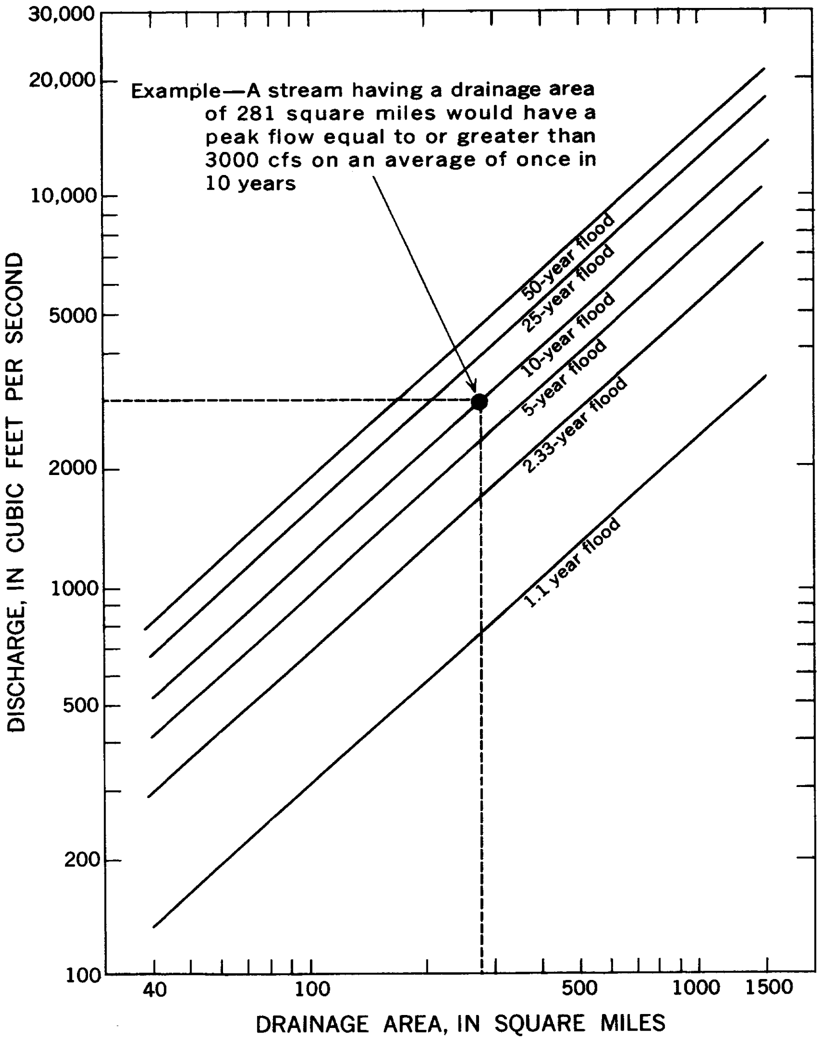


FIGURE 12.—Floodflows vary with drainage area and frequency of recurrence.

flow. Curves for recurrence intervals of 10 and 20 years are shown in figure 13. These curves permit estimation of storage requirements for any location where the index of low flow is known or can be determined. The following steps are necessary in using the curves for making storage estimates:

1. Determine the drainage area upstream from the point of interest.

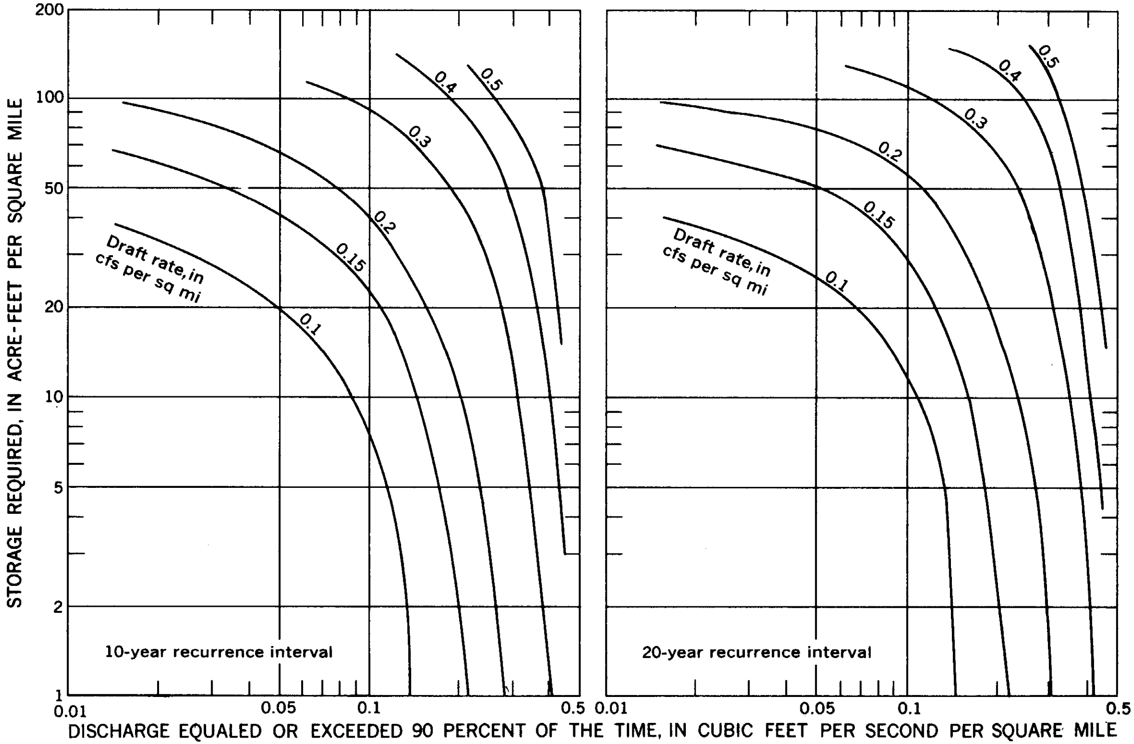


FIGURE 13.—Regional draft-storage curves permit estimation of storage requirements (after Knutilla, 1968).

2. Estimate the low-flow index (90-percent-duration flow). Values of the 90-percent flow are given for 40 sites on plate 1, and estimates of low-flow index may be made for other locations from these figures. Values of the 90-percent flow can also be estimated by making several base-flow measurements, preferably on different recessions and in different years, and correlating these measurements with concurrent data for locations having a known low-flow index.
3. Determine the storage required per square mile of drainage area from curves of figure 13 using the 90-percent-flow estimate and the desired flow-rate (draft) curve.
4. Determine the total storage needed by multiplying the drainage area by the storage per square mile obtained from figure 13.

Water available from a reservoir generally is lessened by evaporation. According to Kohler, Nordenson, and Baker (1959), annual evaporation from a reservoir in the Tri-County region would be slightly more than 30 inches per year; about 80 percent of the total evaporation occurs during the period May–October. Evaporation losses, therefore, should be considered in reservoir design. Where impoundments inundate large wetland areas, the reduction in evapotranspiration from the wet lands may offset evaporation from the reservoir. Other factors to be considered are (1) seepage and conveyance losses, (2) losses in storage through sedimentation, (3) increased reservoir storage due to ground-water storage, and (4) subsurface diversion or interbasin flow of water caused by high ground-water levels resulting from impoundment.

Storage estimates obtained from the regional curves are useful primarily in making a preliminary evaluation of potential development and for comparing the possibilities among different streams. Derivation of the curves was limited to those draft rates that could be maintained by the amount of storage replenished each year. Higher rates can be obtained if storage facilities are large enough to carry over storage from years of excessive annual flows.

STORAGE RESERVOIRS

In most places in the Tri-County region, the generally flat terrain precludes the development of large storage reservoirs. Some stream valleys, however, are wide and deep enough to provide for small- to moderate-sized impoundments. Such reservoirs can be created at many locations in the Tri-County region and adjacent areas, although it is not always possible and economical to utilize every location. For example, lakes that could be made into storage reservoirs are generally limited in use to esthetics and recreation because the potential damage to recreational and esthetic values of shoreline property resulting from fluctuating water levels would make most lake-storage projects prohibitively expensive. Many other possible locations have similar restraints to the construction of reservoirs but, barring economic limitations, many locations are favorable for reservoir development. Reservoir sites in and adjacent to the region have been identified and inventoried by various State and Federal agencies, including 55 sites identified by the U.S. Department of Agriculture and 35 sites identified by the U.S. Corps of Engineers. Most of these sites are shown in figures 14 and 15, and data on them are listed in table 1.

TABLE 1.—*Reservoir sites and storage in and adjacent to the Tri-County region*

Site	Drainage area (sq mi)	Reservoir capacity (acre-ft)	Pool area (acres)	Site	Drainage area (sq mi)	Reservoir capacity (acre-ft)	Pool area (acres)
			Identified by the U. S. Department of Agriculture				
9	48.4	19,000	1,600	148	15.2	2,500	400
10	25.0	4,300	510	149	9.8	3,670	530
35	13.0	11,600	570	151	4.1	1,310	190
37	24.0	23,300	1,920	153	49.9	10,805	1,400
50	35.0	12,300	2,230	154	3.7	3,160	490
56	32.0	25,000	2,220	155	5.5	600	80
67	82.8	14,130	375	158	9.8	2,000	330
100	9.8	12,600	1,230	162	20.1	12,340	1,380
101	32.5	25,000	2,030	168	4.5	3,420	330
102	26.7	25,000	1,950	170	8.2	1,000	200
103	21.9	25,000	1,850	171	30.1	7,800	2,200
105	4.0	4,200	420	172	15.6	3,420	650
107	10.1	3,000	500	174	71.7	25,000	5,500
108	7.4	7,880	740	175	3.4	1,710	160
109	29.3	6,250	280	177	23.5	18,080	1,690
110	11.1	8,210	546	178	28.8	23,650	2,040
115	5.3	1,990	350	179	11.2	14,090	1,150
124	18.2	3,200	715	180	9.1	7,760	750
125	21.7	7,370	1,120	182	6.8	1,230	110
130	5.3	1,010	170	185	4.5	2,410	190
131	13.0	15,120	1,780	187	3.8	770	70
135	3.2	2,480	250	219	10.9	3,760	320
138	4.0	5,720	540	220	6.8	430	70
141	7.4	10,400	1,400	222	11.4	3,250	190
142	3.1	4,510	360	223	8.4	520	40
143	3.7	3,410	530	226	4.8	3,250	250
144	14.8	11,700	980	227	9.8	3,590	260
146	4.0	2,050	180				
			Identified by the U. S. Army Corps of Engineers				
5	856	63,700	5,780	52	310	36,000	3,350
6	846	14,700	1,860	53	262	10,900	1,330
7	569	221,300	29,200	54	161	11,500	2,110
8	409	109,300	19,310	55	102	14,000	1,300
9	53	6,900	1,210	56	32	31,600	3,160
10	25	4,300	510	57	306	23,800	2,040
11	10	7,500	520	58	228	67,200	6,610
34	10	10,600	1,060	59	33	38,900	2,610
35	13	11,600	570	60	35	12,300	2,230
36	190	42,500	4,600	61	18	19,100	2,200
36A	161	20,900	2,790	62	89	115,100	7,460
36B	190	87,600	7,350	63	159	20,900	10,440
37	24	23,300	1,710	67	50	14,300	920
45	139	49,000	4,900	68	12	18,800	1,530
46	766	89,800	11,220	69	6	14,200	910
48	82	47,500	2,170	72	9	14,400	1,020
49	205	61,000	8,210	73	652	44,000	3,900
51	312	36,700	3,230				

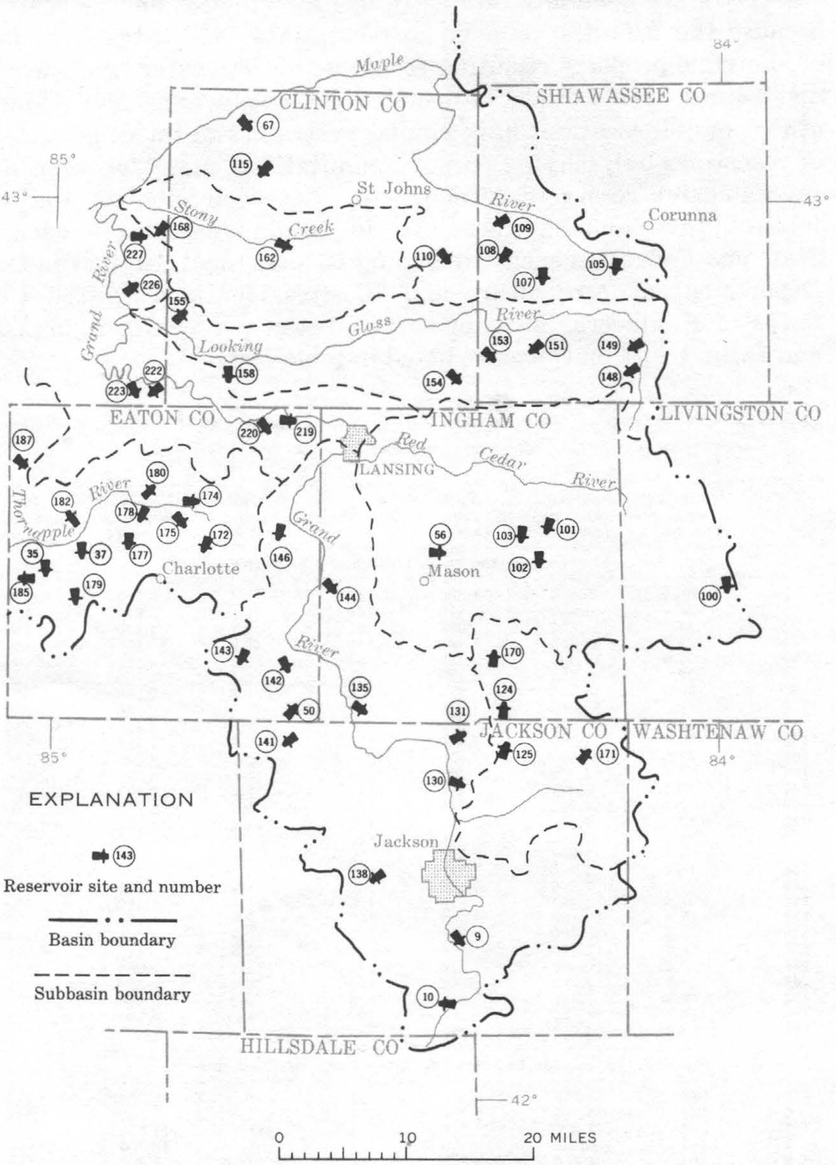


FIGURE 14.—Fifty-five reservoir sites in and adjacent to the Tri-County region have been identified by the U.S. Department of Agriculture (U.S. Dept Agriculture, 1967).

Some reservoirs may be utilized primarily for esthetics or recreation rather than storage. Most reservoirs constructed for such purposes, however, can also be utilized for flood prevention by

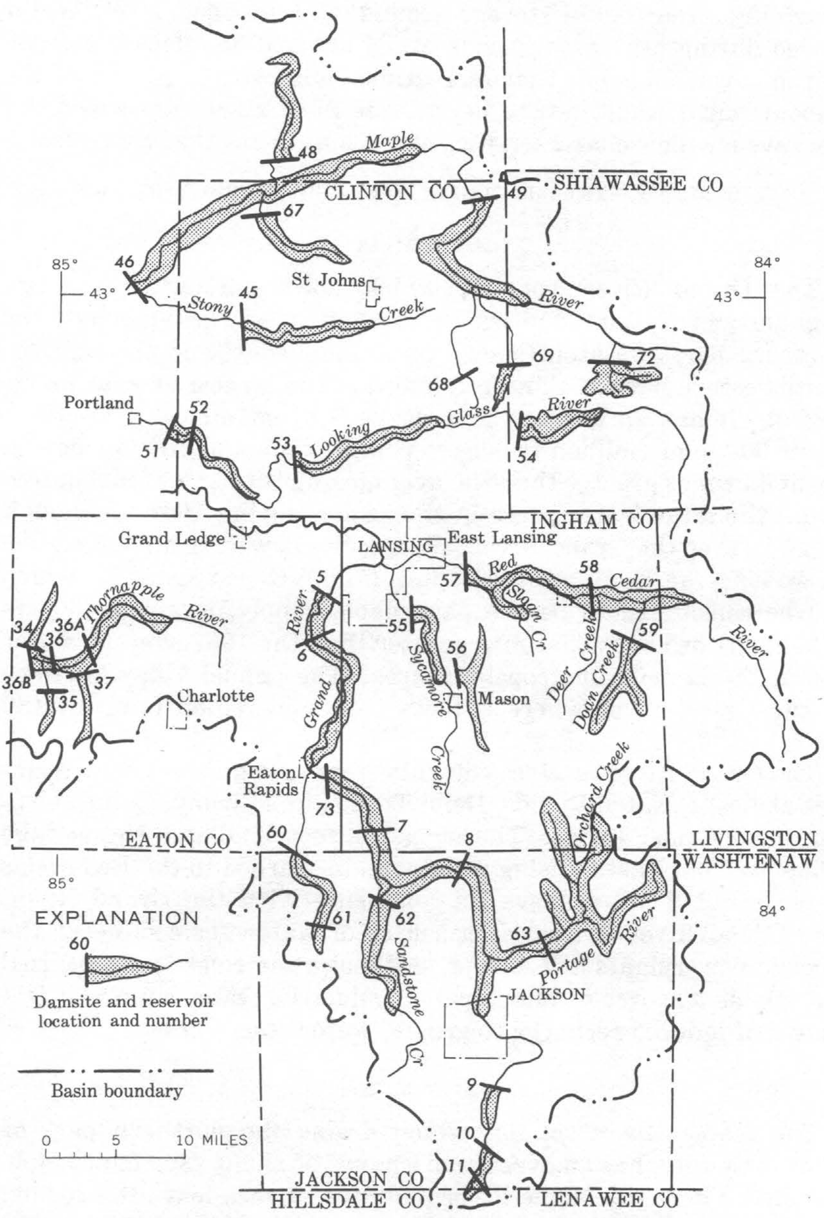


FIGURE 15.—Thirty-five reservoir sites in and adjacent to the Tri-County region have been identified by the U.S. Corps of Engineers (U.S. Army Corps of Engineers, 1967).

providing a few feet of storage above the normal pool level. Water stored during peak flow periods would have to be released as soon as the flow declined so that recreational and esthetic values of the impoundment would not be decreased. Such reservoirs would not improve low-flow characteristics of streams below the reservoirs.

THE MAJOR STREAMS—THEIR USES AND CHARACTERISTICS

GRAND RIVER

The Grand River (pl. 1), which flows northward through Ingham and Eaton Counties to Lansing, westward through the northern part of Eaton County to Grand Ledge, and through the southwestern part of Clinton County, is the largest stream in the region. It has an average flow at Lansing of almost 800 cfs or about 500 mgd (million gallons per day). This quantity of flow is about 14 times greater than the average quantity of water required by all the large water users in the region during 1967. Although mean flow of the Grand River is large, the flow varies from season to season. The 7-day mean low flow (7-day Q_2) at Lansing, which can be considered to be the dependable supply, is about 150 cfs (100 mgd) or about 2.5 times greater than the 1967 average water use in the Lansing metropolitan area. The annual 7-day low flow of the Grand River where it flows from the region is about 180 cfs.

The Grand River receives effluents from sewage-treatment facilities at Leslie, Eaton Rapids, Delhi Township, Lansing, Delta Township, and Grand Ledge. The stream also assimilates the sewage effluents from East Lansing which are discharged to the Red Cedar River about 2 miles above its confluence with the Grand River. The Grand River is used as a source of water for cooling at the electric powerplants at Lansing. Although the river is not utilized directly as a source of municipal or industrial water supply, it is a source of induced recharge to ground-water reservoirs.

MAPLE RIVER

The Maple River (pl. 1), which drains the northern part of Clinton County, has an average discharge of about 230 cfs at Maple Rapids. Where the Maple River and Stony Creek leave the region, they have a combined annual 7-day low flow of about 45 cfs. The lower reach of the Maple River is in a large valley cut by the river that drained an area from Saginaw Bay south to Lake Erie late in the glacial period. Lowland areas along the lower reach of the river are chiefly swamp and marsh, and the drainage area includes several small lakes. The main stem of the Maple River receives effluents from the Ovid sewage-treatment plants, and Hayworth Creek, the largest tributary of the Maple in the region, receives effluents from Fowler and St. Johns.

The Maple River is not used as a source of industrial or municipal supply. However, a few miles above Maple Rapids the stream is used as a source of water for a flooding project for wildlife. Water from the Maple and some of its tributaries is also used for irrigation. During periods of dry weather the flow at Maple Rapids is relatively low, and during long dry periods the flow may be less than that at Elsie, about 25 miles upstream. This is the result of large evapotranspiration losses, withdrawals for irrigation, and flooding of a marsh for wildlife habitat in a reach between the two villages.

LOOKING GLASS RIVER

The Looking Glass River (pl. 1) had an average flow of 157 cfs at Eagle for the period 1944 to 1966; the annual 7-day low flow, where the river flows from the region, is more than 25 cfs. The basin includes Park Lake, Round Lake, and several other small lakes. As the name of the stream suggests, there is little current and the flow is small during prolonged periods of dry weather. A minimum flow of 10 cfs was recorded in July 1965 at the gaging station near Eagle. During floods, however, the stream carries a considerable volume of water. The maximum discharge recorded at Eagle was 2,860 cfs in April 1947. The stream presently (1969) is not used as a source of municipal or large-industrial water supply; it is used, however, as a source of water to maintain the level of an artificial lake near De Witt.

The stream receives discharge from the sewage-treatment plant at De Witt. Although the stream is used for recreation, its esthetic and recreational values decline in summer months when the flow is small.

RED CEDAR RIVER

The Red Cedar River (pl. 1) drains most of the northern two-thirds of Ingham County. Its average flow at East Lansing is about 190 cfs, and its annual 7-day low flow, where it enters the Grand River, is about 30 cfs. The basin contains Lake Lansing and a few other small lakes as well as several large wetland areas. The stream is not utilized for municipal or industrial water supplies. Recreational and esthetic values of the stream are fairly high although sewage-treatment plants at Webberville, Williamston, East Lansing, and Mason discharge to the stream.

THORNAPPLE RIVER

The Thornapple River (pl. 1) drains most of Eaton County. The average flow near Hastings for the period 1944 through 1966 was 278 cfs; minimum flow of 33 cfs was recorded at this site in August 1964. Within the region the annual 7-day low flow is about 25 cfs. The river is not used for municipal or large-industrial supply, but it is utilized for irrigation and stock watering and is a potential source of fairly large water supply for the village of Vermontville.

BATTLE CREEK

Battle Creek (pl. 1), a major tributary of the Kalamazoo River, drains the southern part of Eaton County. The annual 7-day low flow from the Battle Creek basin within the region is about 20 cfs. The stream is not utilized for municipal or industrial supply, the major use of the stream in this area being for dilution and transportation of waste from treatment plants at Charlotte, Olivet, and Bellevue. Although this does not preclude its development for industrial or municipal supply, it does provide a major obstacle to such development because of the degradation in water quality. The water-quality characteristics of the stream probably do not seriously affect its use for irrigation.

PORTAGE CREEK

Several tributaries of Portage Creek (pl. 1) drain a part of southern Ingham County. These streams are small and drain only a small quantity of water from the region. Some water is taken from the streams for stock watering and irrigation.

WATER FROM LAKES

Lakes in the region, which are too few and mostly too small to be considered as potential major sources of water supply, are used primarily for their recreational and scenic values. Development of the lakes for water supplies would conflict with these uses. Lakes do, however, provide a source of emergency water supply, such as for firefighting.

The Great Lakes are potential sources of very large supplies of water for municipalities and industries in Michigan. The principal drawbacks to importing Great Lakes water to the Tri-County region are economic, legal, and political. Technological and engineering problems involved are not complex; however, the capital costs involved are fairly high.

Costs per unit of water obtained from a Great Lakes system would tend to decrease with the quantity of water produced. If water were to be imported from the Great Lakes, an economically feasible system probably would call for the combined efforts of most communities in the Lansing metropolitan area, including Michigan State University.

Water can be imported from either Lake Michigan or Lake Huron. Lake Michigan is a few miles nearer to the region than Lake Huron, but for two reasons Lake Michigan faces a greater threat of being polluted than does Lake Huron. First, the flow through Lake Michigan is much smaller than the flow through Lake Huron. Second, several very large communities and industrial areas discharge waste to Lake Michigan, whereas only a few large communities and industries discharge waste to Lake Huron (fig. 16). The long-term possibilities of degradation of water quality should be considered in the choice of the lake from which water may be imported, provided that economic and other factors indicate that importation of Great Lakes water is desirable.

GROUND-WATER RESERVOIRS

Water is found almost everywhere: in the atmosphere, on the land surface, and in the ground. Although water's presence in the ground is generally known, the problem of evaluating the potential supplies available is very complex. The supply of fresh ground water available for development is a function of the amount of recharge, natural and artificial, available to the ground-water reservoirs; the permeability of the aquifers; the amount of water in storage; and the quality of the water in, and recharged to, the ground-water reservoirs. Most of these factors can be measured and evaluated only through a study of various geologic and hydrologic relationships.

The importance of ground water in the region is illustrated by the fact that nearly all the water withdrawn for use, other than that for cooling of steam-generating plants, is obtained from wells. Nearly all municipalities in the region have been able to develop adequate supplies from wells within their corporate limits.

GEOLOGIC HISTORY

The Tri-County region is underlain by unconsolidated clay, silt, sand, and gravel of glacial origin which rest upon about 10,000 feet of consolidated sediments deposited in ancient seas. The consolidated sediments, referred to as bedrock, are composed principally of limestone, shale, siltstone, sandstone, salt, and gypsum. The glacial deposits and the upper bedrock layers are important sources of fresh water (fig. 17) in the region.

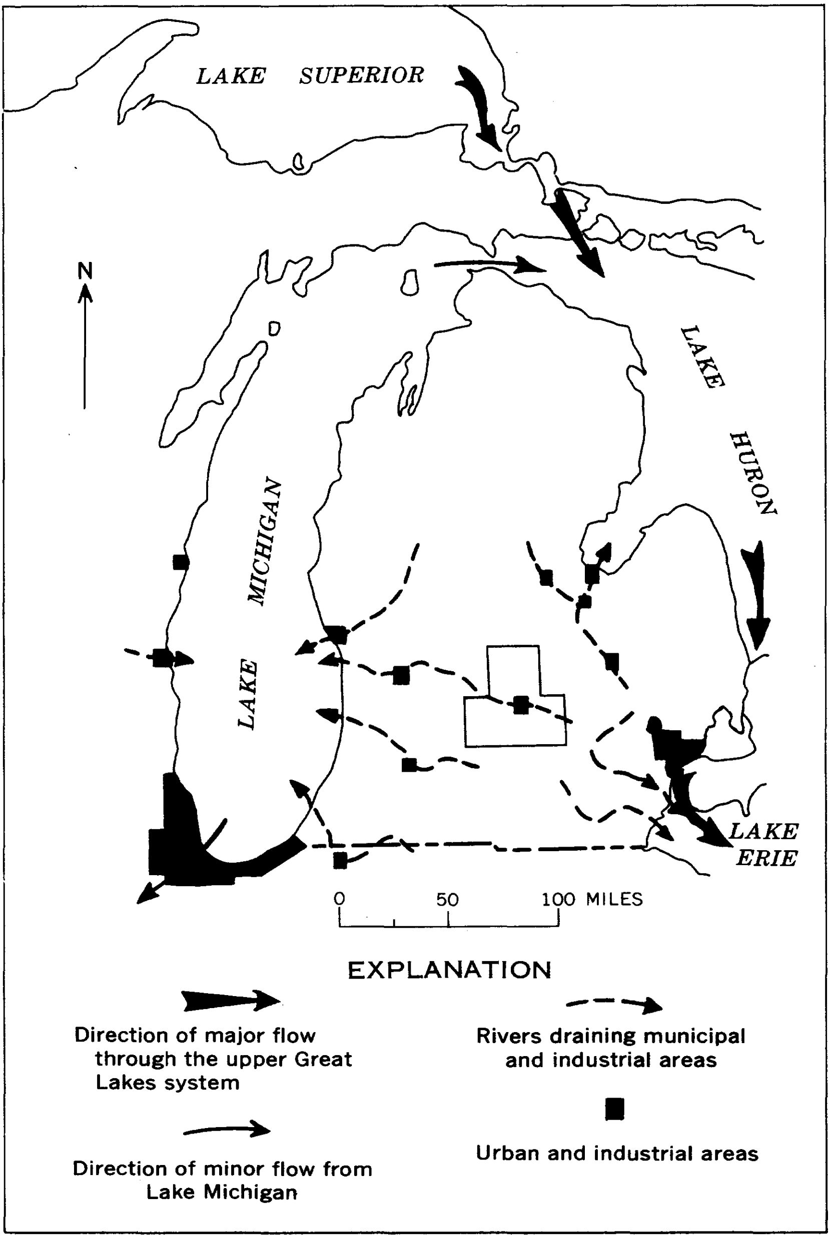


Figure 16.—The Great Lakes could be used as a source for water supplies.

The glacial deposits of the region overlie a bedrock surface (pl. 2) that was eroded by wind and running water for a long period of

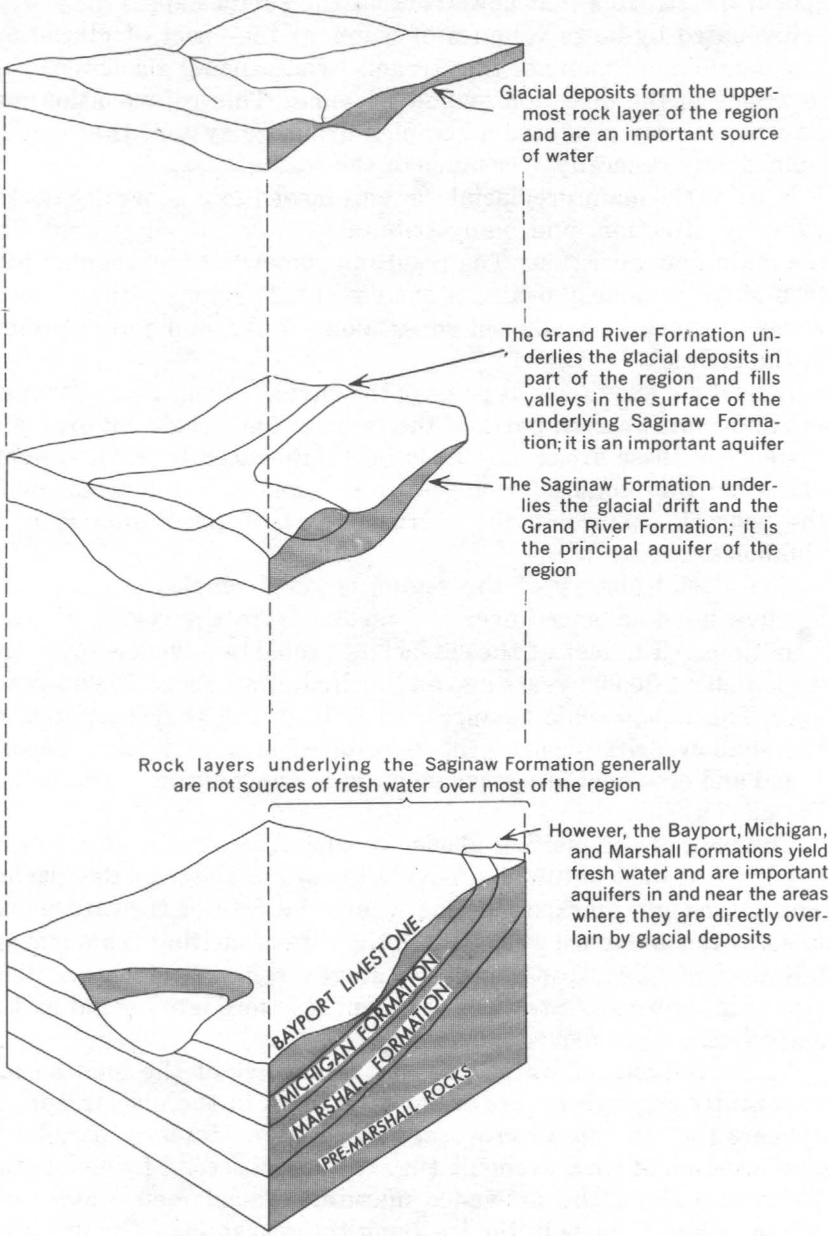


FIGURE 17.—How the ground-water reservoirs underlie the region.

geologic time; this surface ranges in altitude from less than 300 to more than 900 feet. Although most erosion predates the glacial epoch, the streams that flowed across the surface apparently were rejuvenated by large volumes of water at the onset of glaciation. The damming of many of the streams by advancing glaciers caused reversals in the direction of flow of some. This rejuvenation and stream reversal produced a complex drainage system that can be defined only generally over much of the region.

Most of the main preglacial streams flowed in a generally northwesterly direction, and many tributaries were at right angles to the main flow direction. The resulting somewhat rectangular pattern of the preglacial drainage system (pl. 2) suggests that stream valleys formed in weakened zones along faults and joint systems in the bedrock.

Limestone strata are at or near the surface along the southeastern and southwestern parts of the region. The preglacial drainage systems in these areas may have been influenced by cave systems and other limestone solution features. Some closed depressions in the bedrock surface in the southern part of the region may be sinkholes.

The glacial history of the region is very complex. Continental glaciers have advanced over and melted from the region at least four times. The last of these glaciers probably advanced over the region about 30,000 years ago and melted away about 15,000 years ago. The topographic features, as well as the characteristics of the shallow drift deposits, have resulted primarily from depositional and erosional processes involved in the melting of the last of the glaciers.

The bulk of the melting glacier consisted of a mass of active or live ice that was continually moving toward the edge of the glacier. The ice margin marked the line where the rate of forward movement of the active ice was equal to the rate of melting. This margin migrated northward in a series of stages, some of which are illustrated in figure 18. Strips of stagnant ice were left behind as the active-ice margin moved northward.

Large volumes of water ran off the surface of the melting ice, apparently through ice crevasses (fractures in the glacial ice). It appears that the major crevasse system formed nearly parallel to the direction of ice movement (fig. 19), and a second formed parallel to and along the active-ice margin. Glacial melt waters cut channels and tunnels in the ice along these systems. The drainage system that formed on and in the melting ice mass apparently was superimposed on the land surface when the ice finally melted. The present streams, which flow along the channels of the old glacial melt-water streams, are much smaller than their glacial ancestors, and many of them flow in opposite directions.

The first glacier to advance over the region moved over weathered bedrock and alluvial deposits. Later glaciers advanced over sediments deposited by previous glaciers and in some places reworked all the underlying unconsolidated sediments. In other places only the uppermost beds of the underlying sediments were altered by the glaciation.

The mantle of glacial deposits left by the succession of ice sheets varies greatly in composition from one locality to another and with depth. Adequate definition of the composition and water-bearing potential of the glacial deposits at depth can be obtained only through analysis of data obtained from drilling and geophysical studies.

The water-bearing potential of the glacial deposits is in part related to their thickness, which ranges from 50 to 200 feet in most of the region. The deposits generally are thinnest in the southern part of the region and thickest in the northwestern part (pl. 2), but they are very thin along the Red Cedar River at Williamston and Okemos and along the Grand River at Lansing and Grand Ledge. The glacial deposits are very thick along the traces of valleys in the bedrock surface (pl. 2). Although glacial sediments filling bedrock valleys in many areas of Michigan yield large quantities of water to wells, the glacial deposits filling most of the bedrock valleys of the Tri-County region are relatively impermeable.

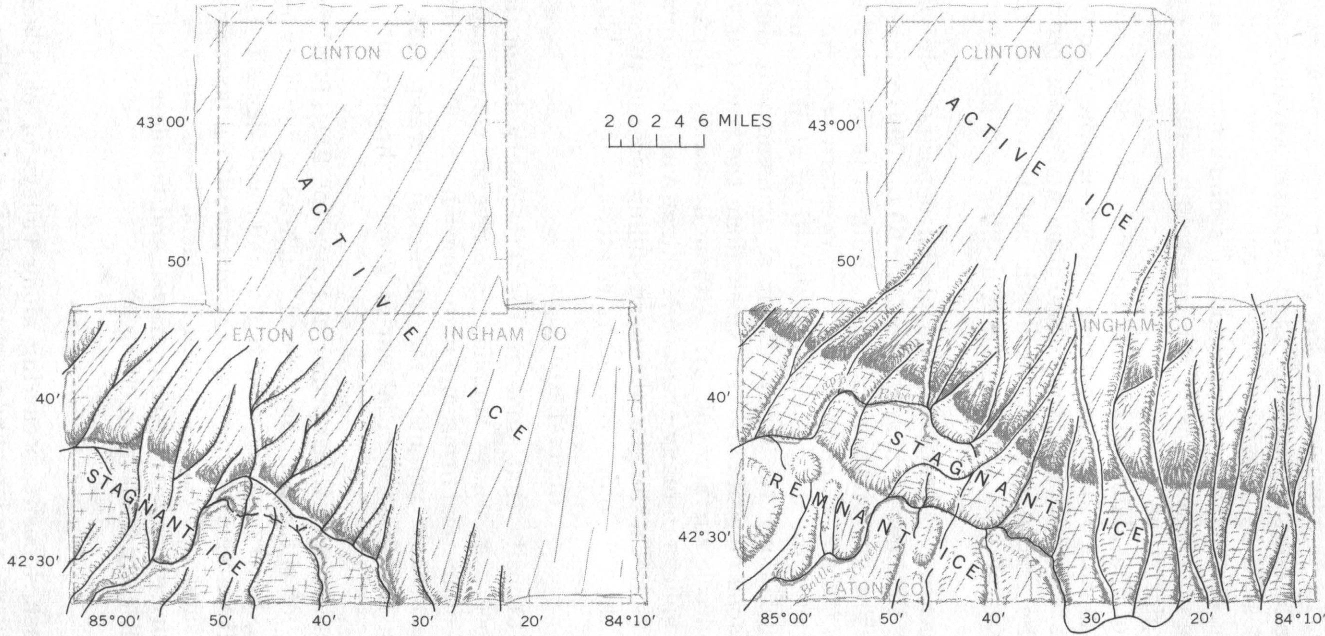
GLACIAL AQUIFERS

The glacial deposits that underlie the Tri-County region are presently tapped for water supplies for several communities, industrial and commercial firms, and many households. These aquifers have considerable potential for additional development of water supplies, but this potential varies greatly throughout the region.

Glacial deposits are of three principal types (pl. 2): (1) a well-sorted mixture of silt, sand, and gravel, such as valley outwash, outwash plains, eskers, kames, and buried outwash, deposited by streams of melt water draining from the glacier, (2) a layered sequence of silt, sand, and clay deposited in glacial lakes, and (3) an unsorted mixture of clay, silt, sand, gravel, and boulders, such as till, deposited directly from the melting ice.

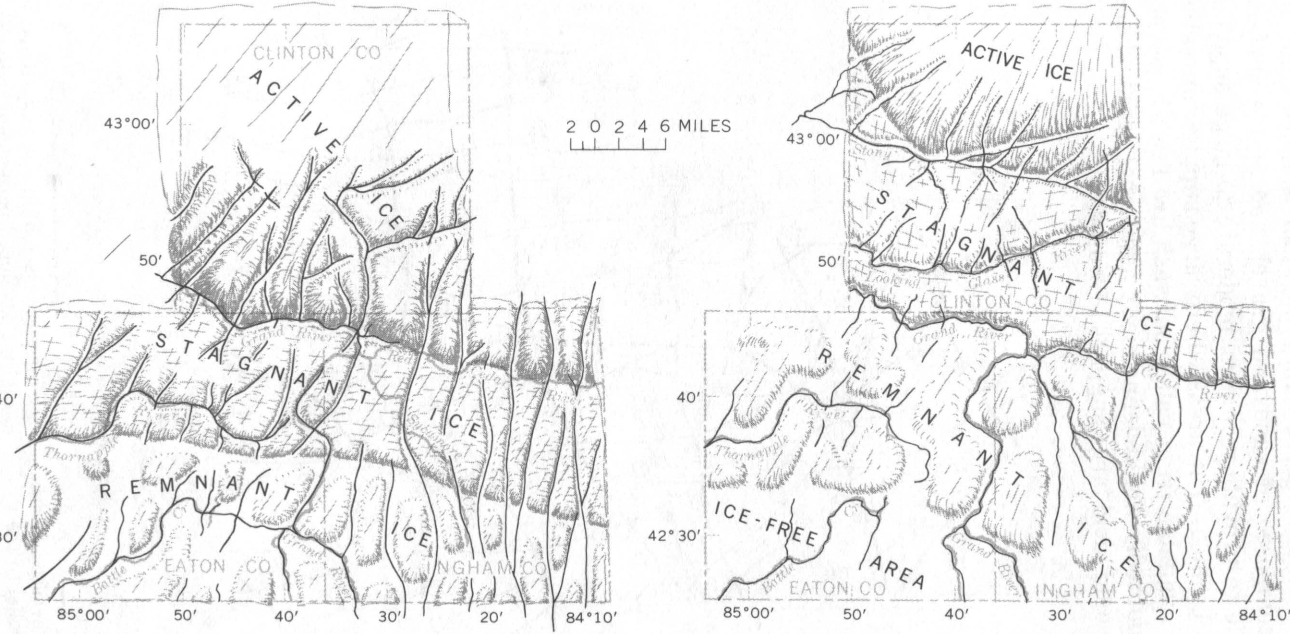
VALLEY OUTWASH

Valley-outwash deposits, occurring along valleys of old glacial melt-water streams, are long and narrow and often fairly thin. In many areas the valley outwash is less than 40 feet thick, is composed largely of silt and sand, and is not a source of moderate or



A. – During the early melting stages of the glaciers most melt water drained through the Battle Creek drainage system.

B. – As the glaciers melted northward, some melt water began to drain through what is now the Thornapple River basin.

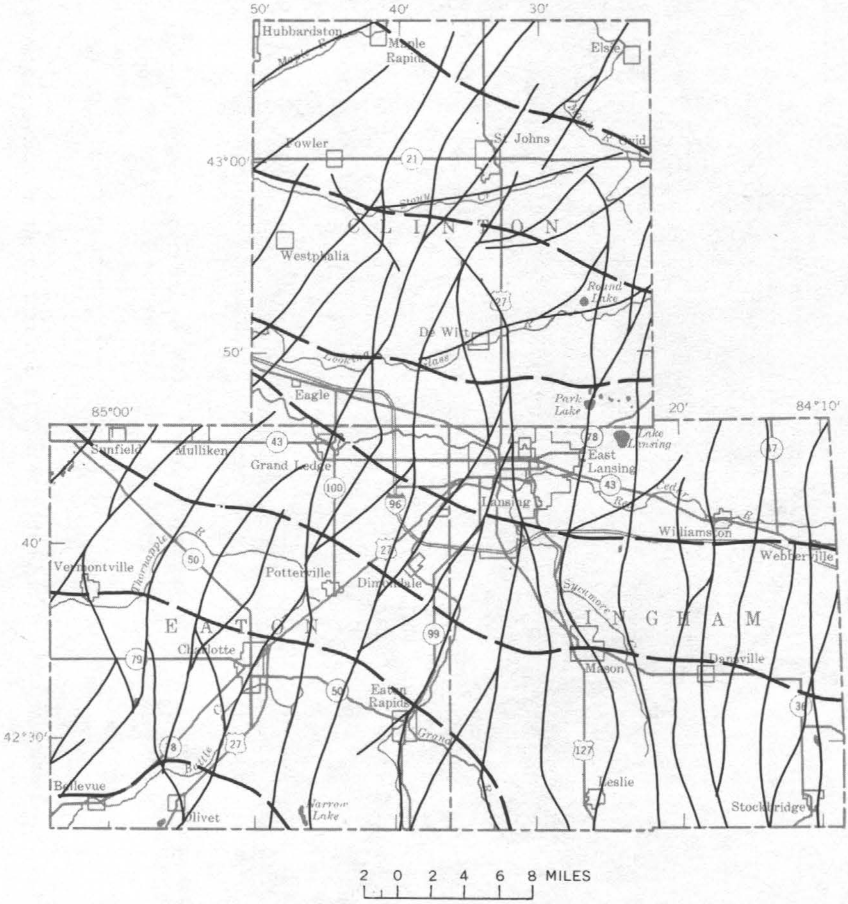


C. — With further melting, some melt water began to drain westward along an early ancestor of the Grand River.

D. — By the time active glaciers had nearly melted from the region, the Thornapple, Grand, Cedar, and Looking Glass Rivers had assumed most of their present drainage patterns and were draining most of the region.

FIGURE 18.—Drainage in the Tri-County region is a direct result of active glaciation.

large supplies of water. Where valley outwash is more than 40 feet thick and composed of sand and gravel, and ample surface water is available to provide recharge, moderate to large supplies of water can be obtained. The areas where large supplies of water are known to be available from valley outwash are few; however, test drilling undoubtedly would define many additional areas where valley outwash would yield large supplies of water.



EXPLANATION

Apparent trace of crevasse systems that developed parallel to the direction of ice movement

Apparent trace of crevasse systems that developed perpendicular to the direction of ice movement

FIGURE 19.—Crevasse systems in the glaciers appear to have had a major influence on drainage patterns.

In some areas, the streams have cut through the valley outwash leaving the beds of sand and gravel "high and dry" above the stream. The following rivers in Clinton County are examples of streams entrenched below their valley outwash: The Maple River in Lebanon Township, Stony Creek in Dallas Township, and Hayworth Creek in Essex Township. Although the valley-outwash deposits in these areas have little value as sources of moderate or large water supplies, they are potential sources of construction aggregate.

OUTWASH PLAINS

The outwash plains of the region were formed where large quantities of glacial melt waters flowed from the melting ice sheet. They differ from valley outwash principally in that the plains generally are wider and higher.

The largest outwash area in the region is south of Dansville in Ingham County. Here, the sand and gravel of several glacial melt water streams coalesced in a large area to form a rolling plain. The outwash of this area varies considerably in thickness and in the type of material deposited. Apparently most of it is fine sand, although some is coarse sand and gravel. The outwash of the Dansville area is tapped only by a few household wells; hence, few data are available on its water-bearing capacity. From present information, it is estimated that the Dansville outwash area would yield large supplies of water.

Another outwash plain that covers several square miles is just east of Eaton Rapids. In the northern part of this plain, the sand and gravel beds may yield large supplies of water to wells. In the southern part of the plain, the sand and gravel beds have less potential because they are largely situated above the water table.

A smaller outwash plain lies just east of Charlotte. Throughout much of this plain the bedrock surface is fairly high; consequently, the outwash deposits are thin. Although a detailed test-drilling program would be needed to define accurately the glacial aquifer in this area, most available data indicate that its ground-water potential is low.

ESKERS

Long narrow ridges of sand and gravel, called eskers, are present in Ingham County and parts of Eaton and Clinton Counties (pl. 2). Eskers apparently were formed by streams flowing through tunnels at the base of stagnant ice. In some places they rest directly on the bedrock, whereas in other places they rest on till. Eskers commonly occur parallel to, and are in contact with, valley-outwash deposits.

Although much of the sand and gravel in most eskers is above the water table, in some eskers permeable materials extend below the water table. Such eskers commonly have considerable potential as sources of water. The fact that eskers are very narrow limits their potential as sources of water; however, many are hydraulically connected to other types of water-bearing outwash, and most water obtained from wells tapping sand and gravel beds of most eskers would be induced from adjacent outwash.

Esker deposits yield considerable water to municipal wells at Williamston and Mason, and others in the region are potential sources of water supply. However, as eskers underlie only a small part of the region, they have limited value as a major source of large supplies.

Many eskers in the region have been used as sources of sand and gravel, thus reducing many of the esker ridges to water-filled trenches. The Mason esker, which extends from Lansing through Mason, has been almost mined out; only a few segments remain. Although the mined-out eskers have limited usefulness as sources of water, they are potentially important as recharge pits through which adjacent outwash and underlying beds of sandstone may be artificially recharged.

KAMES

Hills or mounds of sand and gravel, called kames, were formed during glacial time where melt-water streams drained off stagnant ice or plunged into pools within the stagnant ice. Kames generally are relatively small in areal extent (pl. 2), but in some places, several kames have coalesced to form larger areas of sand and gravel. Some of these "kamic" areas may have considerable potential as sources of water. Kames also are important sources of construction aggregate.

BURIED OUTWASH

The last glacier that covered the Tri-County region advanced over broad areas of outwash deposited by the preceding glacier. Some of this older outwash was carried away; however, much of it was left relatively undisturbed but covered by a layer of till. The most extensive of these buried outwash deposits is in the southern part of Clinton County and adjacent parts of Eaton and Ingham Counties (pl. 2). Other buried outwash deposits are present in the region, and some are favorable sources for water supplies. The thickness and extent of most of these aquifers, however, cannot be accurately defined on the basis of presently available data. With the exception of a few large-capacity wells in southern Clinton County and northern Ingham County, the deposits of buried outwash generally are tapped only by wells supplying household needs.

Buried outwash is a potential source of large supplies of water; however, most household wells are completed in bedrock aquifers because of the better quality water available. The lack of development of buried-outwash aquifers does not mean that they lack potential as sources of large supplies of water but that there is little demand for large supplies of water in the areas where buried outwash is present.

The deposits of buried outwash in the Lansing metropolitan area probably will be utilized for municipal water supply, and possibly for irrigation, in the near future. Buried-outwash deposits in the southern part of Clinton County and the northern parts of Eaton and Ingham County may be capable of yielding as much as 50 mgd to wells, and an additional 10 mgd might be obtained in other parts of the region. These estimates of yield, however, should be verified through test drilling and tests of well yields.

LAKE PLAINS

Beds of clay, silt, and sand deposited in glacial lakes underlie parts of Clinton County (pl. 2). These deposits generally are thin and in most places are not sources of water to wells. Locally, beds of lake-deposited sand are tapped for water supply by shallow dug or driven wells.

TILL

Most of the region's surface is underlain by deposits of till (pl. 2) that were laid down either at the active-ice margin or in the areas covered by the masses of stagnant ice of the last glacier. Till generally is not a source of water to wells, although in some places it includes thin beds of sand and gravel that yield water in amounts adequate for household needs. Also, in some areas till overlies bodies of sand and gravel outwash that may yield moderate to large supplies of water. In other places, however, the till extends from the land surface to the top of the bedrock, and here the glacial deposits do not yield water.

BEDROCK AQUIFERS

The glacial aquifers are underlain by several thousand feet of Paleozoic sediments. Only the upper part of these strata are sources of fresh water; strata below a depth of 500 feet in the region generally contain saline water.

Water in the bedrock aquifers is under artesian pressure. Thus, the potentiometric surface is not directly influenced by land-surface topography. Water levels in some topographically lower areas in Clinton County are higher than in topographically higher areas in Ingham and Eaton Counties. The potentiometric surface shown in figure 20 is that produced by the combined artesian pressures in the bedrock aquifers penetrated by wells; its altitude ranges from 650 to 950 feet.

The Grand River, Saginaw, Bayport, and Michigan bedrock formations (fig. 21) are the principal source of water in most of the region. The formations that yield fresh water vary considerably in lithology and thickness from one area to another, so their water-bearing characteristics vary widely throughout the region.

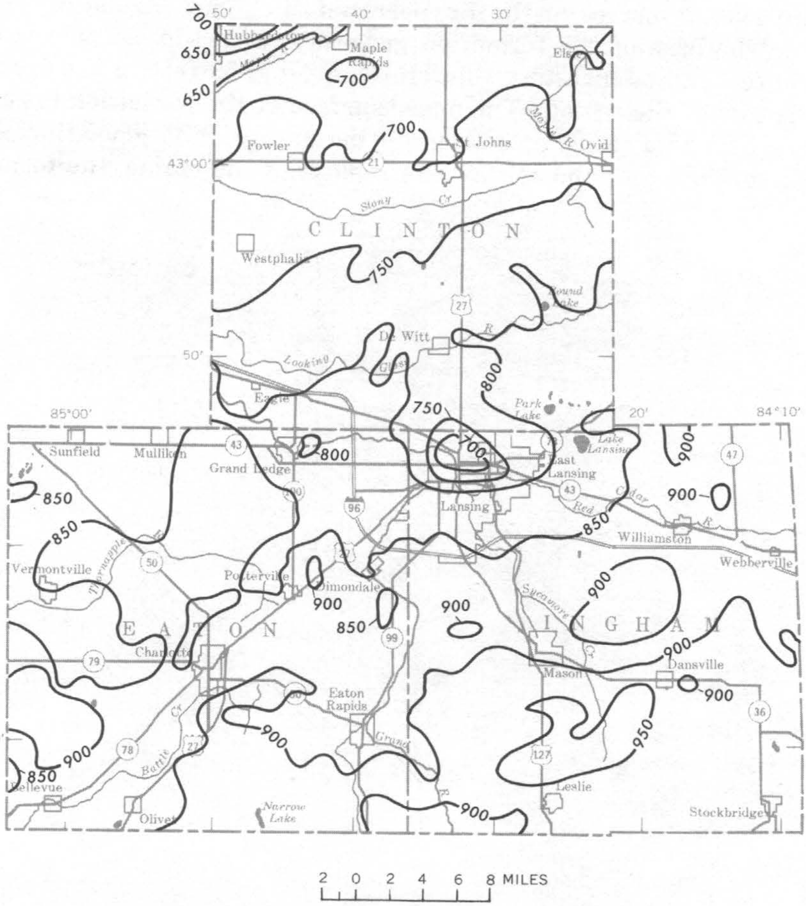
GRAND RIVER FORMATION

The Grand River Formation is the uppermost bedrock unit of the region. It is composed principally of red and white sandstone and red and black shale and generally can be distinguished from the underlying Saginaw Formation by its red color. The formation occurs principally in Clinton County, but subcrops too small to show on plate 3 occur in Ingham and Eaton Counties. After deposition, erosion removed most of the Grand River Formation, and as a result only a few large remnants remain. These remnants are thickest (up to 125 feet) along the traces of valleys in the Saginaw Formation (pl. 3).

In areas where the Grand River Formation is more than a few feet thick, it generally can yield water in supplies adequate for household needs. Where it is more than 50 feet thick, it may in most places yield moderate supplies of water. Low yields apparently result from the sandstone pores being filled with mineral cement.

The Grand River Formation and the underlying Saginaw Formation function as a single complex aquifer. Thus, in areas where the aquifers are not extensively developed, ground-water levels tend to be common to both.

The Grand River Formation is not too important as a potential source of municipal water supply, as most of the areas where the formation is moderately productive are somewhat remote from the localities of potential need. If the formation were properly developed, it probably would yield several million gallons of water per day to wells.



EXPLANATION

——800——

Potentiometric contour

Shows altitude of potentiometric surface. Contour interval 50 feet. Datum is mean sea level

FIGURE 20.—The altitude of the potentiometric surface of the bedrock aquifers ranges between 650 feet and 950 feet.

SAGINAW FORMATION

The Saginaw Formation, which underlies almost the entire region, is the region's principal aquifer and offers the greatest potential for future development. The Saginaw was deposited on

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the eroded surface of the Bayport and Michigan Formations (pl. 3). The base of the formation generally ranges in altitude from 100 feet in northwestern Clinton County to 850 feet in the southern part of the region. The upper surface of the formation is very irregular as a result of erosion during and prior to glaciation. In the southeastern and southwestern parts of the region, the forma-

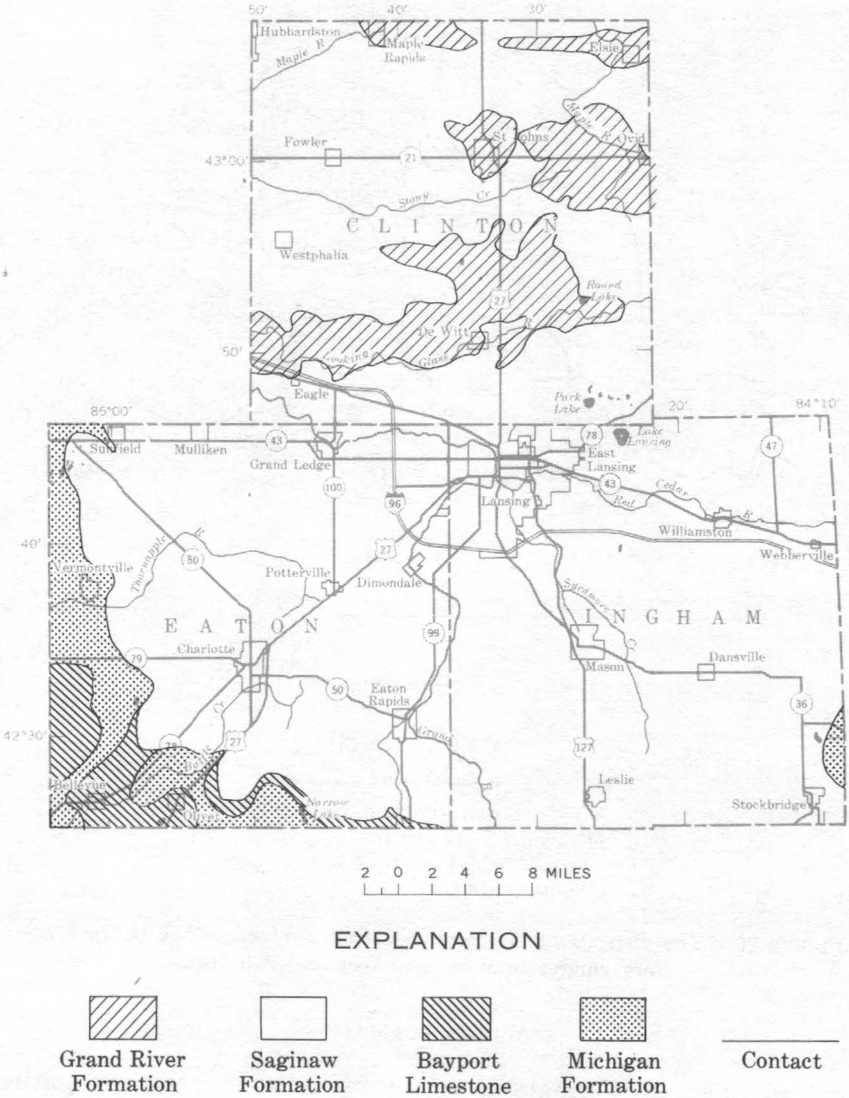


FIGURE 21.—The four bedrock formations that underlie the glacial deposits are the Grand River, Saginaw, Bayport, and Michigan.

tion was completely eroded away. Over most of the region, however, the formation is more than 300 feet thick; it is more than 400 feet thick in parts of Ingham and Clinton Counties and more than 500 feet thick in some other localities (pl. 3). This great variation in the thickness results primarily from the thinning of the formation by erosion.

The Saginaw is composed principally of beds of sandstone and shale, but it includes some thin beds of coal and limestone. The formation has been described as a cyclical sediment (Kelly, 1936) produced by repetitive deposition of a particular lithologic sequence. Each sedimentary sequence is reported to include the following, in ascending order: sandstone, shale, coal, shale, and limestone. Such cycles cannot be defined from well records; several major sandstone-shale sequences, however, do occur in the formation (pl. 3). The proportion of shale to sandstone in each sequence varies throughout the region. In some areas a given sequence is composed primarily of sandstone and in other areas its stratigraphic equivalent may be composed primarily of shale. On a more general level, all the sequences in some areas are composed primarily of sandstone, whereas in other areas they are all composed primarily of shale. Over much of the region the sandstone beds are water bearing.

The yield of a well tapping the Saginaw Formation is controlled primarily by the thickness of sandstone penetrated. Generally, the more sandstone penetrated the higher the yield. In some areas, however, beds of sandstone are not highly permeable owing to filling of the pores between sand grains with mineral matter. It also appears that, in most areas, sandstone at shallow depth is more permeable than deeply buried sandstone. The higher permeability may result in part from openings along fractures in the shallow beds, which in deeper beds may be closed by the weight of overlying sediments.

The yield of the formation also is controlled by the availability of recharge water. The long-term yield is greater where sandstones of the formation are overlain by permeable sand and gravel than where the upper part of the formation is composed of shale or is overlain by clayey glacial sediments. Recharge from streams also increases long-term yield. In areas where streams are underlain by sand and gravel that are in turn underlain by permeable sandstone, large quantities of water can be induced into the formation when water levels are lowered by pumping. Conditions are suitable for artificially recharging the aquifer in some of these areas.

The Saginaw and Grand River Formations along with some of the overlying glacial sediments act as a complex aquifer system. The combined productivity of this system is indicated on plate 3. The areas of highest productivity include much of the western half of Ingham County and much of the eastern half of Clinton County, and there is an area of high productivity in southwestern Clinton County and northeastern Eaton County.

BAYPORT LIMESTONE

The Bayport Limestone, which underlies the Saginaw Formation throughout most of the region, is composed largely of white and gray limestone and sandstone. Because it was extensively eroded prior to the deposition of the Saginaw Formation, the Bayport varies considerably in thickness from one area to another. In some areas it was completely eroded away, and most remnants of the formation are less than 50 feet thick.

The Bayport contains saline water in areas where it is overlain by the Saginaw Formation. However, in southwestern Eaton County, where it is overlain directly by glacial drift (fig. 21), the Bayport is the source of fresh water to household wells. Sandstone beds in the formation supply many of these wells, although some limestone beds are also water producing. The areas where the formation is a source of water are relatively small.

The Bayport probably will never be a major source of water supply, although it may yield moderate supplies in a few localities where solution cavities have formed in some beds of the formation. In some localities glacial sediments do not yield water and strata underlying the Bayport contain saline water, so the Bayport may be the only source of fresh ground water.

MICHIGAN FORMATION

The Michigan Formation underlies the Bayport Limestone and the Saginaw Formation. It is composed primarily of shale but includes beds of sandstone, limestone, and gypsum. The formation is the source of fresh water in southwestern and western Eaton County, where it is overlain directly by glacial deposits or by the Bayport Limestone (fig. 21). Where it is overlain by the Saginaw Formation, the Michigan Formation generally is of low permeability and contains saline water.

The quality of water yielded by the formation varies considerably. In the southwestern and western parts of the region, beds of sandstone in the formation yield water suitable for household use. Where wells penetrate beds of gypsum or where the water-bearing strata are in contact with gypsum, the water commonly contains objectionable concentrations of calcium sulfate. Locally the water contains objectionable concentrations of chloride. In some areas shallow beds in the formation yield fresh water, whereas deeper beds contain saline water.

The principal problem involved in developing the Michigan Formation as a source of water supply is water quality. The location and extent of sandstone beds that yield good-quality water cannot be defined accurately until more data become available. Because beds yielding fresh water generally are of low permeability and limited areal extent, the formation has little importance as a source of moderate or large supplies of water.

Although the Michigan Formation is not important as a major source of water supply, it is an important part of the hydrologic system of the region. The impermeable shales in the upper part of the formation restrict the upward migration of saline water into the Saginaw Formation. Potential points of leakage of saline water into the overlying fresh-water system are created where the Michigan Formation is breached by wells.

MARSHALL FORMATION

The Marshall Formation, which underlies the entire region, is one of the principal aquifers of the southern peninsula of Michigan. Over most of the Tri-County region, however, the formation yields saline water. It yields potable water (fig. 22) in the southwestern part of Eaton County, where it is tapped for municipal supply at Bellevue and at Olivet. In this area, the Marshall has considerable potential as a source of water supply.

The area where the Marshall yields potable water can be defined only roughly on the basis of present data. In some areas where the Marshall Formation yields fresh water, the overlying Michigan Formation contains saline water which must be sealed off in wells tapping the Marshall to prevent the wells from yielding poor-quality water. When a well yields salty water, it is commonly difficult to determine whether the salty water is from the Michigan Formation or from the Marshall Formation. Water samples obtained during and at the completion of the drilling of a well can aid in determining the true quality of the water in each formation.

PRE-MARSHALL ROCKS

Several thousand feet of consolidated sediments underlie the Marshall Formation. These strata contain hypersaline waters and are not sources of fresh water. They generally are of low permeability and are not important from a water-supply standpoint.

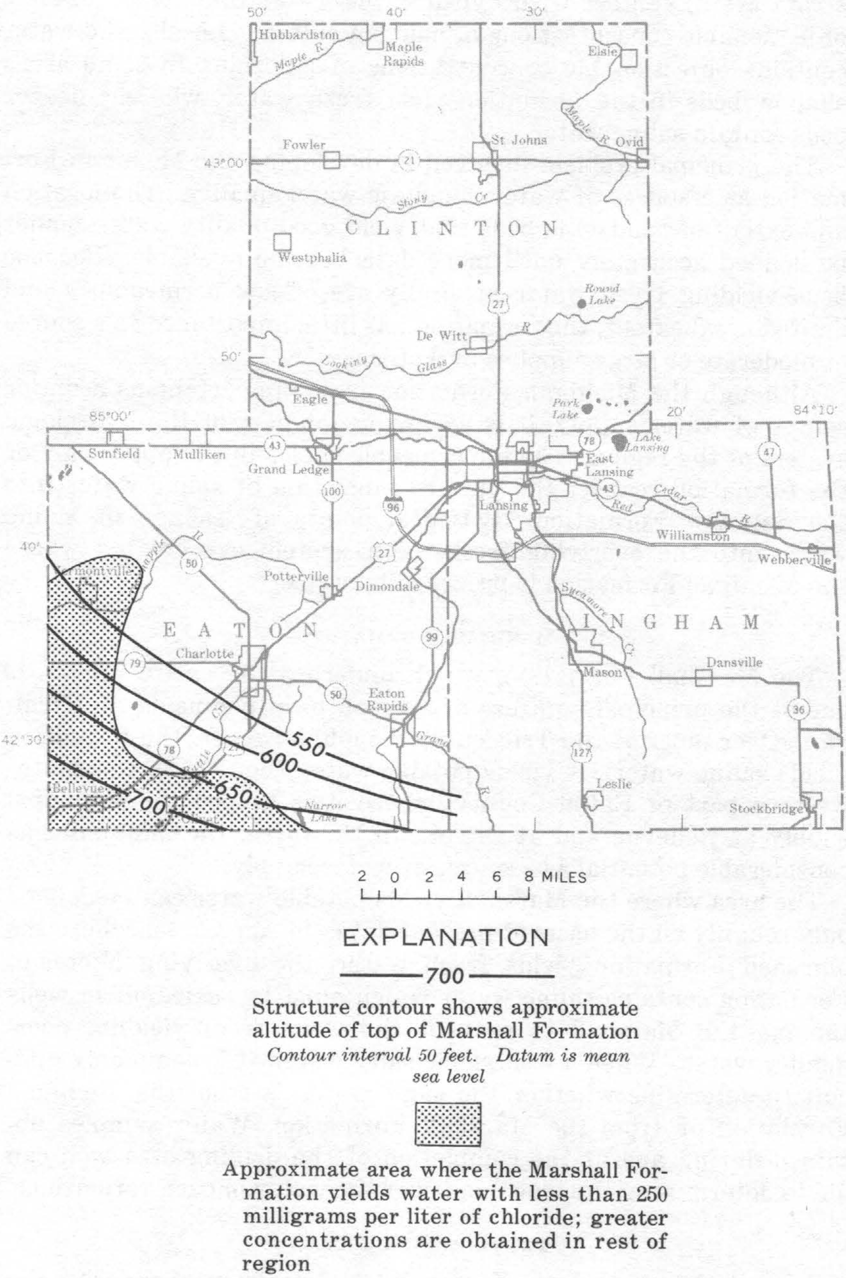


FIGURE 22.—The Marshall Formation yields salty water over most of the region.

QUALITY OF WATER

An appraisal of water quality is an important part of an evaluation of water resources. The word "quality," however, implies a value that must be related to an intended use. Sea water, for example, may be of excellent quality for swimming and other recreation but of poor quality for drinking and many other uses. The analyses presented herein are quantitative expressions of the types and concentrations of dissolved materials in water and can be utilized to define water quality in relation to intended uses.

Water is a nearly universal solvent; within limits it will dissolve almost all substances. Natural waters thus contain a variety of dissolved minerals, most of which are present only in trace amounts and do not affect the usefulness of water. Chloride, sulfate, and bicarbonate salts of calcium, magnesium, and sodium make up more than 98 percent of the dissolved solids in waters of the region. Excessive concentrations of these ions will significantly affect the usefulness of water. Nitrates, pesticides, and other substances introduced into the water by man also may limit the usefulness of water. Table 2 lists many of the important chemical and physical characteristics of water and their effects on water usefulness.

SURFACE WATER

The streams and lakes of the region are fed either directly by precipitation or by surface runoff and ground-water discharge. The relative proportion of water received from the last two sources varies considerably from one season to another. During periods of high flow the water in streams is largely surface runoff, whereas during low flows the water is principally discharged ground water. The chemical characteristics of the water vary with the relative proportion of water received from the two sources, but the actual variance in chemical content is not large, which indicates that surface runoff is not significantly different in chemical content from discharged ground water.

Table 3 lists chemical analyses of waters from most streams in the region. Most of the samples were collected during periods of low flow. Because the dissolved-solids concentrations normally increase with decreasing discharge, the values shown generally indicate the upper range of dissolved-solids concentration.

QUALITY STANDARDS

To assist in defining water quality, the Michigan Water Resources Commission (1969) has established minimum standards

TABLE 2.—*Some chemical and physical properties of water*

[mg/l, milligrams per liter]

Parameter	Maximum recommended concentration (mg/l)	Significance
Dissolved solids	500	Includes all material in water that is in solution. Water containing amounts up to 1,000 mg/l is generally considered acceptable for drinking if no other water is available.
Iron (Fe)	.3	Objectionable as it causes red and brown staining of clothing, porcelain, and utensils.
Hardness (as $CaCO_3$).	-------	Affects the lathering ability of soap. Water may become objectionable for some domestic uses when the hardness goes above 100 mg/l; however, it can be treated readily with softening agents.
Temperature	-------	Affects the desirability and economy of water use, especially for industrial cooling and air conditioning. Most users want water with a uniformly low temperature.
Calcium (Ca) and magnesium (Mg).	-------	Principal causes of hardness and scale-forming properties of water. Reduces the lathering ability of soap.
Sodium (Na) and potassium (K).	-------	Imparts a salty or brackish taste when combined with chloride. Large quantities may limit use for irrigation.
Sulfate (SO_4)	250	Commonly has a laxative effect when the concentration is 600 to 1,000 mg/l, particularly when combined with magnesium or sodium. Causes bitter taste when combined in large amounts with other ions.
Chloride (Cl)	250	Large amounts combined with sodium impart a salty taste. When combined with calcium and magnesium may increase the corrosive activity of water.
Fluoride (F)	2.0	Concentrations over 2.0 mg/l cause mottling of enamel on teeth of children. However, concentrations of about 1 mg/l play a part in the reduction of tooth decay.
Silica (SiO_2)	-------	Contributes to formation of boiler scale. Inhibits deterioration of zeolite-type water softeners.
Bicarbonate (HCO_3) and carbonate (CO_3).	-------	Raises the alkalinity and usually the pH of water. In combination with calcium and magnesium, causes carbonate hardness and scale. Releases corrosive carbon dioxide gas on heating.
Nitrate (NO_3)	45	Water with high nitrate content may cause methemoglobinemia or cyanosis in infants. High concentrations suggest organic pollution from sewage, decayed organic mater, nitrate in the soil, or chemical fertilizer. Because of this, concentrations are characteristic of individual wells and not of any one aquifer.
pH	-------	A pH of 7.0 indicates neutrality of a solution; a pH lower than this generally causes an increase in the corrosiveness of water.

for five major existing water uses and has assigned a use category to each stream or stream segment in Michigan. The five major water-use categories for surface waters in Michigan are the fol-

TABLE 3.—*Chemical analyses*

[Results in millgrams per liter except as indicated. Discharge: B, base flow; R, overland

Station Number	Source	Location	Date sampled	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)
				Streams tributary		
4–1042.8	Battle Creek	SW¼ sec. 2, T. 1 N., R. 5 W.	July 11, 1967	B	—	—
			June 28, 1968	R	—	0.18
.9	Big Creek	SW¼ sec. 15, T. 1 N., R. 5 W.	July 11, 1967	B	—	—
			June 28, 1968	R	—	.13
1043.0	Indian Creek	NW¼ sec. 20, T. 1 N., R. 5 W	Oct. 6, 1964	4.08	—	—
1044.5	Battle Creek	NE¼ sec. 26, T. 1 N., R. 6 W	June 28, 1968	R	—	.14

lowing: water supply; recreation; fish, wildlife, and other aquatic life; agricultural; and commercial. Table 4 lists natural characteristics of the water for each category. This classification scheme is intended primarily for pollution control, but it provides a good indication of the values that are normally required for the various uses. Application of the five water-use categories to the Tri-County area follows.

No waters are protected specifically for domestic or industrial water supply. All waters accessible to the public for recreation are to be protected for partial body contact, and all natural lakes are protected for total body contact. Reservoirs protected for total body contact are listed below:

Name	River	County	Location
Moores Park Impoundment.	Grand River	Ingham	Sec. 21, T. 4 N., R. 24 W.
Lake Victoria	Alder Creek	Clinton	Secs. 12, 13, T. 6 N., R. 1 W.
Lake Geneva	Looking Glass River	Clinton	Sec. 7, T. 5 N., R. 2 W.
Sleepy Hollow Reservoir.	Maple River	Clinton	Secs. 3, 10, T. 6 N., R. 1 W. (from Jason Road downstream to dam).

All waters will be protected for intolerant warm-water species of fish except for (1) the Red Cedar River from Harrison Road bridge downstream to its confluence with the Grand River and (2) the Grand River from Moores Park Dam in Lansing downstream to Grand Ledge Dam. These two areas, however, are protected for tolerant warm-water species of fish. This use designation will apply until January 1974, at which time waste-disposal uses involved are to be reviewed by the Water Resources Commission with a view toward raising the quality standards. None of the streams have been protected for intolerant cold-water species of fish. All water will be protected for agriculture and commerce.

of stream water

runoff. Carbonate: Tr., trace. Analyst: 1, U.S. Geol. Survey; 2, Mich. Dept. Public Health]

Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids (evaporated at 180°C)	Hardness as $CaCO_3$: Ca, Mg	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (Hazen color unit)	Analyst
to Battle Creek															
—	—	—	—	342	0	77	36	7.4	479	375	94	760	7.7	—	1
—	—	—	—	136	0	43	6.0	12	254	166	54	335	7.3	75	1
—	—	—	—	348	0	125	8.0	3.6	513	425	140	147	7.9	—	1
—	—	—	—	198	0	109	4.0	20	412	294	132	548	7.3	100	1
—	—	—	—	320	0	60	16	1.3	415	347	84	652	7.8	—	1
—	—	—	—	156	0	62	8.0	21	284	212	84	423	7.3	125	1

TABLE 3.—*Chemical analyses*

Station Number	Source	Location	Date sampled	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)
			Streams tributary to the Upper			
4–1089.0	Grand River ----	NE¼ sec. 35, T. 3 S., R. 1 W	Sept. 19, 1963	3.59	—	0.28
1095.0	Orchard Creek --	NW¼ sec. 32, T. 1 S., R. 2 E	Sept. 2, 1959	R	16	.7
			Dec. 17, 1959	R	7	.8
			Apr. 21, 1960	R	6	.6
			July 7, 1960	B	7	.7
1097.0	Orchard Creek --	NE¼ sec. 30, T. 1 N., R. 2 E	June 28, 1968	R	—	2.7
1105.9	Batteese Creek --	SW¼ sec. 28, T. 1 N., R. 1 E	July 11, 1967	B	—	—
			June 28, 1968	R	—	.30
1106.0	Batteese Creek --	NE¼ sec. 27, T. 1 S., R. 1 E-	Sept. 19, 1963	0.16	—	.27
.2	Portage River ---	SE¼ sec. 11, T. 2 S., R. 3 W-	Sept. 2, 1959	R	16	.8
			Dec. 17, 1959	R	7	.3
			Apr. 21, 1960	R	3	.4
			Sept. 7, 1960	B	9	.5
.45	Huntoon Creek --	SE¼ sec. 20, T. 1 N., R. 1 W	June 28, 1968	R	—	.02
.5	Huntoon Creek --	SW¼ sec. 28, T. 1 N., R. 1 W	Oct. 6, 1964	1.45	—	—
1107.0	Sandstone Creek-	NE¼ sec. 21, T 1 S., R. 2 W-	Sept. 19, 1963	6.98	—	.68
			Sept. 2, 1959	R	12	.3
			Dec. 17, 1959	R	6	.2
			Apr. 21, 1960	R	4	.3
			July 7, 1960	B	10	.3
1108.0	Grand River ----	SW¼ sec. 2, T. 1 N., R. 3 W-	Sept. 2, 1959	R	14	.4
			Dec. 17, 1959	R	6	.1
			Apr. 21, 1960	R	4	.4
			July 7, 1960	B	11	.7
.9	Spring Brook ---	NW¼ sec. 27, T. 1 N., R. 3 W	June 28, 1968	R	—	.18
1109.0	Spring Brook ---	N½ sec. 8, T. 1 N., R. 3 W--	Sept. 19, 1963	1.86	—	.07
			Sept. 2, 1959	R	16	1.0
			Dec. 17, 1959	R	8	.0
			Apr. 21, 1960	R	2	.3
			July 7, 1960	B	10	.7
			Streams tributary to			
4–1112.0	Red Cedar River-	NE¼ sec. 5, T. 3 N., R. 3 E-	Sept. 19, 1963	4.01	—	0.32
.8	Kalamink Creek -	SW¼ sec. 23, T. 2 N., R. 2 E	July 11, 1967	B	—	—
			June 28, 1968	R	—	.18
1113.0	Kalamink Creek -	SW¼ sec. 2, T. 3 N., R. 2 E-	Oct. 5, 1964	1.28	—	—
.8	Red Cedar River -	NW¼ sec. 4, T. 3 N., R. 2 E-	Sept. 2, 1959	R	15	.90
			Dec. 17, 1959	R	7	.40
			Apr. 20, 1960	R	4.5	.20
			July 7, 1960	B	9.0	.50
1114.02	Doan Creek ----	SE¼ sec. 36, T. 3 N., R. 1 E-	July 11, 1967	B	—	—
			June 28, 1968	R	—	.19
.0	Squaw Creek ----	NW¼ sec. 32, T. 4 N., R. 2 E	Oct. 5, 1964	0.08	—	—
.05	Dietz Creek -----	SW¼ sec. 33, T. 3 N., R. 2 E	July 11, 1967	B	—	—
			Streams tributary			
4–1145.5	Maple River ----	NW¼ sec. 3, T. 6 N., R. 2 E-	Sept. 2, 1959	R	12	0.80
			Dec. 16, 1959	R	7.0	.50
			Apr. 20, 1960	R	4.5	.40
			July 8, 1960	B	9.0	.60
.8	Maple River ----	SE¼ sec. 11, T. 7 N., R. 1 W-	Oct. 5, 1964	5.96	—	—
.92	Little Maple River.	NE¼ sec. 33, T. 7 N., R. 1 W-	July 10, 1967	B	—	—
			June 30, 1968	R	—	.19
1146.0	Maple River ----	NW¼ sec. 11, T. 8 N., R. 1 W	Feb. 16, 1954	B	8.0	.15
			Sept. 19, 1963	12.5	—	—
1149.0	Pine Creek ------	SW¼ sec. 9, T. 9 N., R. 3 W-	Sept. 19, 1963	3.26	—	—
1150.0	Maple River ----	SW¼ sec. 5, T. 8 N., R. 3 W-	Sept. 27, 1963	11.0	—	.99
			Apr. 15, 1967	629	—	—
			June 28, 1968	R	—	.03
.2	South Fork Hayworth Creek.	SW¼ sec. 35, T. 8 N., R. 3 W	July 10, 1967	B	—	—
			June 30, 1968	R	—	.06
.5	Hayworth Creek -	NE¼ sec. 19, T. 8 N., R. 3 W	July 10, 1967	B	—	—
			June 30, 1968	R	—	.12
.95	Cox Drain ------	NE¼ sec. 18, T. 8 N., R. 3 W	July 10, 1967	B	—	—
			June 30, 1968	R	—	.02

of stream water—Continued

Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids (evaporated at 180°C)	Hardness as $CaCO_3$: Ca, Mg	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (Hazen color unit)	Analyst
Grand River and Portage River															
60	23	5.4	1.0	272	0	30	6.0	—	278	244	21	467	7.1	—	1
98	28	4.6	1.6	288	0	105	6	2.5	450	360	124	610	8.0	35	2
114	28	4.6	1.2	264	0	170	7	20	510	400	184	700	7.8	100	2
98	24	4.6	2.0	250	0	125	10	16	466	345	140	650	7.9	80	2
108	29	4.6	1.2	318	0	121	4	1.5	450	390	130	700	7.8	50	2
—	—	—	—	118	0	78	3.0	17	298	194	98	370	6.9	200	1
—	—	—	—	284	0	80	7.0	2.6	384	320	87	589	7.9	—	1
—	—	—	—	130	0	43	1.0	4.9	246	160	54	297	7.6	180	1
67	22	4.6	2.2	242	0	65	7.0	—	340	258	59	503	7.4	—	1
82	26	45.8	3.7	285	0	59	69	1.0	540	310	77	750	7.7	75	2
94	23	7.8	1.6	220	0	125	15	13	440	330	150	640	7.6	90	2
75	16	15	1.5	205	0	85	27	7.5	368	255	87	590	7.9	80	2
85	21	9.2	.8	282	0	60	14	1.0	400	300	69	580	7.5	100	2
—	—	—	—	260	0	152	26	38	574	420	207	793	7.2	25	1
—	—	—	—	352	0	164	30	.2	604	469	180	938	7.4	—	1
67	23	7.3	1.3	278	0	41	8.0	—	307	262	34	513	7.0	—	1
64	18	4.6	1.2	254	0	33	3	0	270	236	34	450	8.0	15	2
86	22	5.7	.8	254	0	100	7	4	376	305	97	540	7.7	35	2
76	20	6.0	1.2	258	0	58	13	2.0	328	270	59	530	8.1	40	2
80	20	5.1	.8	303	0	32	5	0	350	280	32	540	7.9	60	2
76	23	36	3.5	290	0	66	41	2.0	430	284	46	700	7.9	25	2
86	22	13	1.6	234	0	110	17	12	420	305	114	600	7.7	40	2
72	18	8.3	2.6	222	0	73	14	6.4	352	225	43	520	8.0	60	2
74	18	8.5	1.2	270	0	33	11	1.5	370	260	39	520	7.8	70	2
—	—	—	—	166	0	26	2.0	1.6	196	164	28	317	7.3	115	1
78	12	4.2	1.3	262	0	35	5.0	—	282	244	30	472	7.0	—	1
64	23	3.7	.9	259	0	42	3	2.0	318	255	43	500	7.9	30	2
76	19	4.6	.8	244	0	63	3	5.0	330	270	70	510	7.9	70	2
64	17	3.5	1.2	230	0	43	5	1.2	276	230	42	450	8.1	60	2
68	17	2.8	.8	240	Tr.	23	0	.8	296	240	23	450	8.4	70	2
the Red Cedar River															
79	25	37	4.6	334	0	57	42	—	443	300	26	729	7.0	—	1
—	—	—	—	337	0	71	7.0	2.1	414	355	78	630	8.1	—	1
—	—	—	—	216	0	83	6.0	30	428	290	113	523	7.7	150	1
—	—	—	—	362	0	98	18	.5	488	404	107	787	7.6	—	1
88	27	11	2.9	317	0	52	15	5.0	422	330	70	610	7.5	55	2
94	24	5.8	1.0	305	0	70	11	10	420	333	83	610	7.6	110	2
76	19	4.6	2.0	265	0	55	10	4.4	340	270	53	530	7.9	90	2
92	28	7.8	1.6	350	0	63	7.0	2.2	420	345	59	620	8.2	55	2
—	—	—	—	348	0	117	12	4.1	496	420	135	746	8.1	—	1
—	—	—	—	190	0	82	10	23	318	260	104	493	7.3	150	1
—	—	8.0	—	364	0	82	10	.2	452	396	98	713	7.9	—	1
—	—	—	—	380	0	153	14	4.4	592	490	178	856	7.7	—	1
to the Maple River															
92	22	7.0	2.0	296	0	78	5.0	0.0	670	320	78	600	7.9	40	2
102	27	6.9	1.7	320	0	100	10	5.6	460	365	103	680	7.8	70	2
90	25	6.9	1.6	310	0	78	10	2.0	400	330	76	630	7.9	40	2
98	30	8.5	1.2	360	0	75	7.0	1.5	430	370	75	700	8.0	25	2
—	—	—	—	333	0	96	14	1.5	425	372	98	703	8.0	—	1
—	—	—	—	362	0	54	5.0	2.2	413	360	63	637	7.9	—	1
—	—	—	—	238	0	60	5.0	4.6	354	268	72	486	7.2	150	1
90	32	11	—	348	0	83	8.0	.0	424	355	70	720	7.8	10	2
73	31	18	6.3	308	0	72	19	—	395	310	58	652	7.1	—	2
94	28	14	6.1	248	0	149	20	—	483	350	147	713	7.0	—	1
63	26	25	5.3	230	0	76	38	—	410	264	76	617	7.0	—	1
—	—	—	—	176	0	45	12	—	—	212	68	400	7.9	—	1
—	—	—	—	290	0	51	18	4.9	372	300	62	582	7.5	25	1
—	—	—	—	332	0	94	30	15	534	410	138	764	7.8	—	1
—	—	—	—	160	0	44	16	28	308	206	75	424	8.0	60	1
—	—	—	—	308	0	122	28	14	494	390	137	774	7.9	—	1
—	—	—	—	174	0	56	18	29	330	236	94	481	7.4	60	1
—	—	—	—	280	0	49	8.0	16	346	305	75	549	8.0	—	1
—	—	—	—	216	10	60	13	37	382	294	100	546	8.5	22	1

TABLE 3.—*Chemical analyses*

Station Number	Source	Location	Date sampled	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)
				Streams tributary to the		
4-1151.0	Hayworth Creek	SW¼ sec. 7, T. 8 N., R. 3 W.	Sept. 2, 1959	R	12	0.20
			Dec. 16, 1959	R	5.0	.40
			Apr. 20, 1960	R	2.0	.20
			July 8, 1960	B	6.0	.30
			Sept. 19, 1963	6.29	—	—
.1	Maple River	SW¼ sec. 6, T. 8 N., R. 3 W.	Sept. 2, 1959	R	12	.0
			Dec. 16, 1959	R	5	.6
			Apr. 20, 1960	R	2	.2
			July 8, 1960	B	6	1.5
1156.0	Fish Creek	NE¼ sec. 36, T. 9 N., R. 5 W	Sept. 19, 1963	34.7	—	—
.8	Stony Creek	SW¼ sec. 36, T. 7 N., R. 2 W	July 10, 1967	B	—	—
.95	Spalding Drain	NE¼ sec. 30, T. 7 N., R. 2 W	July 10, 1967	R	—	—
			June 30, 1968	R	—	.05
1157.0	Stony Creek	SE¼ sec. 26, T. 7 N., R. 3 W	Oct. 5, 1964	3.09	—	—
.3	Stony Creek	NE¼ sec. 33, T. 7 N., R. 3 W	July 10, 1967	B	—	—
			June 30, 1968	R	—	.13
.6	Muskrat Creek	SE¼ sec. 31, T. 7 N., R. 3 W.	Sept. 2, 1959	R	14	.50
			Dec. 16, 1959	R	7.0	.90
			Apr. 20, 1960	R	4.0	.30
			July 8, 1960	B	6.0	.10
			Oct. 5, 1964	2.28	—	—
.85	Fuller Creek	NW¼ sec. 28, T. 7 N., R. 4 W	July 10, 1967	B	—	—
			June 30, 1968	R	—	.08
.9	Stony Creek	SW¼ sec. 21, T. 7 N., R. 4 W	Sept. 2, 1959	R	13	.90
			Dec. 19, 1959	R	8.0	.60
			Apr. 20, 1960	R	4.0	.40
			July 8, 1960	B	4.0	.50
1158.0	Stony Creek	NE¼ sec. 24, T. 7 N., R. 5 W	Sept. 19, 1963	9.06	—	—
				Streams tributary to		
4-1167.0	Thornapple River.	SE¼ sec. 7, T. 3 N., R. 4 W.	Oct. 6, 1964	8.36	—	—
1168.0	Thornapple River.	NE¼ sec. 25, T. 3 N., R. 6 W	Sept. 19, 1963	8.77	—	0.20
.05	Unnamed tributary to Thornapple River.	SE¼ sec. 36, T. 3 N., R. 6 W	July 10, 1967	B	—	—
.1	Thornapple River.	SE¼ sec. 26, T. 3 N., R. 6 W.	Dec. 3, 1962	B	7.0	.30
			Apr. 1, 1963	R	—	.40
.2	Shanty Brook	SE¼ sec. 33, T. 3 N., R. 6 W	July 10, 1967	B	—	—
1170.0	Quaker Brook	NW¼ sec. 13, T. 2 N., R. 7 W	Sept. 26, 1963	1.30	—	.33

In general, streams in the Tri-County region (table 3) are within the chemical-quality standards set by the Water Resources Commission, and the streams are, from a chemical standpoint, suitable for most uses. It is important to note that a stream that is chemically suited for an intended use may not be bacteriologically suited for that use. Table 3 does not list the concentration and types of bacteria in the water.

GROUND WATER

Most water obtained from the fresh-water aquifers of the region is of the calcium-magnesium bicarbonate type. Some of the water *of stream water*—Continued

Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids (evaporated at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color (Hazen color unit)	Analyst
										Ca, Mg	Noncarbonate				
Maple River--Continued															
84	26	18	3.5	312	0	68	17	2.0	400	315	59	640	8.1	15	2
100	29	12	2.4	286	0	120	18	16	486	370	136	710	7.7	25	2
96	28	9.2	2.2	288	0	110	18	9.2	450	355	119	700	7.8	15	2
86	28	14	2.0	315	0	88	13	3.0	424	330	72	630	8.0	20	2
79	31	26	4.2	316	0	83	28	—	438	325	66	706	7.2	—	1
64	32	17	4.5	288	0	67	22	5.0	448	290	54	640	7.6	35	2
94	29	12	2.4	350	0	10	14	16	420	310	119	610	7.6	25	2
74	22	7.0	2.3	240	0	75	5	6.4	344	276	79	550	7.9	20	2
94	29	12	2.4	350	0	70	14	0	472	355	68	864	7.9	50	2
70	25	17	1.9	254	0	54	38	—	360	278	70	598	7.2	—	1
—	—	—	—	282	10	88	10	5.0	406	340	92	625	8.4	—	1
—	—	—	—	358	0	135	20	5.2	543	450	156	810	8.2	—	1
—	—	—	—	168	0	56	14	28	326	226	88	446	7.2	70	1
—	—	—	—	362	0	95	12	.4	450	392	95	714	8.2	—	1
—	—	—	—	338	0	98	14	4.8	466	385	108	708	7.8	—	1
—	—	—	—	166	0	59	10	21	314	222	86	431	7.3	90	1
85	37	8.7	3.1	361	0	75	5.0	4.0	438	364	68	660	7.6	25	2
90	27	6.0	2.3	264	0	105	9.0	15	440	335	119	620	7.6	90	2
80	24	4.6	2.4	255	0	90	8.0	7.2	374	300	91	600	7.9	70	2
88	34	12	2.0	380	0	73	4.0	2.5	428	360	48	680	8.2	20	2
—	—	—	—	382	0	85	6.0	.7	449	392	78	714	8.2	—	1
—	—	—	—	330	0	122	24	1.4	493	400	129	768	7.9	—	1
—	—	—	—	196	0	48	10	16	298	226	66	444	7.3	60	1
70	36	8.3	3.7	327	0	57	7.0	5.0	432	325	57	600	7.8	30	2
98	29	7.4	2.3	286	0	105	12	25	468	365	131	680	7.8	70	2
86	24	6.0	2.0	268	0	90	11	8.8	386	315	95	600	7.9	50	2
84	33	11	2.0	340	0	79	6.0	1.0	340	345	67	630	8.3	25	2
66	32	11	3.2	306	0	55	10	—	352	296	45	573	7.3	—	1
the Thornapple River															
—	—	—	—	355	0	125	16	0.6	514	442	151	777	8.2	—	1
119	6.9	7.7	1.8	328	0	59	8.0	—	392	326	56	620	7.1	—	1
—	—	—	—	304	0	65	10	3.6	386	325	76	591	7.9	—	1
94	29	5.8	1.3	352	0	70	8.0	1.0	410	355	67	620	8.0	10	2
110	29	5.8	1.8	285	0	137	10	18	480	395	162	700	7.8	—	2
—	—	—	—	364	0	36	7.0	2.1	374	335	36	607	8.2	—	1
76	27	5.0	1.3	306	0	61	4.0	—	346	301	50	558	7.6	—	1

also contains significant concentrations of chloride, sulfate, and sodium. These six ions constitute over 98 percent of all dissolved solids in the ground water (table 5). Iron is in all ground water and commonly is in objectionable concentrations.

The graphs in figure 23 show the percentage of wells for which given values of hardness, iron, or dissolved-solids concentration are equaled or exceeded; these values vary considerably over the region. For example, one-half of the wells yield water having a hardness concentration greater than 315 mg/l (milligrams per liter). Only 5 percent of the wells yield water having a hardness concentration greater than 440 mg/l.

TABLE 4.—*Water-quality*

[From standards proposed by

Water uses	Parameters: Total dissolved solids	Temperature	Suspended, colloidal, and settleable materials and residues
Water supply	Shall not exceed 500 mg/l as a monthly average, nor exceed 750 mg/l at any time.	The maximum natural water temperature shall not be increased by more than 10°F.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use. No residues or floating solids of unnatural origin.
Fish, wildlife, and other aquatic life.	None established	In general, the ambient temperature range must be from 32°F to the natural maximum; the maximum limit ranges from 70°F for cold-water fish to 87°F for some warm-water fish.	Same as for "Water supply."
Recreation	Limited to concentrations less than those which are or may become injurious to the designated use.	90°F maximum	do
Agricultural	Less than 700 mg/l	Not applicable	do
Commercial and industrial.	*Commercial:* Same as for "Recreation." *Industrial:* Same as for "Water supply."	Same as for "Water supply."	do

standards for streams

the State of Michigan, 1969]

Parameters—Continued			
Taste and odor producing substances and nutrients	Toxic and deleterious substances	Dissolved oxygen	Hydrogen ion (pH)
Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use. Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent adverse effects on water treatment processes or the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Must conform to current U.S. Public Health Service drinking water standards except: *Cyanide:* Normally not detectable with a maximum upper limit of 0.2 mg/l. *Chromium:* Normally not detectable with a maximum upper limit of 0.05 mg/l.	Present at all times in sufficient quantities to prevent nuisance.	pH shall not have an induced variation of more than 0.5 unit as a result of unnatural sources.
Same as for "Water supply" with the designated use being for fish or game.	Not to exceed one-tenth of the 96-hour median tolerance limit obtained from continuous flow bioassays where the dilution water and toxicant are continuously renewed except in specific cases when justified and approved by the appropriate agency.	At the average 7-day Q_{10} the following dissolved-oxygen values shall be maintained in rivers capable of supporting: *Intolerant, cold-water fish:* Not less than 6 mg/l at any time. *Intolerant, warm-water fish:* Average daily not less than 5 mg/l nor any single value less than 4 mg/l. *Tolerant fish:* Average daily not less than 4 mg/l nor any single value less than 3 mg/l. At greater flows the dissolved-oxygen content shall be in excess of these values.	Maintained between 6.5 and 8.8 with a maximum artificially induced variation of 1.0 unit within this range. Changes in the pH of natural waters outside these values must be toward neutrality (7.0).
Same as for "Water supply" except as it applies to water-treatment processes.	Limited to concentrations less than those which are or may become injurious to the designated use.	Same as for "Water supply."	Maintained within the range 6.5–8.8 with a maximum induced variation of 0.5 unit within this range.
Same as for "Recreation." Also, NO_3 concentrations shall conform to U.S. Public Health Service drinking water standards.	Conform to current U.S. Public Health Service drinking water standards as related to toxicants. Toxic and deleterious substances shall be less than those which are or may become injurious to the designated use.	Not less than 3 mg/l at any time.	Same as for "Water supply."
Same as for "Recreation"	Same as for "Recreation."	*Commercial:* Average daily not less than 2.5 mg/l nor any single value less than 2 mg/l. *Industrial:* Same as for "Water supply."	Same as for "Recreation."

TABLE 5.—*Chemical*

[Result in milligrams per

Local well No.: Numbers consist of five principal parts. For example, the number 05N 01W range; 14, designating section; ABAA, designating location within the section; and 1, section into quadrants which are then lettered counterclockwise as A, B, C, and D. The the well site to a 2.5-acre tract of land. Individual wells are numbered in sequential order
Aquifer: N1SA, Saginaw Formation; QGOO, glacial drift; N3GR, Grand River Formation;
Analyst: 1, U.S. Geol. Survey. 2, Mich. Dept. Public Health; 3, Mich. State Univ. Dept. of

Local well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
								Clinton
05N 01W 14ABAA-1	505	N1SA	3-11-65	45	----	1.0	----	----
17DBDD-2	378	QGOO	3-11-65	----	----	----	----	----
18CBC-1	220	N1SA	11-30-67	----	----	.40	67	14
23CDDB-1	300	N1SA	3-11-65	42	----	2.4	----	----
26ABBB-1	76	QGOO	3-11-65	----	----	3.0	----	----
29CD-1	161	N1SA	3- 9-45	----	8.6	5.0	64	23
02W 05AC-1	200	N1SA	1-17-45	----	17	3.0	73	29
09BBC-1	44	QGOO	6-26-67	----	----	4.4	85	28
13CC-1	160	N1SA	1-22-45	----	6.0	.30	61	19
16AAAA-1	260	N1SA	6-22-67	----	----	.90	55	14
18DCD-1	215	N1SA	6-22-67	----	----	.60	58	19
20DB-1	217	N1SA	1-17-45	----	4.6	.60	62	16
22BB-1	192	N1SA	1-18-45	----	12	.40	71	29
DCDA-1	225	N1SA	4- 4-68	----	----	.49	68	20
DCDC-1	230	N1SA	3-28-68	----	----	.10	62	22
27CAAA-1	85	QGOO	3-28-68	----	----	3.8	106	34
CBDB-1	240	N1SA	3-28-68	----	----	2.4	57	13
CCAB-1	105	QGOO	4- 4-68	----	----	7.2	76	18
CCAD-1	240	N1SA	3-28-68	----	----	.80	83	25
CDBA-1	92	QGOO	3-28-68	----	----	1.3	80	21
28BBDA-1	190	N1SA	4- 4-68	----	----	2.0	93	24
DCAC-1	200	N1SA	3-28-68	----	----	3.0	129	38
29DC-1	135	N1SA	3- 6-45	----	7.8	.60	77	20
33ABAB-1	245	N1SA	3-28-68	----	----	.70	127	34
ACB-1	200	N1SA	3-28-68	----	----	.45	74	20
BAAA-1	235	N1SA	3-28-68	----	----	1.2	184	42
CDDB-1	231	N1SA	4- 4-68	----	----	4.5	178	51
35AB-1	180	N1SA	3- 1-45	----	7.2	1.5	40	24
03W 05CCDD-1	180	N3GR	6-13-68	----	----	.73	60	26
10BA-1	279	N1SA	1-18-45	----	16	.60	97	38
13DC-1	178	N1SA	1-18-45	----	7.6	.30	64	23
15BBCC-1	160	N1SA	6-13-68	----	----	.60	100	33
CD-1	168	N1SA	3- 7-45	----	13	.30	76	26
18AABB-1	154	N1SA	6-13-68	----	----	1.8	90	32
CCAA-1	140	N1SA	6-13-68	----	----	.47	82	27
21BBB-1	220	N1SA	6-22-67	----	----	.60	70	26
23BABB-1	180	N1SA	6-13-68	----	----	.43	77	25
24DC-1	187	N1SA	3- 1-45	----	10	.50	62	25
27BCBB-1	142	N1SA	6-13-68	----	----	1.8	93	22
29AA-1	164	N1SA	3- 7-45	----	15	.40	109	29
31CBCB-1	140	N1SA	8- 8-67	----	----	----	----	----
32DC-1	268	N1SA	1-16-45	----	14	5.0	99	34
04W 12DDDD-1	140	N1SA	6-22-67	----	----	2.5	115	53
16ACBA-1	140	N1SA	6- 6-68	----	----	1.6	82	32
18CBDA-1	165	N1SA	6- 6-68	----	----	.95	78	28
DAAA-1	120	N3GR	2-16-65	----	----	2.4	----	----
19DADD-1	393	N1SA	2-16-65	42	----	----	----	----
21ADCD-1	305	N1SA	6-13-68	----	----	.79	78	28
BDAC-1	155	N1SA	6-13-68	----	----	1.2	96	40
24ABBB-1	170	N1SA	6-13-68	----	----	.79	86	30
06N 01W 12BDBD-1	69	QGOO	6-23-67	----	----	2.3	80	28
14DBDD-1	250	N1SA, N3GR	11-30-67	----	----	.58	52	20
19ACDC-1	200	N1SA	11-30-67	----	----	4.5	82	33
02W 09CCBC-1	200	N3GR	7-11-68	----	----	.25	70	32

analyses of ground water

liter except as indicated]

14ABAA–1 can be broken down as follows: 05N, designating township; 01W, designating designating individual well. Location within the section is accomplished by dividing the smaller quadrants are subdivided similarly. The four letters "ABAA" in the example define within the smallest designated tract.
M1MA, Marshall Formation; M3MI, Michigan Formation; M3BA, Bayport Formation.
Geology.

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids		Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Analyst
							Calculated	Evaporated at 180°C	Carbonate	Noncarbonate			
County													
----	----	310	55	12	----	----	----	----	260	6	591	7.6	1
----	----	308	27	2.0	----	0.9	----	----	264	11	518	7.5	1
18	4.9	305	9.0	3.2	----	----	278	----	225	0	----	7.62	3
----	----	284	35	5.0	----	.1	----	----	232	0	505	7.6	1
----	----	326	12	6.0	----	.2	----	----	262	0	521	7.5	1
12	----	332	5.3	4.0	----	----	----	281	257	0	----	----	1
5.8	----	365	8.9	4.0	----	----	----	317	302	2	----	----	1
6.5	1.4	395	27	2.5	----	.0	349	----	327	3	----	7.92	3
13	----	305	2.6	4.0	----	----	----	255	231	0	----	----	1
20	4.2	310	3.2	2.0	0.8	1.4	254	----	294	40	----	7.75	3
18	3.1	318	2.4	1.5	----	.0	260	----	223	0	----	7.55	3
17	----	301	2.0	4.0	----	----	----	253	219	0	----	----	1
8.3	----	374	2.5	4.0	----	----	----	311	297	0	----	----	1
9.0	3.2	312	8.0	1.3	----	----	264	----	252	0	----	7.70	3
20	3.6	308	19	5.9	----	----	285	----	246	0	----	7.19	3
25	1.6	354	81	48	----	----	473	----	405	115	----	7.15	3
21	4.4	290	13	1.5	----	----	256	----	196	0	----	7.19	3
12	4.2	307	37	2.0	----	----	305	----	264	12	----	7.62	3
9.0	3.0	385	8.0	1.2	----	----	320	----	310	0	----	7.10	3
12	3.7	351	17	1.5	----	----	310	----	286	0	----	7.25	3
9.0	2.0	329	94	4.3	----	----	389	----	331	61	----	7.56	3
7.5	1.8	417	140	6.7	----	----	532	----	478	136	----	7.12	3
10	----	307	29	9.0	----	----	----	303	273	21	----	----	1
8.0	4.4	346	170	1.9	----	----	517	----	458	174	----	7.23	3
8.0	2.3	317	22	1.4	----	----	284	----	267	7	----	7.20	3
14	7.2	361	340	7.5	----	----	774	----	632	336	----	7.18	3
10	2.5	519	240	25	----	----	767	----	654	228	----	7.20	3
29	----	312	7.2	5.0	----	----	----	309	200	0	----	----	1
14	1.9	351	11	1.2	----	----	288	----	257	0	----	7.50	3
1.9	----	425	27	4.0	----	----	----	407	400	29	----	----	1
12	----	333	2.5	5.0	----	----	----	279	256	0	----	----	1
4.0	1.5	461	8.0	1.3	----	----	376	----	386	8	----	7.28	3
4.4	----	358	5.1	4.0	----	----	----	304	295	1	----	----	1
9.5	2.2	454	9.0	1.1	----	----	370	----	357	0	----	7.40	3
5.5	2.1	405	9.0	1.0	----	----	328	----	316	0	----	7.22	3
14	4.3	400	6.8	2.0	----	.0	321	----	282	0	----	7.72	3
15	4.8	386	9.0	1.6	----	----	323	----	295	0	----	7.40	3
18	----	354	1.8	5.0	----	----	----	297	260	0	----	----	1
4.0	1.8	318	42	1.9	----	----	324	----	323	61	----	7.52	3
5.2	----	478	6.4	4.0	----	----	----	440	323	1	----	----	1
----	----	394	3.6	4.0	----	----	----	321	290	0	558	7.7	1
2.5	----	466	5.9	2.0	----	----	----	386	386	4	----	----	1
12	2.2	635	44	3.0	----	.0	547	----	506	0	----	7.50	3
7.5	1.6	434	12	1.1	----	----	352	----	337	0	----	7.22	3
6.0	1.2	380	11	1.7	----	----	314	----	310	0	----	7.78	3
----	----	410	13	1.0	----	.4	----	----	342	6	625	7.6	1
----	----	370	434	120	----	2.0	----	----	266	0	1,820	7.6	1
9.5	1.8	412	11	1.2	----	----	334	----	310	0	----	7.35	3
12	1.9	462	49	14	----	----	443	----	406	26	----	7.40	3
7.0	1.2	405	46	2.8	----	----	374	----	338	6	----	7.62	3
7.5	1.3	394	24	5.0	----	.0	342	----	315	0	----	7.52	3
14	3.4	307	2.0	1.8	----	----	245	----	212	0	----	7.55	3
8.0	1.6	440	1.0	1.2	----	----	348	----	341	0	----	7.60	3
13	2.4	392	11	1.2	----	----	325	----	306	0	----	7.25	3

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
Clinton County								
06N 02W 09DCCC–1	265	N1SA	7–11–68	----	----	0.52	58	30
14CBBB–1	200	N3GR	6–18–68	----	----	1.4	77	36
22DAAA–1	255	N3GR	6–18–68	----	----	2.4	56	26
23CAAA–1	180	N3GR	6–18–68	----	----	3.5	82	34
24ACCD–1	230	N3GR	6–18–68	----	----	.20	62	18
ADDC–1	56	QGOO	6–18–68	----	----	13	102	32
28ADAA–1	250	N3GR	6–18–68	----	----	1.8	79	24
29BAAA–1	205	N1SA, N3GR	2– 8–68	----	----	.31	74	28
–2	70	QGOO	2– 8–68	----	----	1.7	92	36
30CDDD–1	225	N1SA	7–11–68	----	----	.69	78	36
03W 08BAB–1	57	QGOO	6–23–67	----	----	1.2	65	26
13AAAA–1	204	N1SA, N3GR	7–11–68	----	----	.90	56	23
15BABB–1	135	N3GR	7–11–68	----	----	1.2	84	31
36DDAA–2	230	N3GR	6–18–68	----	----	2.6	82	29
04W 04CCC–1	462	N1SA	10–25–56	----	11	.75	88	29
	462	N1SA	8– 6–63	----	13	1.1	84	32
CCCC–2	355	N1SA	9–20–57	----	11	.75	81	32
	355	N1SA	8– 6–63	----	13	.60	84	30
05AAAA–1	67	QGOO	6– 6–68	----	----	3.2	86	35
23BABB–1	305	N1SA	2– 8–68	----	----	1.2	80	36
25ACB–1	111	QGOO	6–23–67	----	----	3.0	92	41
34CCBB–1	340	N1SA	6– 6–68	----	----	.70	75	36
07N 01W 12DBCA–1	346	N1SA	12– 7–54	----	9.0	.00	74	28
	346	N1SA	9– 7–61	----	10	.40	74	27
	346	N1SA	5–15–64	----	10	.30	76	23
30DAA–1	220	N1SA, N3GR	6–26–67	----	----	.20	75	38
02W 03BDAA–1	137	N3GR	2–18–65	----	----	3.6	----	----
09BCAD–1	500	N1SA	12–11–57	----	11	.20	62	26
BCBC–1	501	N1SA	1– 7–55	----	8.0	.35	56	30
CBBA–2	525	N1SA	6–18–54	52	12	.34	66	29
	550	N1SA	1– 7–55	----	9.0	.30	58	29
13BAA–1	250	N1SA	2– 1–68	----	----	.26	34	10
15CBAA–1	303	N1SA	2– 1–68	----	----	.51	62	30
CBAB–1	41	QGOO	2– 1–68	----	----	6.0	111	46
36CDDD–1	260	N1SA	6–26–67	----	----	.60	38	38
03W 13ADDD–1	138	QGOO	7–11–68	----	----	.34	35	12
14BBBB–1	380	N1SA	7–11–68	----	----	.44	53	21
16BBBA–1	235	N1SA	7–11–68	----	----	1.2	68	19
22CCCD–1	203	N1SA	2–16–65	----	----	.82	----	----
27DDDD–1	230	N1SA	7–11–68	----	----	.14	13	4.5
	260	N1SA	3– 8–66	----	----	----	----	----
30BABB–1	547	N1SA	2–16–65	----	----	4.3	----	----
33ADDA–1	272	N1SA	2–16–65	----	----	.74	----	----
35CCCB–1	340	N1SA	10–12–66	----	----	----	----	----
04W 08DDCC–1	64	QGOO	6–25–67	----	----	.90	130	43
10BAAA–1	105	QGOO	2– 1–65	----	----	.64	----	----
11DACD–1	366	N1SA	1– 3–57	----	7.0	.10	18	5.4
16DAAD–1	307	N1SA, N3GR	2–16–65	----	----	1.8	----	----
24DDDB–1	185	QGOO	2– 8–68	----	----	1.8	88	49
30BAD–1	75	QGOO	6– 6–68	----	----	.40	75	26
08N 01W 01CDCC–1	223	N1SA	5– 2–61	----	----	.34	62	20
08DBCA–1	200	N3GR	4–13–61	----	----	1.0	79	32
09ADD–1	250	N1SA, N3GR	2– 1–68	----	----	.45	80	31
11CBCC–1	299	N1SA	5– 2–61	----	----	2.9	92	21
	71	N1GR	5– 2–61	----	----	.38	67	22
12BBCB–1	325	N1SA N3GR	10–12–66	----	12	1.2	68	22

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Evaporated at 180°C	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Analyst
--Continued													
24	2.8	389	9.0	1.6	----	----	320	----	268	0	----	7.35	3
13	2.2	480	9.0	1.0	----	----	377	----	340	0	----	7.50	3
16	2.0	361	7.0	1.0	----	----	288	----	247	0	----	7.90	3
16	1.8	471	19	2.1	----	----	363	----	345	0	----	7.40	3
30	2.6	316	9.0	1.5	----	----	280	----	238	0	----	7.60	3
12	1.4	482	12	3.4	----	----	401	----	387	0	----	7.57	3
6.5	1.8	390	7.0	1.0	----	----	313	----	296	0	----	7.56	3
6.5	2.0	394	3.0	1.2	----	----	309	----	300	0	----	7.60	3
15	1.7	464	17	16	----	----	408	----	378	0	----	7.40	3
11	2.0	426	21	.8	----	----	360	----	343	0	----	7.30	3
16	1.8	361	13	2.0	----	0.0	303	----	269	0	----	7.75	3
44	3.1	376	25	5.0	----	----	344	----	234	0	----	7.42	3
13	3.4	407	36	3.5	----	----	374	----	337	7	----	7.75	3
15	1.4	402	23	5.3	----	----	358	----	324	0	----	7.49	3
12	1.5	422	7.0	1.0	0.1	.0	----	362	340	0	600	7.4	2
13	1.5	435	22	----	.3	.0	----	386	340	0	620	7.4	2
10	1.6	430	8.0	1.0	.0	.0	----	356	335	----	620	7.3	2
11	1.4	435	10	.0	.2	.0	----	364	335	----	600	7.3	2
16	1.8	436	22	7.1	----	----	386	----	359	1	----	7.4	3
18	2.7	462	16	2.2	----	----	386	----	348	0	----	7.46	3
11	2.0	512	22	2.0	----	----	429	----	398	0	----	7.60	3
18	3.7	452	19	1.5	----	----	377	----	373	2	----	7.42	3
----	----	354	53	22	.0	.0	----	414	300	10	740	7.8	2
31	2.0	350	45	20	.0	.0	----	392	295	8	700	7.4	2
29	2.2	340	45	17	.2	.0	----	358	285	6	630	7.4	2
12	2.1	465	14	1.5	----	.0	372	----	343	0	----	7.60	3
----	----	230	12	3.0	----	.7	----	----	102	0	383	7.9	1
35	2.1	340	37	10	.4	.0	----	350	260	----	620	7.4	2
----	----	356	47	18	.1	----	----	400	265	----	720	7.5	2
45	2.0	362	53	22	.4	.3	408	404	283	0	692	7.4	1
----	----	356	40	20	.2	.0	----	394	265	----	720	7.4	2
46	3.8	239	33	3.2	----	----	247	----	126	0	----	7.72	3
21	2.4	398	4.0	1.8	----	----	319	----	278	0	----	7.47	3
13	1.6	484	76	23	----	----	512	----	466	69	----	7.30	3
26	2.6	393	13	1.5	----	.0	314	----	251	0	----	7.65	3
40	1.8	261	12	1.7	----	----	233	----	137	0	----	7.60	3
55	4.0	390	23	9.1	----	----	360	----	218	0	----	7.39	3
84	4.3	317	200	9.2	----	----	541	----	248	0	----	7.51	3
----	----	355	96	90	----	.7	----	----	246	0	1,020	7.9	1
295	3.8	460	170	104	----	----	819	----	41	0	----	8.20	3
89	----	366	52	33	----	.3	----	430	200	0	738	7.7	1
----	----	422	168	65	----	1.0	----	----	242	0	1,150	7.8	1
----	----	352	30	16	----	1.2	----	----	316	27	627	7.8	1
----	----	316	1,830	3,030	----	----	----	8,040	364	105	12,400	7.9	1
10	1.3	420	57	94	----	.0	542	----	500	156	----	7.70	3
----	----	320	63	3.5	----	2.1	----	----	194	0	609	7.7	1
210	2.0	507	70	23	1.0	.0	----	580	66	0	1,000	8.0	2
----	----	525	62	4.0	----	2.0	----	----	438	8	870	7.5	1
26	2.6	546	37	2.0	----	----	477	----	422	0	----	7.45	3
8.0	1.2	364	18	1.4	----	----	309	----	294	0	----	7.40	3
14	1.5	285	8.4	12	----	----	----	301	237	3	483	7.5	1
14	1.4	398	24	10	----	----	----	359	329	2	653	7.3	1
38	3.5	379	61	34	----	----	435	----	328	17	----	7.29	3
33	4.5	300	75	46	----	----	----	466	316	70	736	7.5	1
8.6	1.1	325	11	.0	----	----	----	285	258	0	487	7.5	1
4.6	.8	296	20	8.0	.0	----	----	300	260	17	500	7.7	2

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
Clinton County								
08N 01W 13BCC-1	61	QGOO	11-27-51	----	12	0.25	70	29
	61	QGOO	11-26-52	----	----	----	----	----
	61	QGOO	2-10-54	51	----	----	----	----
	61	QGOO	10-12-54	51	----	----	----	----
	61	QGOO	12-30-59	----	15	.70	64	26
BDC-1	57	QGOO	5-24-49	----	12	3.2	98	33
	57	QGOO	2-10-54	50	----	----	----	----
	57	QGOO	10-12-54	52	----	----	----	----
	57	QGOO	4- 7-55	48	----	----	----	----
	57	QGOO	12-12-56	51	----	----	----	----
	57	QGOO	12-30-59	----	6.0	.00	110	32
14AAAA-1	341	N1SA	8-19-53	52	8.0	.55	96	28
	341	N1SA	2-10-54	52	----	----	----	----
	341	N1SA	10-12-54	52	----	----	----	----
	341	N1SA	12-30-59	----	10	.70	102	24
ABAA-1	299	N1SA	10-12-54	52	7.5	.38	92	24
15CBB-1	209	N3GR	5- 2-61	----	----	.34	35	8.8
19DADD-1	129	QGOO	2- 1-68	----	----	.83	70	35
21BCCD-1	210	N1SA	4-13-61	----	----	.34	70	32
24AADD-1	38	QGOO	5- 2-61	----	----	.89	96	25
27DDC-1	30	QGOO	5- 2-61	----	----	1.7	87	26
29CDCD-1	215	N1SA	4-13-61	----	----	----	66	32
35AADD-1	38	QGOO	2- 1-68	----	----	1.4	96	31
02W 09ADDD-1	260	N1SA	2- 8-68	----	----	.92	51	25
31AADD-1	380	N1SA	2- 1-68	----	----	.56	72	32
03W 08BA-2	228	N1SA	1- 3-57	----	10	.00	158	45
	228	N1SA	6- 3-64	----	10	.10	188	46
BAB-1	166	QGOO	9-20-57	----	12	.10	84	27
	166	QGOO	6- 3-64	----	12	.00	112	30
27CDDD-1	320	N1SA	6-26-67	----	----	1.2	65	23
32DAAD-1	340	N1SA	2- 8-68	----	----	.52	62	22
04W 02DCC-1	365	N1SA	2-16-65	----	----	3.4	----	----
06ADDD-1	95	QGOO	2- 8-68	----	----	1.4	66	22
CCC-1	375	QGOO	2-16-65	----	----	5.1	----	----
11BBC-1	132	QGOO	6-26-67	----	----	2.2	85	27
Ingham								
01N 01E 23DDDD-1	77	N1SA	10- 5-67	----	----	1.3	106	35
36BBCC-1	98	N1SA	9-29-64	----	----	----	98	34
01W 02CAAA-1	140	N1SA	10- 5-67	----	----	.77	59	14
17BBBB-1	100	N1SA	10- 5-67	----	----	2.0	85	26
28AADD-1	185	N1SA	4-11-61	----	11	.70	136	25
	223	N1SA	2- 8-62	----	11	.60	130	23
29DDAD-1	118	N1SA, QGOO	10- 5-67	----	----	1.9	90	28
02E 19ADC-1	70	N1SA	9-29-64	----	----	----	85	22
02W 29CAAC-1	178	N1SA	11- 9-67	----	----	.65	74	21
02N 01E 15DDBB-1	164	N1SA	10- 5-68	----	----	.80	87	25
25CDDA-1	136	N1SA	11- 5-68	----	----	.84	60	23
28DACC-1	120	N1SA	11- 5-68	----	----	.53	57	18
01W 05ACCC-1	218	N1SA	5-12-61	----	14	.30	80	27
DDAD-1	169	N1SA	10-26-59	----	----	----	130	33
08AACD-1	48	QGOO	1-23-53	54	----	.00	108	32
	48	QGOO	5-12-61	----	10	.10	120	35
09CBBB-1	43	QGOO	1-23-53	50	10	.00	108	30
	43	QGOO	4-10-62	----	8.0	.00	84	30
13BCBB-1	135	N1SA	10-17-68	----	----	.37	54	22
18DCCC-1	125	N1SA	10- 5-67	----	----	1.8	100	28
26BDBB-1	130	N1SA	10-17-68	----	----	.96	95	36
28CBBB-1	119	N1SA	10-17-68	----	----	1.2	90	28
02E 02ACDD-1	110	N1SA	10- 5-67	----	----	1.6	94	30
24DAAA-1	101	M1MA, M3MI	10- 5-67	----	----	1.9	114	36

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Evaporated at 180° C	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Analyst
--Continued													
32	2.1	312	53	39	0.6	0.0	----	400	----	----	605	7.9	2
----	----	---	50	34	----	----	----	----	260	----	690	----	2
----	----	310	48	36	----	----	----	----	280	26	720	----	2
----	----	318	45	36	----	----	----	----	280	19	700	----	2
23	1.6	296	47	21	.5	.0	----	360	265	22	590	7.7	2
----	----	332	110	24	.7	.0	----	472	380	108	----	----	2
----	----	325	43	29	----	----	----	----	300	33	710	----	2
----	----	333	73	29	----	----	----	----	325	52	750	----	2
----	----	316	150	28	----	----	----	----	425	166	870	----	2
----	----	325	57	30	----	----	----	----	310	43	725	----	2
5.8	2.0	290	120	18	.4	32	----	504	405	167	800	7.5	2
71	----	290	87	127	.4	.7	----	560	355	117	1,000	7.2	2
----	----	306	87	134	----	----	----	----	355	104	1,080	----	2
----	----	276	87	134	----	----	----	----	350	124	1,030	----	2
76	7.0	292	75	145	.2	.0	----	600	355	115	1,000	7.5	2
86	6.1	324	98	110	.2	.2	584	586	328	63	989	7.8	1
28	3.1	220	5.2	.0	----	----	----	208	124	0	344	7.7	1
14	2.3	419	13	3.4	----	----	307	----	319	0	----	7.44	3
11	1.1	380	12	5.0	----	----	----	314	306	0	587	7.8	1
4.1	1.4	330	69	11	----	----	----	402	343	72	640	7.5	1
4.1	.5	325	58	4.0	----	----	----	378	324	58	597	7.4	1
12	1.3	370	15	4.0	----	----	----	310	296	0	580	7.2	1
3.5	1.0	339	71	12	----	----	382	----	368	90	----	7.40	3
18	2.0	333	2.0	1.1	----	----	264	----	230	0	----	7.70	3
30	2.0	420	25	11	----	----	381	----	312	0	----	7.55	3
184	2.3	220	300	345	.0	.0	----	1,300	580	400	1,800	7.4	2
220	4.1	214	372	435	.0	1.7	----	1,512	670	494	2.380	7.6	2
29	.9	280	63	51	.0	3.0	----	446	315	85	730	7.5	2
81	2.0	264	143	150	.0	3.2	----	726	405	189	1,150	7.4	2
19	3.0	351	32	2.5	----	----	318	----	256	0	----	7.68	3
28	1.9	329	42	3.6	----	----	323	----	246	0	----	7.53	3
----	----	207	630	900	----	1.0	----	----	1,120	950	4,120	7.4	1
13	1.4	347	2.0	2.6	----	----	280	----	256	0	----	7.48	3
----	----	268	648	700	----	2.2	----	----	984	764	3,530	7.5	1
5.0	1.7	365	45	6.0	----	.0	351	----	323	23	----	7.70	3
County													
5.3	0.8	410	38	21	----	----	409	----	406	68	----	7.70	3
5.8	.7	406	49	8.0	----	----	----	408	385	52	699	7.4	1
6.6	4.6	272	3.0	.5	----	----	223	----	207	0	----	8.05	3
3.3	.7	330	51	3.9	----	----	335	----	317	47	----	7.80	3
5.1	1.6	370	155	.0	0.3	0.0	----	530	445	----	800	7.1	2
5.7	1.2	360	125	2.0	.0	.0	----	484	420	----	750	7.6	2
3.0	.9	366	32	2.6	----	----	338	----	337	37	----	7.85	3
6.1	1.1	228	108	6.0	----	----	----	382	303	116	583	7.6	1
3.3	2.1	329	16	1.0	----	----	280	----	271	1	----	7.60	3
20	6.8	434	11	3.2	----	----	368	----	320	0	----	7.80	3
6.0	1.1	324	3.0	.9	----	----	253	----	245	0	----	7.80	3
7.5	1.8	295	2.0	.9	----	----	231	----	226	0	----	7.51	3
4.6	1.0	374	6.0	8.0	.2	.0	----	344	310	----	580	7.4	2
25	8.4	392	172	14	----	----	----	616	460	139	890	6.8	1
----	----	356	80	44	.0	1.0	----	520	400	----	820	7.3	2
42	2.5	350	91	108	.0	4.5	----	620	442	----	1,000	7.4	2
11	----	361	93	18	.0	----	----	484	395	----	800	7.3	2
14	2.5	308	73	23	.0	1.5	----	400	335	----	670	7.3	2
32	7.4	376	.0	1.1	----	----	299	----	226	0	----	7.50	3
5.6	1.5	370	42	14	----	----	274	----	363	59	----	7.75	3
5.5	1.2	414	58	1.7	----	----	400	----	385	45	----	7.30	3
4.0	1.2	396	19	2.4	----	----	338	----	340	15	----	7.32	3
5.7	1.0	380	41	12	----	----	373	----	359	47	----	7.93	3
4.0	1.3	435	78	2.2	----	----	452	----	433	75	----	7.73	3

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aqui-fer	Date of collec-tion	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
						Ingham	County	
02N 02W 19AABA-1	160	N1SA	5- 2-68	----	----	0.38	80	30
03N 01E 02AAAA-3	167	N1SA	3-15-67	----	----	----	----	----
	167	N1SA	6-24-54	51	7.7	.25	33	11
	167	N1SA	10-29-58	----	7.0	.15	34	10
	165	N1SA	3-24-67	----	----	----	----	----
BBA-1	40	QGOO	2- 8-52	----	7.3	.90	60	18
	38	QGOO	10-29-58	----	9.0	2.5	86	22
08ABAB-1	185	N1SA	10-12-67	----	----	.35	47	12
DDCC-1	81	N1SA	10-12-67	----	----	1.2	80	30
12BCC-1	184	N1SA	3-15-67	----	----	----	----	----
	184	N1SA	10-17-68	----	----	1.1	90	30
22BAAD-1	110	N1SA	10-24-68	----	----	.70	65	25
32BBCC-1	100	N1SA	10-17-68	----	----	.57	72	28
34ADDD-1	165	N1SA	10-12-67	----	----	.35	44	15
BCB-1	32	QGOO	12-12-68	50	----	----	----	----
01W 17BBBC-1	172	N1SA	10-17-68	----	----	2.4	94	27
03BABB-1	280	N1SA	10-17-68	----	----	.77	91	30
07AAAA-1	150	N1SA	10-17-68	----	----	.44	82	28
10ABBC-1	240	N1SA	10-12-67	----	----	.40	75	29
15BBDA-1	200	N1SA	10-17-68	----	----	.37	88	27
23DCCC-1	235	N1SA	10-17-68	----	----	.63	90	30
25ADAA-1	110	N1SA	10-17-68	----	----	.77	90	32
29CCAA-1	110	N1SA	10-12-67	----	----	.80	94	30
31BBAA-1	96	N1SA	10-17-68	----	----	1.1	96	30
32ABAA-1	130	N1SA	10-17-68	----	----	.68	86	30
02E 04ACCC-1	180	N1SA	10-24-68	----	----	.60	85	31
06ADDD-1	200	N1SA	9-29-64	----	----	1.0	11	5.0
12BCAD-1	144	N1SA	10-12-67	----	----	1.9	84	27
15ABBC-1	140	N1SA	9-29-64	----	----	4.1	83	23
17ADDD-1	295	N1SA	10-12-67	----	----	.92	46	10
25CAAA-1	125	N1SA	10-24-68	----	----	.43	76	28
26CCDC-1	32	QGOO	12-12-68	50	----	2.1	----	----
02W 02DACC-1	90	QGOO	10-24-68	----	----	3.3	83	27
11ADAD-1	113	N1SA	11- 5-68	----	----	.61	75	25
18DCB-1	110	N1SA	11- 5-68	----	----	.70	65	21
	50	N1SA	11- 5-68	----	----	.88	86	32
19CCCB-1	100	N1SA	11- 5-68	----	----	.35	72	24
21CBB-2	118	N1SA	11- 5-68	----	----	.70	77	26
23ADBB-1	268	N1SA	10-14-59	----	14	2.2	87	30
BCDD-1	228	N1SA	10-14-59	----	----	----	24	27
CBAD-1	403	N1SA	6-13-68	----	13	.60	94	30
04N 01E 08DADA-1	344	N1SA	10-12-67	----	----	.95	68	18
11DCC-1	250	N1SA	10-12-67	----	----	.60	54	14
13CCAA-1	325	N1SA	4- 4-68	----	----	.78	124	24
20CCA-1	260	N1SA	4- 4-68	----	----	.46	74	14
CCAA-1	260	N1SA	4- 4-68	----	----	1.2	176	21
CCBC-1	235	N1SA	10-12-67	----	----	.80	80	10
01W 07CACD-1	392	N1SA	12-29-65	51	12	2.0	114	36
	392	N1SA	2-29-68	----	----	1.0	96	34
DBBC-1	385	N1SA	7-31-52	----	10	.40	80	30
	385	N1SA	4-23-53	51	----	----	----	----
	385	N1SA	4-26-54	51	----	----	----	----
	385	N1SA	11-19-59	----	17	2.9	116	44
	385	N1SA	5-12-61	----	14	.80	86	35
	385	N1SA	2-29-68	----	----	1.2	85	22
DCAB-1	380	N1SA	2- 8-52	----	10	----	82	36
	385	N1SA	4-26-54	51	----	----	----	----
	385	N1SA	5-12-61	----	13	.80	76	33
	380	N1SA	2-29-68	----	----	1.0	80	34
DDAD-1	391	N1SA	3-31-55	51	8.0	.50	82	22
	391	N1SA	2-29-68	----	----	4.0	106	38
08CCCA-1	411	N1SA	2-29-68	----	----	2.9	120	43

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids		Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH	Analyst
							Calculated	Evaporated at 180° C	Carbonate	Noncarbonate			
--Continued													
7.0	2.2	398	14	1.5	----	----	331	----	323	0	----	7.45	3
104	----	396	16	6.0	----	----	----	368	98	0	633	7.8	1
116	5.6	431	18	8.5	0.5	0.0	413	405	125	0	689	7.7	1
117	6.2	427	17	7.0	.1	.0	----	410	125	----	700	7.6	2
100	----	400	21	8.0	----	----	----	396	110	0	654	7.7	1
3.5	----	214	49	2.0	.0	.0	----	256	225	----	378	7.8	2
6.6	1.2	256	93	9.0	.0	.0	----	424	307	----	610	7.3	2
90	7.8	444	5.0	1.8	----	----	384	----	168	0	----	7.73	3
7.9	1.6	405	6.0	.8	----	----	327	----	322	0	----	7.65	3
8.6	----	246	9.2	4.0	----	.1	----	222	194	0	392	7.9	1
7.5	4.0	445	2.0	1.6	----	----	354	----	348	0	----	7.45	3
9.5	1.5	346	3.0	1.3	----	----	277	----	265	0	----	7.75	3
10	1.6	378	5.0	1.0	----	----	302	----	295	0	----	7.51	3
65	7.4	376	6.0	1.1	----	----	324	----	171	0	----	8.03	3
----	----	348	58	5.5	----	----	426	----	324	39	640	7.5	1
3.0	1.6	373	61	2.9	----	----	373	----	346	40	----	7.32	3
4.0	2.6	423	23	1.2	----	----	358	----	350	3	----	7.29	3
5.0	2.0	390	15	2.8	----	----	325	----	320	0	----	7.45	3
13	4.0	385	8.0	.8	----	----	321	----	306	0	----	7.75	3
8.5	6.0	436	3.0	1.0	----	----	346	----	331	0	----	7.33	3
11	5.6	441	11	1.5	----	----	366	----	348	0	----	7.25	3
7.5	1.6	414	18	1.1	----	----	352	----	357	17	----	7.20	3
5.0	1.4	354	73	5.1	----	----	385	----	361	71	----	7.83	3
3.0	.8	395	49	5.9	----	----	379	----	363	39	----	7.50	3
3.0	.6	334	79	5.7	----	----	367	----	338	64	----	7.65	3
9.0	3.1	432	1.0	.9	----	----	343	----	340	0	----	7.40	3
272	1.7	542	138	14	----	----	----	746	48	0	1,180	8.5	1
4.9	2.2	386	8.0	.7	----	----	319	----	320	4	----	7.90	3
6.1	8.5	384	1.6	1.0	----	----	----	316	302	0	577	7.4	1
90	8.4	382	25	16	----	----	384	----	156	0	----	7.70	3
13	6.4	399	7.0	3.7	----	----	330	----	305	0	----	7.32	3
----	----	342	18	1.5	----	----	338	----	268	0	520	7.6	1
3.0	.9	347	52	1.6	----	----	342	----	318	33	----	7.40	3
2.5	.9	344	2.0	.9	----	----	276	----	290	7	----	7.30	3
7.0	1.2	289	26	3.1	----	----	265	----	248	11	----	7.51	3
5.0	1.4	428	2.0	.8	----	----	337	----	347	0	----	7.50	3
5.0	1.8	322	18	1.7	----	----	281	----	279	15	----	7.42	3
4.0	.9	346	27	1.8	----	----	307	----	299	15	----	7.42	3
2.9	.6	370	34	7.0	----	.2	361	347	341	38	618	7.6	1
5.9	1.4	200	11	12	----	----	----	198	171	7	310	7.2	1
3.2	.9	390	55	4.0	.2	.0	----	438	360	----	640	7.1	2
29	5.2	368	4.0	1.0	----	----	308	----	244	0	----	7.50	3
16	4.4	327	5.0	.6	----	----	267	----	236	0	----	7.55	3
20	5.4	292	180	1.7	----	----	500	----	409	169	----	7.51	3
11	4.3	302	13	1.5	----	----	267	----	243	0	----	7.55	3
26	6.4	373	320	2.7	----	----	688	----	525	301	----	7.50	3
10	4.8	298	22	1.1	----	----	277	----	242	0	----	7.50	3
9.2	1.4	390	108	15	.5	.0	----	540	435	----	780	7.2	2
13	3.0	395	76	12	----	----	430	----	380	56	----	7.23	3
13	----	388	45	4.0	.3	.0	----	378	325	----	650	7.5	2
----	----	376	40	3.0	----	----	----	----	320	----	650	----	2
----	----	388	40	2.0	----	----	----	----	330	----	710	----	2
10	1.6	452	118	5.0	.2	.0	----	565	470	----	850	7.2	2
10	1.5	384	55	7.0	.5	.0	----	420	360	----	680	7.4	2
12	1.4	396	44	6.2	----	----	376	----	345	20	----	7.30	3
11	----	417	38	3.0	----	----	----	390	355	----	590	7.7	2
----	----	400	35	3.0	----	----	----	----	330	----	700	----	2
13	1.7	388	33	4.0	.4	.0	----	394	325	----	620	7.4	2
9.5	2.2	414	32	4.1	----	----	367	----	340	1	----	7.43	3
----	----	395	35	2.0	.0	.0	----	376	340	----	650	7.5	2
12	2.3	436	93	9.1	----	----	478	----	421	64	----	7.28	3
12	2.3	462	130	13	----	----	551	----	477	99	----	7.20	3

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aqui-fer	Date of collec-tion	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
							Ingham County	
04N 01W 08CDAD-1	393	N1SA	2- 9-68	----	12	0.20	71	26
10BADA-1	390	N1SA	11-19-59	----	14	.30	54	24
	300	N1SA	6- 7-65	----	13	.20	64	16
	390	N1SA	3- 7-68	----	----	1.3	56	22
11CDD-1	333	N1SA	3- 7-68	----	----	1.2	62	23
CDDC-1	343	N1SA		----	----	2.1	70	24
	343	N1SA	4- 5-55	50	13	.60	66	24
	343	N1SA	11-19-59	----	15	.30	58	23
	343	N1SA	6- 7-65	----	18	.70	70	19
	250	N1SA	3- 7-68	----	----	1.2	62	23
17ABAA-1	413	N1SA	4- 4-68	----	12	.40	76	27
18BAD-1	460	N1SA	7-31-52	----	10	1.1	88	34
	460	N1SA	4-23-53	51	----	----	----	----
	460	N1SA	4-27-54	51	----	----	----	----
	460	N1SA	5-12-61	----	14	.80	86	32
	460	N1SA	2-29-68	----	----	1.7	114	42
CBDD-1	370	N1SA	2-29-68	----	----	.52	86	29
CCA-1	375	N1SA	8-10-53	52	11	.15	58	28
	375	N1SA	9-10-54	52	----	----	----	----
19CCAA-1	365	N1SA	2-29-68	----	----	3.0	90	30
24CABC-1	200	N1SA	2-20-65	----	----	----	----	----
CDBC-1	285	N1SA	2-20-65	----	----	1.5	----	----
DAAD-1	297	N1SA	4- 4-68	----	----	.34	72	10
DDAA-1	170	N1SA	2-20-65	----	----	----	----	----
	170	N1SA	4- 4-68	----	----	1.7	141	19
25CDBC-1	257	N1SA	4- 4-68	----	----	.25	20	8.0
26BCA-1	422	N1SA	11-19-59	----	10	3.4	62	17
	422	N1SA	6- 4-65	----	9.0	1.6	66	12
	422	N1SA	3- 7-68	50	----	1.6	88	24
27BABB-1	400	N1SA	10-31-66	----	16	3.6	54	24
	335	N1SA	3- 7-68	----	----	----	89	27
CACA-1	291	N1SA, N3GR	6- 2-65	----	16	.90	74	27
CBBA-1	301	N1SA	4-15-66	----	14	2.3	82	27
-2	280	N1SA	9-17-66	----	14	1.7	84	28
	280	N1SA	3- 7-68	----	----	1.8	82	28
DADD-1	310	N1SA	6-16-66	----	12	4.5	78	27
28DAB-1	276	N1SA	7-28-66	----	14	.90	84	27
	300	N1SA	8-26-66	----	14	1.0	82	25
29BBBB-1	255	N1SA	3- 7-68	----	----	2.0	111	37
-2	240	N1SA	7-12-66	----	15	2.3	104	33
	240	N1SA	3- 7-68	----	----	4.4	124	40
30BBAA-1	374	N1SA, N3GR	2-29-68	----	----	.40	80	28
BCDD-1	355	N1SA	2-29-68	----	----	.52	80	27
31ABBB-1	362	N1SA	2-29-68	----	----	.48	78	26
35BBBB-1	300	N1SA	10-31-66	----	10	1.0	68	21
02E 16DDD-1	116	QGOO	10-12-67	----	----	1.2	64	26
33CDDD-1	159	N1SA	6- 2-64	50	----	----	4.4	1.4
02W 04CABC-1	443	N1SA	3-22-54	51	----	----	----	----
	443	N1SA	9- 8-54	51	----	----	----	----
	443	N1SA	3-31-55	51	----	----	----	----
DDCC-1	435	N1SA	4-23-53	51	12	.28	69	25
	435	N1SA	3-31-55	51	----	----	----	----
05CCCC-1	382	N1SA	1- 4-52	----	8.1	.20	82	28
	382	N1SA	4-22-53	52	----	----	----	----
	382	N1SA	3-30-55	----	----	----	----	----
CCDB-1	60	QGOO	3-30-55	49	----	----	----	----
DCDC-1	505	N1SA	1- 4-52	----	8.5	.20	66	25
	505	N1SA	4-27-54	52	----	----	----	----
	505	N1SA	4-22-63	51	----	----	----	----

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Evaporated at 180° C	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Analyst
--Continued													
20	2.4	360	44	2.0	0.6	0.0	----	366	295	----	620	7.6	2
11	1.0	320	2.0	.0	.2	.0	----	246	233	----	500	7.8	2
12	1.1	310	.0	.0	.5	.0	----	262	225	----	440	7.5	2
12	1.4	295	3.0	1.3	----	----	241	----	231	0	----	7.83	3
8.0	1.6	317	7.0	1.5	----	----	260	----	250	0	----	7.71	3
7.0	1.6	346	3.0	1.3	----	----	279	----	274	0	----	7.61	3
----	----	336	12	2.0	.3	.0	----	296	265	----	540	7.8	2
10	1.2	308	7.0	1.0	.5	.0	----	275	240	----	500	7.7	2
7.6	1.3	350	.0	.0	.5	.0	----	300	255	----	490	7.5	2
8.0	1.6	317	7.0	1.5	----	----	260	----	250	0	----	7.71	3
15	2.2	360	35	2.0	.5	.0	----	366	300	----	610	7.4	2
7.0	----	392	55	8.0	.2	.0	----	410	360	----	700	7.6	2
----	----	378	52	5.0	----	----	----	----	350	----	670	----	2
----	----	376	70	11	----	----	----	----	370	----	800	----	2
18	1.2	365	70	12	.4	.0	----	430	345	----	700	7.4	2
14	2.0	437	110	25	----	----	524	----	458	99	----	7.20	3
7.0	2.0	398	25	4.9	----	----	350	----	334	8	----	7.23	3
5.0	----	327	6.0	1.0	.0	.6	----	284	260	----	500	8.2	2
----	----	383	5.5	1.0	----	----	----	----	300	----	600	----	2
4.5	1.4	396	38	2.5	----	----	358	----	248	23	----	7.30	3
----	----	280	1,320	4.0	----	.3	----	----	1,580	1,350	2,240	7.4	1
----	----	195	710	7.5	----	.7	----	----	836	676	1,460	7.6	1
10	4.4	271	20	1.4	----	----	252	----	221	0	----	7.60	3
----	----	290	83	5.0	----	1.2	----	----	307	69	602	7.6	1
17	5.8	278	235	2.5	----	----	559	----	430	202	----	7.59	3
84	3.0	303	13	6.5	----	----	284	----	85	0	----	7.80	3
30	3.2	330	20	5.0	.0	.0	----	325	225	----	540	7.4	2
30	3.7	320	20	4.0	.3	1.0	----	310	215	----	500	7.4	2
8.5	4.3	405	5.0	1.5	----	----	335	----	319	0	----	7.40	3
3.7	.7	266	22	.0	.2	.0	----	312	235	----	420	8.0	2
3.5	1.0	388	18	1.7	----	----	332	----	333	15	----	7.35	3
7.6	1.2	370	12	.0	.4	.0	----	330	295	----	540	7.9	2
6.9	1.6	400	.0	.0	.4	.0	----	360	315	----	550	7.5	2
6.9	1.2	405	7.0	.0	.5	.0	----	362	325	----	600	7.5	2
7.5	2.0	410	4.0	1.1	----	----	329	----	320	0	----	7.32	3
6.4	1.5	370	6.0	.0	.5	.0	----	370	305	----	480	7.6	2
5.1	1.2	398	5.0	.0	.4	.0	----	352	320	----	600	7.5	2
4.8	1.2	400	3.0	.0	.4	.0	----	348	310	----	600	7.4	2
10	2.0	380	99	18	----	----	466	----	429	117	----	7.35	3
8.3	1.2	370	92	15	.4	.0	----	490	395	----	750	7.5	2
10	2.0	390	140	21	----	----	533	----	475	155	----	7.20	3
3.5	1.4	385	16	.7	----	----	319	----	315	0	----	7.30	3
3.0	1.1	402	21	1.9	----	----	333	----	311	0	----	7.31	3
4.0	1.0	382	3.0	1.1	----	----	301	----	302	0	----	7.40	3
23	3.7	356	13	.0	.4	.6	----	330	255	----	530	7.6	2
12	1.0	340	7.0	.1	----	----	280	----	267	0	----	7.50	3
149	4.1	374	31	10	----	----	----	376	17	0	648	7.4	1
----	----	330	123	21	----	----	----	----	470	----	780	----	2
----	----	415	140	21	----	----	----	----	465	----	900	----	2
----	----	405	135	21	----	----	----	----	390	----	900	----	2
8.1	2.0	348	4.6	1.2	.5	.10	----	294	274	----	526	7.1	1
----	----	344	4.5	1.0	----	----	----	----	230	----	590	----	2
11	1.7	364	44	6.0	.2	.0	----	365	320	----	515	7.4	2
----	----	366	52	5.0	----	----	----	----	330	----	620	----	2
----	----	369	59	7.0	----	----	----	----	275	----	700	----	2
----	----	310	60	13	----	----	----	----	260	----	620	----	2
13	1.5	354	7.0	3.0	.2	.0	----	298	268	----	440	7.6	2
----	----	352	13	2.0	----	----	----	----	265	----	630	----	2
----	----	359	9.6	1.0	----	----	----	----	270	----	540	----	2

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
							Ingham	County
04N 02W 08BCDC-1	410	N1SA	4-22-53	51	14	0.32	86	40
	410	N1SA	4-23-53	51	2.0	.25	94	39
	410	N1SA	4-22-53	51	2.0	.25	94	39
09BDAD-1	400	N1SA	10- 8-59	----	12	2.0	75	25
CBAD-1	430	N1SA	3-30-55	51	----	----	----	----
CBCA-1	432	N1SA	6-27-52	51	14	.55	83	32
	432	N1SA	6-17-54	----	15	.02	103	37
11DBDD-1	395	N1SA	4-22-53	50	3.3	.80	80	30
12CCD-1	407	N1SA	7-31-52	----	10	7.0	144	50
	407	N1SA	8-21-61	----	17	16	188	62
	410	N1SA	2-29-68	----	----	1.2	115	38
CDA-1	385	N1SA	7-31-52	----	10	2.5	112	36
	385	N1SA	4-23-53	50	----	----	----	----
	385	N1SA	8-21-61	----	15	3.5	128	40
	385	N1SA	2-29-68	----	----	3.2	110	38
16DAA-1	445	N1SA	2- 8-52	----	8.4	.30	110	36
	445	N1SA	4-22-53	53	----	----	----	----
	455	N1SA	3-29-55	53	----	----	----	----
18BDAB-1	399	N1SA	10-27-60	----	15	.40	76	24
CAAC-1	404	N1SA	4-22-53	50	2.0	.30	68	28
	404	N1SA	3-22-54	51	----	----	----	----
	404	N1SA	10-27-60	----	16	.40	86	27
CACA-1	417	N1SA	10-27-60	----	16	.40	78	28
23BBCC-1	400	N1SA	4-22-53	51	11	.50	106	39
24ADDD-1	425	N1SA	4-23-53	52	15	1.1	79	27
DDCC-1	352	N1SA	4-23-53	51	3.3	.25	70	27
25AABA-1	360	N1SA	2-29-68	----	----	.44	90	30
BADA-1	367	N1SA	4-23-58	----	----	.30	72	17
	367	N1SA	2-29-68	----	----	.56	76	26
27CDA-1	336	N1SA	4-22-53	50	3.0	.50	80	24
31CDCC-1	450	N1SA	7- 7-61	----	----	1.3	105	28
36DAAD-1	375	N1SA	2-29-68	----	----	.88	94	29
								Eaton
01N 04W 06CCBB-1	184	N1SA	9- 8-67	----	----	----	----	----
13ABA-1	150	N1SA	3-14-68	----	----	2.5	56	20
05W 29AABA-1	150	N1SA	10-19-67	----	----	3.3	106	29
DCA-1	121	N1SA	6-15-55	50	15	.62	113	41
32DADD-1	100	N1SA	10-19-67	----	----	5.6	108	30
06W 02DDAA-1	235	M3MI	6-17-65	----	----	----	----	----
20BBA-1	110	M3BA	9-16-64	----	----	1.0	82	37
02N 03W 30DAB-1	250	N1SA	3-14-68	----	----	2.7	85	20
32DDD-1	95	QGOO	3-14-68	----	----	3.5	86	30
34ACAB-1	294	N1SA	1-17-61	----	10	.30	80	21
DDDC-1	185	N1SA	10-19-67	----	----	.45	116	29
04W 04CBBC-1	110	N1SA	3-14-68	----	----	2.4	76	23
10ABCC-1	70	N1SA	10-19-67	----	----	.87	98	27
19CBBC-1	25	QGOO	4-10-59	----	11	.16	68	23
05W 03BCCC-1	140	M3BA	5- 2-68	----	----	4.8	83	23
23ACDC-1	200	N1SA	10-19-67	----	----	2.5	100	31
25ADDA-1	95	N1SA	10-19-67	----	----	4.1	158	48
26CCB-1	160	N1SA	5- 2-68	----	----	2.7	96	32
27ACAD-1	91	QGOO	9-20-68	51	----	----	----	----
30DADD-1	195	N1SA	10-19-67	----	----	.16	100	30
33DCCD-1	170	N1SA	5- 2-68	----	----	1.1	96	32
06W 02BBAA-1	186	N1SA	9-15-64	----	----	.59	87	42
10DDCC-1	300	N1SA	9-15-64	----	----	1.5	540	141
24ABB-1	230	N1SA	1-11-65	----	----	2.4	----	----
28ADD-1	180	N1SA	4-18-68	----	----	4.5	94	24
31DDCD-1	162	N1SA	9-15-64	----	----	----	81	29

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Evaporated at 180° C	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Analyst
--Continued													
7.3	2.2	426	42	9.0	0.4	1.4	----	440	404	----	726	7.2	1
8.0	----	439	44	5.0	.4	.0	----	416	395	----	710	7.6	2
8.0	----	439	44	5.0	.4	.0	----	416	395	----	710	7.6	2
8.7	2.0	340	22	4.0	----	.6	329	316	290	12	541	7.4	1
----	----	383	38	7.0	----	----	----	----	290	----	680	----	2
6.5	2.5	400	24	2.0	.3	.9	363	355	340	11	630	7.3	1
----	----	426	68	7.0	.3	----	----	----	408	60	723	7.5	1
12	----	406	19	.0	.2	.0	----	354	325	----	630	7.9	2
7.0	----	470	200	7.0	.2	.0	----	746	565	----	1,000	7.2	2
11	1.6	550	270	15	.2	.0	----	1,020	725	----	1,200	7.0	2
8.0	2.0	425	105	9.7	----	----	488	----	443	95	----	7.17	3
7.0	----	421	105	3.0	.2	.0	----	518	430	----	800	7.3	2
----	----	425	103	2.0	----	----	----	----	430	----	750	----	2
6.9	1.6	425	140	6.0	.2	.0	----	614	485	----	810	7.4	2
8.5	2.2	435	91	6.9	----	----	473	----	431	75	----	7.23	3
46	2.4	375	78	90	.0	.0	----	600	425	----	910	7.8	2
----	----	378	60	93	----	----	----	----	410	----	900	----	2
----	----	371	70	107	----	----	----	----	345	----	1,010	----	2
5.7	.8	364	10	.0	.4	.0	----	320	290	----	600	7.5	2
9.7	----	366	5.4	.0	.4	.0	----	314	285	----	580	7.5	2
----	----	373	5.0	.0	----	----	----	----	275	----	550	----	2
6.9	1.0	376	30	2.0	.4	.0	----	370	325	----	610	7.6	2
6.9	.8	372	20	.0	.4	.0	----	350	310	----	600	7.5	2
----	----	415	93	8.0	.1	.0	----	500	425	----	750	7.8	2
5.6	1.6	378	7.1	.9	.2	2.0	----	325	308	----	565	6.9	1
7.1	----	358	6.6	.0	.0	.0	----	300	285	----	570	7.5	2
4.0	1.3	394	35	3.9	----	----	358	----	348	27	----	7.20	3
----	----	372	----	.0	----	----	----	----	250	----	----	7.5	2
5.5	1.3	365	8.0	1.8	----	----	299	----	297	0	----	7.32	3
7.0	----	368	16	1.0	.0	.0	----	326	300	----	600	7.4	2
4.4	.9	387	74	3.0	----	.1	----	444	378	68	687	6.9	1
3.5	1.2	417	23	2.8	----	----	360	----	354	12	----	7.29	3
County													
----	----	342	24	2.0	----	0.0	----	326	298	18	526	7.8	1
60	13	434	1.0	1.4	----	----	370	----	222	0	----	7.65	3
6.6	1.2	390	38	30	----	----	407	----	385	65	----	7.54	3
13	2.8	400	95	23	0.1	.0	501	525	450	122	823	7.3	1
5.7	3.2	384	80	8.4	----	----	422	----	394	79	----	7.44	3
----	----	402	32	2.0	----	1.1	----	----	340	10	740	7.6	1
11	1.4	444	11	2.0	----	----	----	369	357	0	664	7.5	1
6.0	2.4	322	40	1.9	----	----	318	----	294	30	----	7.65	3
3.0	1.0	386	19	3.6	----	----	332	----	337	21	----	7.71	3
3.5	1.8	315	35	2.0	.0	.0	----	308	285	27	525	7.5	2
11	2.6	384	81	16	----	----	446	----	412	97	----	7.67	3
2.0	1.9	298	32	2.9	----	----	286	----	285	41	----	7.62	3
3.0	1.0	346	53	4.2	----	----	358	----	356	72	----	7.30	3
6.8	5.2	260	58	5.5	.3	.8	307	311	264	51	509	8.0	1
12	6.9	424	11	1.6	----	----	352	----	302	0	----	7.60	3
3.9	1.4	472	4.0	.9	----	----	381	----	378	0	----	7.55	3
12	1.1	525	120	40	----	----	653	----	592	67	----	7.40	3
4.0	1.2	447	15	3.7	----	----	374	----	372	5	----	7.30	3
----	----	425	27	2.0	----	----	442	----	362	14	680	7.5	1
5.6	2.1	450	5.0	.9	----	----	367	----	374	4	----	7.70	3
4.5	.7	413	39	8.2	----	----	385	----	372	33	----	7.34	3
9.7	1.5	444	37	2.0	----	----	----	412	390	26	725	7.4	1
273	20	180	1,120	810	----	----	----	3,180	1,930	1,780	4,330	7.2	1
----	----	372	8.8	4.0	----	1.3	----	----	282	0	570	7.6	1
13	6.0	410	9.0	1.4	----	----	351	----	334	0	----	7.35	3
5.7	1.0	368	22	2.0	----	----	----	336	321	20	582	7.2	1

TABLE 5.—*Chemical analyses*

Local well No.	Depth (feet)	Aqui-fer	Date of collec-tion	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
							Eaton County	
03N 03W 05BAB-1	111	N3GR	3-14-68	----	----	2.4	75	30
35BAB-1	120	N1SA	3-14-68	----	----	1.5	84	28
04W 09DCCD-1	166	N1SA	10-26-67	----	----	1.6	74	26
23DDB-1	300	N1SA	12-14-60	----	15	2.3	116	39
-2	200	N1SA	12-14-60	----	15	.70	92	32
26BBBB-1	100	N1SA	10-26-67	----	----	7.0	114	36
29BAAA-1	108	N1SA	4-18-68	----	----	1.6	102	35
05W 23AAA-1	269	N1SA	4-18-68	----	----	.51	46	16
-2	268	N1SA	4-18-68	----	----	3.0	80	30
25CBB-1	141	N1SA	4-18-68	----	----	1.1	86	33
29BAB-1	69	QGOO	10-26-67	----	----	2.5	112	38
06W 27AAB-1	410	N1SA	5- 2-68	----	----	1.4	130	32
28BAA-2	167	QGOO	5-28-59	----	15	.90	88	34
34BC-1	94	QGOO	9-16-64	----	----	.38	103	42
04N 03W 03DDB-1	160	N1SA	7- 8-65	----	----	.84	----	----
07ABBB-1	110	N1SA	5- 2-68	----	----	.55	75	32
13ADD-1	425	N1SA	6-19-64	----	10	.60	80	24
14DAB-1	450	N1SA	1- 7-64	----	9.0	.40	62	26
25AD-1	110	N1SA	1-10-45	56	----	.90	73	27
04W 02AACD-1	404	N1SA	12-14-60	----	13	.50	80	29
10BBBA-1	90	N1SA	10-26-67	----	----	.90	72	32
11DCAD-1	190	N1SA	12-14-60	----	17	2.0	80	30
14ABAA-1	225	N1SA	6-17-54	50	16	.83	93	31
	225	N1SA	12-14-60	----	15	.50	92	34
23DDC-1	200	N1SA	10-26-67	----	----	.95	76	32
05W 03CDC-1	260	N1SA	10-26-67	----	----	.50	38	24
06W 02CADB-1	174	QGOO	10-28-59	----	17	1.0	84	32
20DCC-1	340	N1SA	6-14-65	----	----	----	----	----
21AAAA-1	245	N1SA	1-11-65	----	----	1.7	----	----
28CDC-1	245	N1SA	10-26-67	----	----	2.9	80	26

SOURCES OF DISSOLVED SOLIDS

Rain and snow, which contain very little dissolved mineral matter, are the initial source of ground water. Yet ground water in the Tri-County region contains significant amounts of dissolved minerals as a result of leaching of mineral matter from the soil. That leaching is the source of mineral matter in ground water is substantiated by the fact that soil samples when leached with distilled water yield water that has a dissolved-solids content similar to that of much of the ground water in the region. Conversely, samples of sandstone from the Saginaw Formation when leached with distilled water yield water containing only minor amounts of dissolved minerals. This indicates that only a small amount of mineral matter is dissolved by ground water as it moves through some ground-water reservoirs. Apparently contact of rain and melting snow with soil is all that is required to provide the dissolved minerals present in most ground water.

of ground water—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Calculated	Dissolved solids: Evaporated at 180° C	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Analyst
--Continued													
8.0	2.8	354	24	4.4	----	----	323	----	310	20	----	7.78	3
3.5	1.2	402	2.0	1.2	----	----	321	----	325	0	----	7.73	3
3.7	2.4	337	23	2.0	----	----	300	----	293	17	----	7.55	3
12	1.2	440	85	25	0.0	0.0	----	496	450	89	800	7.3	2
4.6	.8	400	38	7.0	.0	.0	----	394	360	32	650	7.5	2
6.7	1.4	450	82	12	----	----	480	----	432	62	----	7.55	3
5.5	1.3	448	33	6.6	----	----	408	----	399	31	----	7.40	3
87	7.8	442	7.0	2.0	----	----	386	----	181	0	----	7.62	3
9.5	2.5	407	10	1.2	----	----	342	----	323	0	----	7.56	3
7.5	1.7	425	13	2.2	----	----	358	----	351	3	----	7.55	3
7.1	1.2	490	56	8.5	----	----	461	----	437	33	----	7.69	3
16	7.2	363	165	4.4	----	----	536	----	457	151	----	7.39	3
5.8	.8	425	23	3.0	.0	.0	----	400	360	----	650	7.5	2
4.2	1.0	444	66	3.0	----	.0	----	458	430	66	758	7.6	1
4.4	----	218	49	2.0	----	.0	----	----	400	57	669	7.6	1
11	2.1	421	9.0	1.3	----	----	338	----	319	0	----	7.50	3
13	2.8	400	4.0	.0	.2	.0	----	334	300	0	560	7.4	2
31	3.0	390	8.0	5.0	.3	.0	----	326	260	0	580	7.4	2
6.4	----	367	3.8	3.0	----	----	----	307	295	0	----	----	1
11	1.5	385	18	5.0	.2	.0	----	354	320	4	600	7.5	2
12	1.9	400	23	2.0	----	----	341	----	313	0	----	7.68	3
6.0	.8	364	43	3.0	.3	.0	----	370	325	27	600	7.5	2
6.9	1.0	406	31	3.5	.1	.1	383	372	360	27	651	7.3	1
6.0	.8	405	50	4.0	.0	.0	----	400	370	38	650	7.4	2
6.6	1.8	373	26	1.5	----	----	329	----	320	15	----	7.67	3
49	3.4	378	10	1.2	----	----	312	----	192	0	----	8.03	3
8.3	1.0	410	17	5.0	.0	.0	----	380	340	----	600	7.7	2
----	----	362	9.6	1.0	----	.2	----	----	320	10	546	8.4	1
----	----	425	4.0	1.0	----	.6	----	----	338	0	618	7.5	1
3.5	1.2	385	8.0	.9	----	----	311	----	308	0	----	7.65	3

That most of the dissolved solids in the waters of the region result from the contact of rain and snow with soluble minerals in the soil is supported also by the chemical characteristics of water in streams. During periods of high flow most water in streams is surface runoff or water that has had contact only with the upper part of the soil mantle. This water, however, is very similar in chemical composition to most ground water of the region.

A small amount of water flows into the Saginaw Formation from the Michigan Formation and other stratigraphically lower formations. This water often contains large amounts of sulfate, calcium, sodium, and chloride. When large quantities of this highly mineralized water are introduced into the Saginaw Formation, the quality of water in the Saginaw often deteriorates. Figure 24 shows the effects of introducing water from a brine well into the Saginaw. This well, which was drilled in the city of Lansing in the latter part of the 19th century, was abandoned without being properly plugged. The marked lowering of the potentiometric surface in the Saginaw Formation in the 1940's caused water from

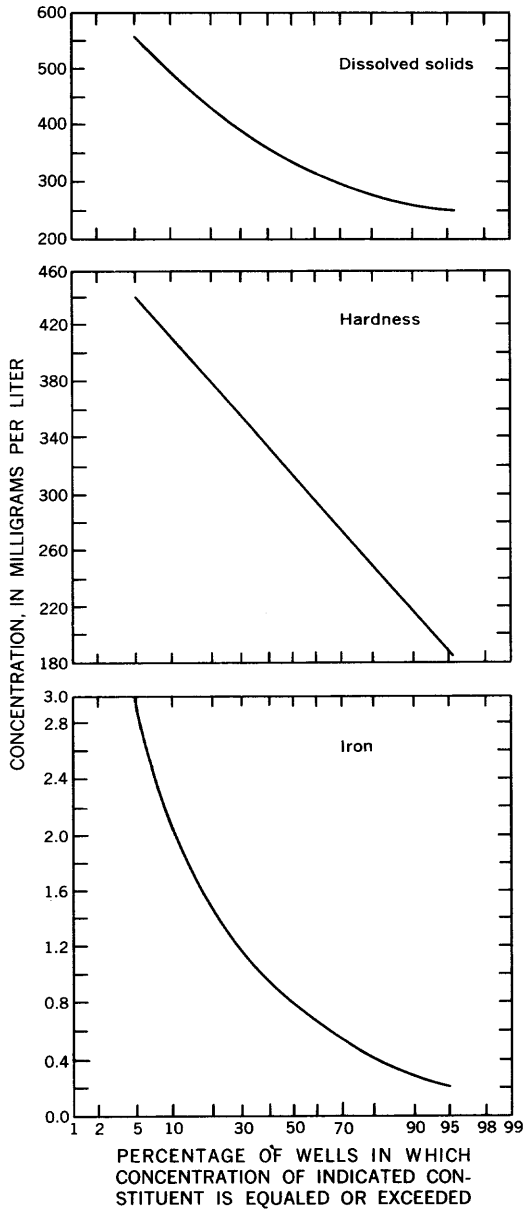


FIGURE 23.—Water from wells ranges considerably in dissolved-solids concentration and in hardness and iron content.

the brine well to flow into the Saginaw, locally increasing the concentration of chloride in this formation. The distribution of chloride within the Saginaw adjacent to the brine well is dependent upon pumpage from nearby water wells. Large withdrawals of water produce an increase in chloride concentration.

GLACIAL AQUIFERS

The glacial sediments of the region are composed of rock fragments and debris from many sedimentary and crystalline rock formations. The glacial soils thus contain a variety of soluble minerals including limestone, dolomite, and gypsum. These minerals provide calcium and magnesium bicarbonate and calcium sulfate, which comprise the common ions present in water from "glacial" wells. The iron in the water is derived from several iron-bearing minerals.

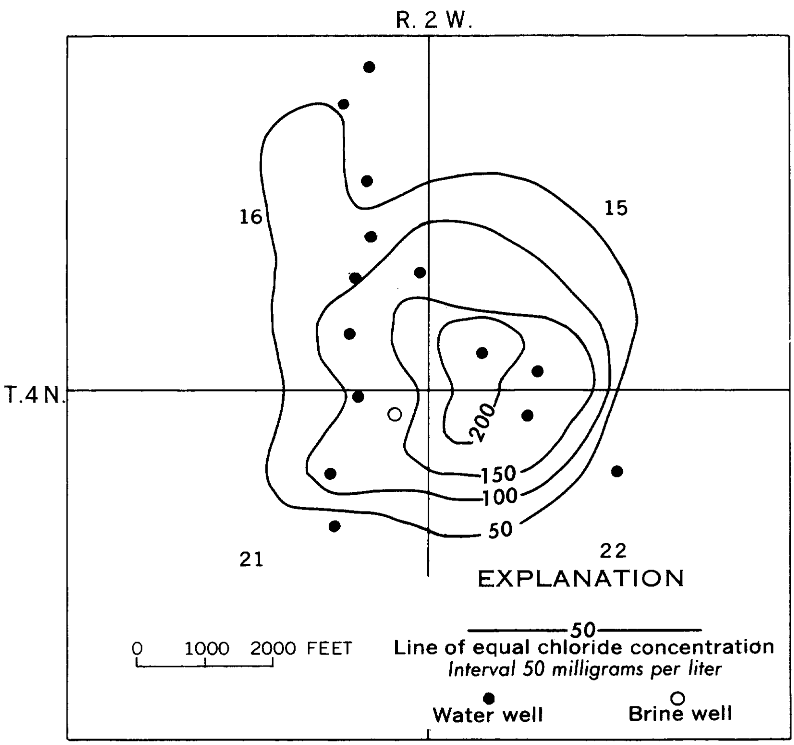


FIGURE 24.—Chloride, in significant concentrations, has intruded the Saginaw Formation near an abandoned brine well in the city of Lansing (modified after Wood, 1969).

The dissolved-mineral content of water obtained from glacial aquifers varies considerably from one locality to another and with depth. The water is hard to very hard, commonly contains objectionable concentrations of iron, and has a total dissolved-solids content ranging generally from 200 mg/l to 1,000 mg/l. The high mineral content of water sampled from some wells probably is the result of mineral enrichment through rejection of some ions by osmotic shale membranes (see discussion of ion filtering on p. 73.). Water sampled from well 05N 02W 27CAAA-1 (table 5) is an example of an enriched water from a glacial aquifer.

GRAND RIVER AND SAGINAW FORMATIONS

The Grand River and Saginaw Formations act as a single hydrologic unit, so the chemical characteristics of water in these formations are very similar. Nearly all the wells tapping these formations yield water that is suited to household needs, although the water generally is hard or very hard and contains objectionable concentrations of iron. In some localities the Saginaw Formation yields soft water. A detailed discussion of the quality characteristics of water in the Saginaw Formation is contained in a report by Wood (1969).

Statistical analyses of quality data from several hundred wells indicate that water obtained from the Saginaw Formation is generally lower in dissolved-solids concentration than that obtained from the glacial drift. Examples of the difference in chemical quality between the two aquifers are shown in the following analyses:

Local well No.	Aquifer	Dissolved constitutents (mg/l)				
		Iron	Sulfate	Chloride	Hardness	Dissolved solids
07N 02W 15CBAA-1	Saginaw Formation	0.51	4.0	1.8	278	319
CBAB-1	Glacial deposit	6.0	76	23	466	512
06N 02W 29BAAA-1	Saginaw Formation	.31	3.0	1.2	300	309
2	Glacial deposit	1.7	17	16	378	408

Each pair of wells is at the same location; however, one of each pair obtains water from a glacial aquifer and the other from the Saginaw Formation. The wells in the glacial drift yield water containing greater concentrations of dissolved solids than do their counterparts in the Saginaw Formation. Because water has moved from the glacial deposits into the Saginaw Formation at these wells, one would expect that the dissolved-solids content of water in the Saginaw would be at least the same as, if not higher than, that of water in the glacial deposits. Since the opposite is true, it appears that some dissolved solids are being filtered out by osmotic clay or shale membranes. The process is believed to operate in the following manner: Precipitation falls on the land surface, dissolves the soluble minerals in the soil, and then infiltrates into the underlying glacial sediments. The water then moves into the Saginaw Formation and passes through beds of shale that may act as osmotic membranes. These osmotic shale membranes may reject some of the dissolved minerals in the water. Such a filtering action could increase the concentration of dissolved solids in the water in and above the shale membranes and decrease the concentration of dissolved solids in water below them. Such filtering would occur only where there are shales in the upper part of the formation.

In some localities water samples obtained from several wells tapping the Saginaw vary considerably in dissolved-mineral content despite the fact that all the wells are completed in the same part of the aquifer. The variance in the chemistry of the water is believed to result primarily from differences in individual well construction. If the more mineralized water in and above the ion-filtering membrane enters the well, the well yields water with higher concentrations of dissolved solids. If the more mineralized water in and above the filtering shale layer cannot enter the well, the well yields water with a low dissolved-solids content. Figure 25 diagrams the ion-filtering process and illustrates why wells in the same area yield water of different chemical character.

Many wells in the Saginaw Formation yield water that has been naturally softened as it migrated through the formation. The softening is the result of clay minerals in the shales and shaley sandstones giving up sodium ions and taking on calcium and magnesium ions. Generally, Saginaw Formation water, whose hardness is less than 200 mg/l, has been naturally softened. The municipal-supply wells at Williamston and Fowler (03N 01E 02AAAA–3 and 07N 04W 11DACD–1, table 5) yield naturally softened water. Iron also is exchanged for sodium in the softening process; consequently, the iron content is low in naturally softened waters.

The value of an adequate supply of naturally softened water to a municipality or household is obvious, as the need for softening and iron removal is eliminated. The city of Williamston found it to be more economical to develop several relatively low-yield wells that produced naturally softened water than to develop large-capacity wells yielding water that needed softening and iron removal. Wells yielding naturally softened water generally are in areas where the Saginaw Formation contains considerable shale and shaley sandstone.

Analysis	Dissolved constituents, in milligrams per liter				
	Iron	Sulfate	Chloride	Total dissolved solids	Hardness
1	1.3	17	2	310	286
2	.6	27	4	407	400
3	.3	62	10	418	340
4	3.8	81	48	473	405
5	2.0	108	15	540	435
6	.2	0	0	262	225
7	.9	14	6	450	390

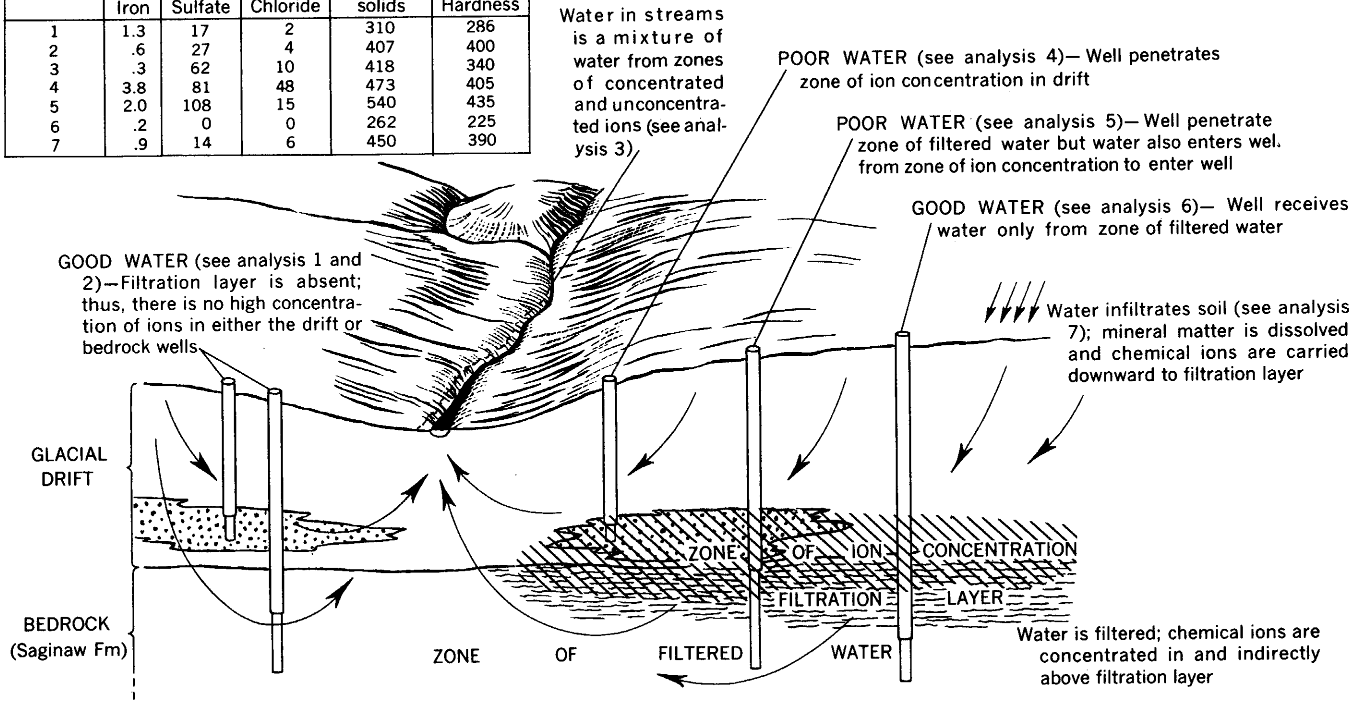


Figure 25.—Water may be filtered by clay layers in the bedrock formations.

BAYPORT LIMESTONE

The Bayport Limestone yields water of relatively good quality in the southwestern part of Eaton County where it is overlain directly by glacial deposits. The analyses of waters sampled from wells 01N 06W 20BBA–1 and 01N 05W 32DADD–1 (table 5) are typical of waters from the Bayport in the area where it yields fresh water. Where the Bayport is not overlain directly by glacial deposits, the formation generally does not yield water or yields water of poor chemical quality.

MICHIGAN FORMATION

The Michigan Formation is a source of fresh water in the south and west parts of Eaton County; over the remainder of the region it yields saline water. Within the fresh-water area, most wells tapping the Michigan yield water of fairly good quality, but a few wells yield saline water. In some places beds in the upper part of the formation yield fresh water, whereas beds in the lower part yield saline water. Additional data are needed before the location and extent of beds yielding saline water can be defined.

The analyses of waters sampled from wells 01N 06W 02DDAA–1 and 04N 06W 20DCC–1 (table 5) are typical of fresh waters from the Michigan Formation. The analysis of water from well 02N 06W 10DDCC–1 is typical of a saline water from the Michigan Formation.

MARSHALL FORMATION

The Marshall Formation yields saline water over most of the region. In the southwestern part of the region, however, it is a source of fairly good quality (fig. 22), yielding fresh water in some areas where the overlying Michigan Formation yields saline water. The analysis of water sampled from well 03N 06W 27AAB–1 is typical of water from the formation in these areas. The poor-quality water from some of the wells tapping the Marshall Formation in the southwestern part of Eaton County may result from the inflow of saline water from the Michigan.

The Marshall Formation will yield large supplies of water in the southwestern part of the Tri-County region. The water, however, may deteriorate in quality through salt-water encroachment if the formation is extensively developed for water supply. Thus, a periodic-water-sampling program may be needed in this area if the formation continues to be the chief source of water for Bellevue and Olivet. The sampling program would identify any changes through time in the quality of water from the Marshall Formation.

WATER MANAGEMENT

In the past, because of the widespread availability of water and limited needs, only the simplest water-management techniques have been needed to obtain adequate water supplies. These techniques generally consisted of drilling new wells in areas where water levels had not declined significantly, lowering of pumps to compensate for water-level decline in existing wells, and redeveloping wells to overcome reduction in well yields resulting from well-bore encrustation.

If the local resources are to be utilized as the sole future source of water supply, complete and comprehensive water-management programs will be needed. Some such current programs (1969) in the region are the use of cooling towers at the Moores Park powerplant, the use of glacial aquifers and recharge facilities by the Lansing Board of Water and Light, and the treatment of wastes by most communities. Even more comprehensive programs, probably increasing the unit cost of water, will be required in the future.

GROUND-WATER WITHDRAWAL AND STREAMFLOW DEPLETION

When water is withdrawn from a well, a new stress is placed on the natural hydrologic system. Under this new stress several adjustments occur in the aquifer. Ground-water levels begin to decline, and most of the water pumped during the initial period of decline is withdrawn from storage. The area of water-level decline expands until the volume of natural discharge to streams from the aquifer decreases. When the rate of decrease in natural discharge is equal to the rate of pumping, the system again is in balance; water is no longer taken from ground-water storage, and water levels, though lower, are again stabilized.

When the rate of pumping is increased, the stress on the system increases and ground-water levels begin to decline, resulting in an additional decrease in natural discharge from the aquifer. Water may also begin to infiltrate from streams into the aquifer. When the rate of decrease in natural discharge and the rate of induced infiltration are equal to the pumping rate, the system is again balanced. Water is no longer taken from ground-water storage, and ground-water levels stabilize at a lower level. The hydrologic system has adjusted to the withdrawal of water from the well by decreasing streamflow and reducing losses through evapotranspiration. This type of stability has been achieved at many small communities in the region.

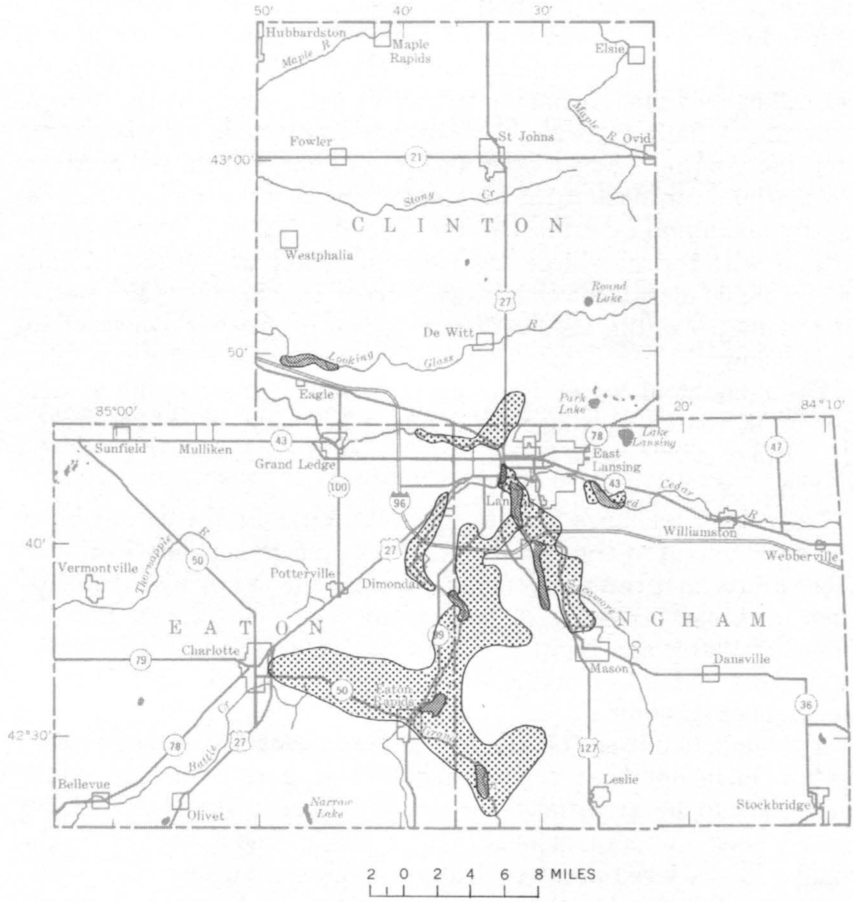
When the rate of pumping exceeds the rate of natural discharge plus the rate of induced recharge, the system cannot achieve a balance. The volume of water in excess of natural discharge and induced recharge is then taken from storage, the ground water in effect being mined as minerals are mined. Such is the case in the central part of the Lansing metropolitan area, where at the present time about half the water withdrawn from wells is taken from storage. As there is no longer natural discharge from the Saginaw Formation over most of the area and induced recharge is approaching its maximum rate, most water taken by future increases in the rate of withdrawal will be from ground water in storage. On the other hand, increased withdrawals from the Saginaw Formation in the metropolitan area will not result in further depletion of streamflow.

The amount of water that can be withdrawn from the system can be increased significantly through artificial recharge. To do this, water would have to be taken from streams to recharge the system.

The rate of recharge from streams is limited by the permeability and areal extent of the sediments on the stream bottom. However, these limitations can be overcome through the use of recharge pits, such as those presently in use at the well field of the Lansing Board of Water and Light along the Grand River southwest of the city. This method of artificial recharge can significantly increase the yield of an aquifer.

Although facilities for artificially recharging the Saginaw Formation have not been constructed, the authors believe that the Saginaw can be artificially recharged where shallow deposits of glacial sand and gravel overlie permeable sandstone beds. The small and scattered areas that appear to have considerable potential for recharging the Saginaw Formation are shown in figure 26. Test drilling is needed to define accurately areas where beds of sand and gravel overlie beds of sandstone. Because water available for artificial recharge in the favorable areas would have to be withdrawn from streams and because of the effect on the waste-assimilation capability of the streams during low-flow periods, large-scale artificial recharge would have to be accomplished during periods of surplus streamflow.

During the next two decades many communities in the Lansing metropolitan area will find it increasingly difficult to obtain adequate water supplies from underlying ground-water reservoirs. Ground-water supplies can be augmented through use of the streams of the area, however, by taking water directly from the streams or from shallow aquifers along the streams. Such use of water should be restricted during low-flow periods when the streams' waste-dilution capacity is lowest. At these times water



EXPLANATION

Areas where beds of sandstone in the Saginaw Formation are overlain by permeable sand and gravel

Areas that appear to be most favorable for artificially recharging the Saginaw Formation

Area boundary

FIGURE 26.—Favorable areas for artificially recharging the Saginaw Formation are small and scattered.

could be taken from the Saginaw Formation, and during periods of ample flow the streams could be used as a source of water supply. Such use, however, would require programs to improve and protect the quality of water in streams.

Reservoirs for storage of excess streamflow should be an important part of a comprehensive water-management program for providing water supplies. During periods of low streamflow water could be taken from the reservoirs or could be used to augment the flow in streams. Increased streamflow would allow for additional withdrawals from aquifers recharged from nearby streams. The location of potential reservoir sites and the potential storage capacities of the reservoirs are discussed in an earlier section of this report (p. 22).

The Great Lakes potentially provide an almost unlimited source of water to the region. The problem that limits development of the Great Lakes as a source of water is primarily an economic one. At present rates of water use in the region, the costs involved in developing such a supply undoubtedly would call for a significant increase in water rates. However, the unit cost of water imported from the Great Lakes would decrease with the volume of water imported (fig. 27), whereas the unit cost of water obtained from local sources will increase with the volume of water produced.

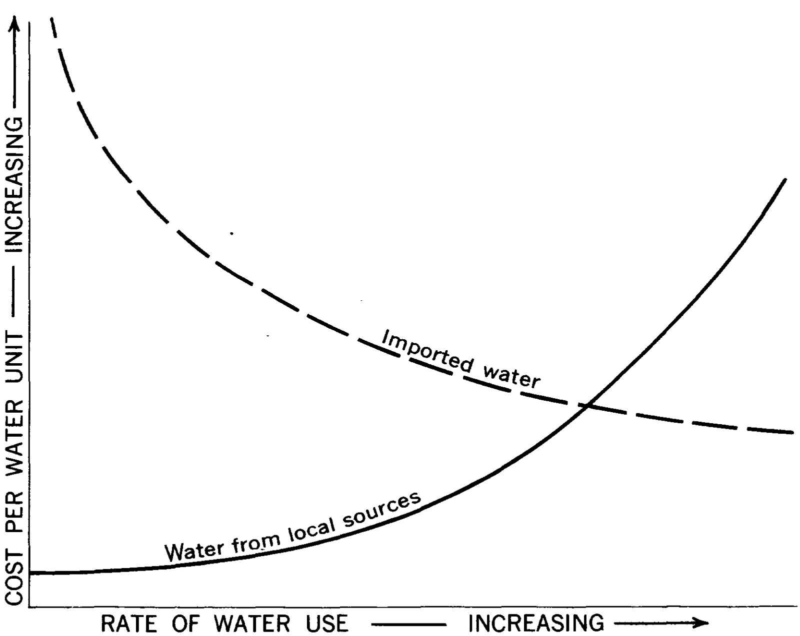


FIGURE 27.—Imported water may be cheapest when large quantities of water are used.

The demand for water in the region will eventually reach a level where the cost of imported water will approach the cost of water from local sources. The determination of relative costs of the two systems is beyond the scope of this investigation; however, systems analysis could provide the information needed to determine if and when importation of Great Lakes water might become the optimum system.

SYSTEMS-ANALYSIS CONSIDERATIONS

Wise management of water resources in the region involves determination of the advantages and disadvantages of several alternative water-development systems. Every possible system can be analyzed to determine its economic feasibility and its social and economic impact.

Systems analysis includes operational analysis, design and engineering analysis, mathematical modeling or simulation, and testing for evaluation. Before the various alternatives can be evaluated to select an optimum method for water-resources development by systems analysis, it is necessary to determine the needs that must be met and to define the alternatives that might meet these needs.

Techniques of analysis are continually evolving, and the state of the art has now developed to the point where most water-supply systems can be analyzed if the variables in the systems can be quantified. In the Tri-County region there are three significant variables. They are listed, along with the alternatives for handling each variable, in the following outline:

- Geographic considerations:
  - Development on a local basis
  - Development on a regional basis
  - A combination of local and regional development
- Sources of water:
  - Utilization of local sources
  - Importation
  - Transition from local sources to importation
- Degree of water management:
  - Minimal
  - Intensive

An intricate part of the preceding outline is the human variable—a variable that is difficult to quantify.

Although a comprehensive systems analysis is beyond the scope of this study, it is possible to describe the various water-supply systems that can be developed and the inherent components of these systems. Such descriptions not only outline some of the factors needed for systems analysis but also serve to illustrate the various alternatives for the region. Water-distribution systems are not included in the following description because it is assumed that distribution of water would be by individual governmental units regardless of the type of water-supply system implemented.

Given the three variables that have been listed, more than a dozen combinations of the alternatives are possible. It is assumed, however, that the five listed below are the ones that will most probably be used.

System 1

Present development methods would be continued; that is, local resources would be developed within local governmental boundaries with only minimum application of water-management techniques.

Facilities needed.—Land, wells, pumps and related equipment, water intakes to streams, water-treatment facilities, and pipelines.

Operating costs.—Pumping costs related to anticipated drawdown, treatment costs, and administrative costs.

Potential problems.—Declining water levels with consequent decline in well yields may result in periodic water shortages. Water shortages would first occur in communities "boxed in" by other communities using large quantities of water. Water shortages would eventually require transition to another system.

Constraints on development.—Present legal and political considerations tend to prohibit water-resource development by a governmental unit within or across an adjacent governmental unit; thus, most supplies would have to be developed within the local political boundaries. Application of intensive water-management techniques probably would be impeded by the lack of cost sharing among users.

Advantages.—Would satisfy desires for local governmental control and autonomy. Would also provide a satisfactory short-term water-supply system if water needs remain much as they are now.

System 2

Resources would be developed on a regional basis with minimum water management.

Facilities needed.—Same as in system 1.

Operating costs.—Same as in system 1.

Potential problems.—In the future the area of water-supply development would become increasingly large, having possible interference effects on the original users in the area.

Constraints on development.—The political-legal framework needed to implement the system has not been developed.

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Advantages.—The land area available for water-resource development would be increased significantly. The collective financial resources of the region could be utilized. Large-scale development often is more economical.

SYSTEM 3

Resources would be developed on a regional basis with maximum utilization of applicable water-management programs.

Facilities needed.—Same as in system 1 with the addition of artificial-recharge facilities and storage reservoirs.

Operating costs.—Same as in system 1 with the addition of the cost of maintaining recharge and storage facilities.

Potential problems.—Continued degradation of the quality of surface water could prohibit the use of this resource and greatly reduce the potential for artificial recharge.

Constraints on development.—Same as in system 2.

Advantages.—Impact of development on the original water users may be reduced. Costs of water-management programs may be offset by decrease of costs that would have been incurred for other water-supply facilities. Also, Federal grants may be more readily available for regional development.

SYSTEM 4

Same as system 2 or 3 with the addition of eventual importation of water from Lake Michigan. The optimum time to import water from the lake would be determined by the analysis of the economics of alternative systems.

Facilities needed.—Same as in system 1 with the addition of lake-intake facilities, a pipeline to the lake, and related facilities.

Operating costs.—Same as in system 1 with the addition of pumping costs for imported water; these costs are related to the height the water is lifted and the distance it is transported.

Potential problems.—Economic feasibility requires the importation of large volumes of water, so development on a large scale and on a regional basis probably would be required. If degradation of quality of Lake Michigan water continues, water-treatment costs would increase with time.

Constraints on development.—Same as in system 2 plus the need for large capital investments in facilities.

Advantages.—Abundant water supply available.

SYSTEM 5

Same as system 4 except that importation of water would be from Lake Huron rather than Lake Michigan. Implementation, development, and advantages would be similar to those for system 4 except that, from a time standpoint, the potential for degradation of water quality is much less in Lake Huron.

The development of a water system that will provide long-range optimum benefits to the region is one of the major challenges in planning for future growth. An alternative to the above systems is the reuse of water, which eventually may become one of the major techniques of water management. Water used in upstream communities will be discharged to streams and with proper treatment can be reused by other communities downstream. Water used by a community also can be treated and reused by that community. The social acceptability of such reuse and the costs involved are difficult to assess; however, it is unlikely that large-scale reuse of water will be practiced in the Tri-County region as long as other sources of supply which can be developed at reasonable costs are available.

WATER QUALITY AND WELL CONSTRUCTION

In most of the region the Saginaw Formation yields water that is of superior quality to that in the overlying glacial aquifers. Thus, most wells are completed in this formation. The difference in water quality appears to be most significant where the upper beds of the formation are shale or shaly sandstone. In some places the water in the overlying glacial deposits is more than twice as hard as water in the Saginaw. In such places well construction can greatly influence the quality of the water obtained.

Where wells in the Saginaw Formation are constructed so that water from the glacial drift enters them, the wells will yield water of low quality. If the low-quality water in the glacial sediments is sealed off, the well will yield better water. The fact that well construction can influence the quality of water obtained from the well explains the large differences in the quality of water samples obtained from wells completed in the same sandstone strata only a few hundred feet apart. Further research is needed to confirm the relationship between well construction and water quality and to provide the techniques to determine the type of well construction needed to insure water of the best quality.

UTILIZATION OF GLACIAL AQUIFERS

The glacial (sand and gravel) aquifers of the region have not been developed extensively for large supplies of water. If, however, the local water resources are to continue to supply the Lansing metropolitan area, these aquifers will have to be fully utilized. To do so will call for an increased awareness of the techniques of effectively developing and maintaining glacial wells. The principal problem involved in the utilization of glacial wells is the reduction in yields with time—a result of plugging of the well screens. The problem is not unique to wells tapping glacial aquifers, as "sandstone" wells in the area also become plugged and decline in yield. Water managers have developed techniques needed to maintain sandstone wells but have had much less experience in the maintenance and utilization of glacial wells.

The city of Kalamazoo, which obtains all its water from glacial aquifers, has over a period of several decades formulated a program of well development and maintenance that illustrates how the yield of glacial wells can be maintained. Techniques used at Kalamazoo, as outlined by Thomas Fricke, utilities manager (written commun., 1969), are as follows:

1. Determine through aquifer tests and other means the long-term sustained yield from the particular well field.
2. Construct wells with appropriate screen lengths, and restrict well yields so that the entrance velocity of the water into the well is much less than the commonly recommended one-tenth of a foot per second. The lower entrances velocity decreases the plugging effect and in so doing adds to the life of wells and decreases maintenance costs.
3. Select the number of wells and the well spacing needed to achieve the predetermined sustained yield of the field.
4. Keep accurate records of static water levels, pumping levels, and pumping rates so that changes in specific yield (ratio of pumping rate to drawdown) can be determined.
5. Start well-rehabilitation program before the specific capacity declines to 50 percent of its original value.

Declines in yield often result either from incrustation of well screens or from migration of fine-grained sediments into the zone adjacent to well screens. At Kalamazoo, declines in well yields are attributed to the migration of fine material into the zone next to the screen rather than screen incrustation. The maintenance program used by the city of Kalamazoo as described by Fricke (written commun., 1969) is as follows:

When we determine that the well is scheduled for some maintenance treatment we implement an automatic surging treatment using a sodium polyphosphate solution. About 200 to 400 pounds of polyphosphate is added to a 1,000-gallon tank connected to the well. Water from the well pumps into the tank until the tank is filled. At this time, the pump stops and the tank drains into the well. When the tank is empty, the pump again fills the tank. This cycle is automatically controlled. Thus, the polyphosphate solution is automatically surged into and out of the well. This loosens the fine-grained materials from the area adjacent to the well screen. These materials are pumped into the tank where they settle out.

We have tried many other chemicals in conjunction with our surge tank treatment, but none have proven anywhere near as effective as the normal polyphosphate treatment. Some wells have to be given this treatment once every year, others once every two years, and a few can go longer than that. After 3 or 4 polyphosphate treatments we have found that we have to put in a well rig and redevelop the well by normal methods. This works out to be an average of every four to eight years, but this is about the time that a well pump should be pulled for inspection and maintenance anyway.

In past years we have tried acid treatments on some wells, but they have proven unsatisfactory. Because of the character of our ground water there is no incrustation of our well screens, so that acid treatment does not help. As a matter of fact, by looking back through our treatments, (this again became quite apparent from our plotting of the well history) the acid treatment really hurts our wells. We stumbled onto the fact that the acid dissolved many of the larger particles immediately adjacent to the well screen and left nothing but the very fine insoluble silicas packed closely into the well-screen area, within perhaps a foot of the screen. We have not been able to devise a means for removing these tightly packed fines; consequently the wells became progressively worse. We are in the process of replacing the wells that were acid treated.

WATER AVAILABILITY

The availability of water is governed by the natural hydrologic system, the present uses made of the water, and the type and degree of water-management programs being utilized. Because such factors vary from place to place, the region has been divided into 12 areas (fig. 28). The availability of water for the region as a whole and for the 12 areas is outlined in the following sections.

It is difficult to predict accurately the rate of growth and anticipated demands for water in the small communities outside the Lansing metropolitan area. The estimates of availability of water for these small communities are related to anticipated demands based on an assumption of normal growth in the communities during the next two decades.

REGIONAL AVAILABILITY

Availability of water on a regional basis is related to the degree of water management called for by the selected programs. Thus, estimates of water availability in two regions having management programs of varying intensity can have a wide range and be difficult to make. However, if intensities of management are specified, the task becomes somewhat easier. In table 6, three levels of water-management intensity guide estimates of water availability under sustained-yield conditions. If additional water were needed, such as it might be during the period of transition from a system

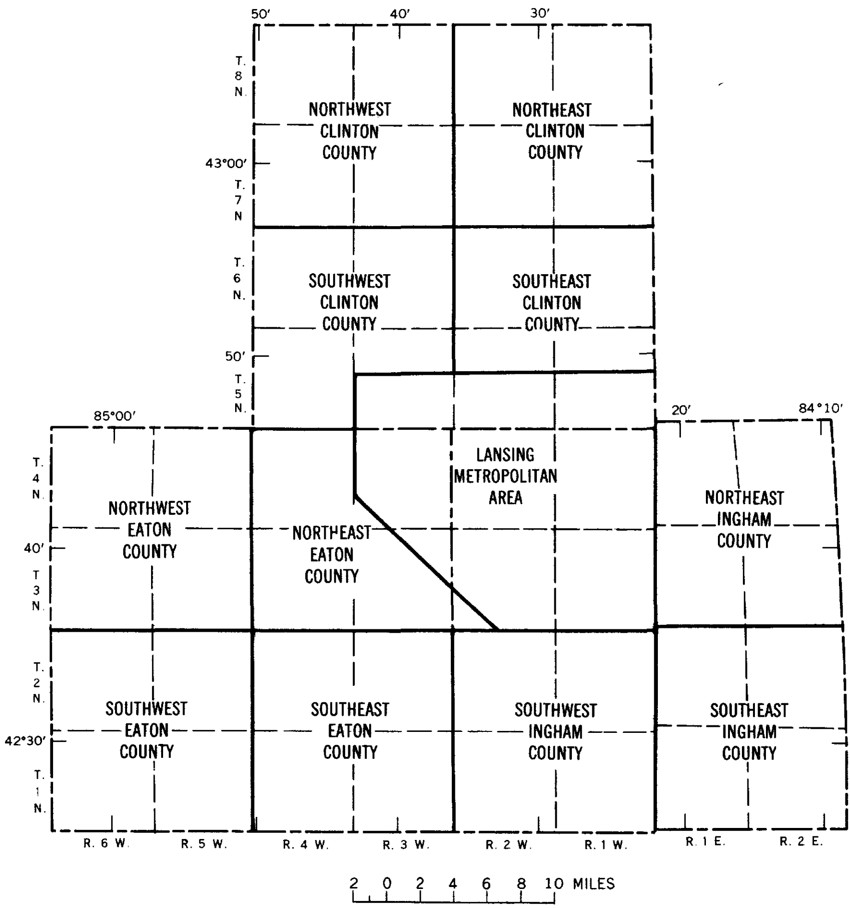

FIGURE 28.—The Tri-County region is divided into 12 areas to facilitate discussion of water availability.

supplied from local sources to an import system, ground water in storage also could be utilized for water supply.

The quantity of water stored in the ground is very large. For example, about 650,000 million gallons of recoverable water are stored in the upper 100 feet of the Saginaw aquifer within surface area having a diameter of 20 miles. This quantity of water is sufficient to supply 100 mgd for a period of 18 years, a supply more than adequate for any foreseeable period of transition to an imported supply.

NORTHWESTERN CLINTON COUNTY

The northwestern part of Clinton County does not have abundant ground-water resources. Glacial sediments, although very

TABLE 6.—*Effects of water-management intensity on estimates of regional water availability*

Source of supply	Area of productive aquifer (sq mi)	Estimated availability (mgd) From natural recharge	From induced recharge	From artificial recharge	Total
Minimum management—All supplies from wells, no artificial recharge					
Saginaw Formation	1,000	50	40	----	90
Surficial outwash	100	30	40	----	70
Buried outwash	275	27	15	----	42
Total	----	----	----	----	202
Moderate management—All supplies from wells, artificial recharge					
Saginaw Formation	1,000	50	40	25	115
Surficial outwash	100	30	40	40	110
Buried outwash	275	27	15	10	52
Total	----	----	----	----	277
Intensive management—Supplies from wells and streams; artificial recharge, storage reservoirs					
Saginaw Formation	1,000	50	40	25	115
Surficial outwash	100	30	40	40	110
Buried outwash	275	27	15	10	52
Streams, 50 percent of time	----	----	----	----	115
Total	----	----	----	----	392

thick in much of this area, include only a few areas of highly permeable sand and gravel. The Saginaw Formation also is a source of water to the area; however, in most of this area wells tapping this formation will yield only small supplies of water.

Much of the surficial outwash in northwest Clinton County is thin, and in many places only a few feet of it is saturated. In a few small areas along the Maple River, Hayworth Creek, and Stony Creek, the outwash may be a source of moderate supplies of water to large-diameter wells. The long-term yield of such aquifers, however, is dependent largely upon the availability of induced recharge from the streams.

Locally, buried-outwash aquifers are also potential sources of moderate supplies of water. One area of buried outwash which may be favorable for the development of moderate supplies of water was identified in this area (pl. 2). Other areas of buried outwash may be present but were not identified owing to the lack of data.

Although the ground-water sources are on the whole not highly productive in this area, they are adequate to meet forseeable future demands. Most of the demands for water will be for farm and household use, and these demands can be met through the drilling of wells. In some localities supplies of water adequate for irrigation may be available from buried-outwash deposits. Some surficial-outwash deposits can supply enough water for irrigation through multiple-well systems or construction of pits that penetrate the water table. Most aquifers of this area yield water of suitable quality for household use. However, some aquifers along the Maple River in Lebanon Township yield saline water, as do the deeper beds of the Saginaw Formation in the south-central part of Bengal Township.

VILLAGE OF MAPLE RAPIDS

The village of Maple Rapids obtains its water from wells tapping glacial aquifers. Although the glacial aquifers are only moderately productive, present and anticipated demands for the next two decades are not large; hence, water-supply problems are not anticipated. Additional test drilling and associated investigations within a mile of the present village limits probably would define sufficient additional well sites to meet future demands.

VILLAGE OF FOWLER

The village of Fowler obtains its water from the Saginaw Formation. Although wells tapping the Saginaw at Fowler yield less than 100 gpm, the formation is capable of yielding sufficient water for anticipated future demands. The drift aquifers are also potential sources of water at Fowler; however, the superior quality of the water from the Saginaw Formation probably makes it economically feasible to locate "bedrock" wells at sites as far as a mile from the center of the village rather than to utilize glacial wells at sites within the village.

NORTHEASTERN CLINTON COUNTY

The northeastern part of Clinton County has moderately abundant water resources. The Maple River is a potential source of water, but its use for assimilating waste effluents from municipal treatment plants would conflict with most withdrawal uses. Some water probably is available from the stream for irrigation use downstream from Ovid and Elsie where water probably would not be of suitable quality for most other withdrawal uses without treatment. Ground-water supplies are available from glacial sediments and the Grand River and Saginaw Formations.

The valley-outwash deposits along the Maple River at Ovid are potential sources of large water supplies. Withdrawal of very large quantities from these deposits, however, would deplete the flow of the Maple River.

The productivity of the outwash throughout most of this region needs to be determined through test drilling and related studies. Agricultural irrigation may become a major use of water from valley-outwash deposits.

The Grand River Formation is a minor source of water in part of this area. Where present, it yields sufficient water to wells to supply household and farm needs.

The Saginaw Formation is the principal aquifer of this area. The formation, although varying considerably in productivity, will yield as much as 300 gpm to large-diameter wells in much of the area. In some areas, however, the formation will yield only about 100 gpm to wells.

VILLAGE OF ELSIE

The village of Elsie obtains its water supply from wells in glacial outwash and in the Saginaw Formation. The glacial aquifer is recharged partly by inflow from Baker Creek. Other deposits of surficial outwash east of the present well field offer considerable potential for additional development (Vanlier, 1962). The Saginaw Formation is not highly productive at Elsie. Because the beds of sandstone at the base of the formation yield water of poor chemical quality, only the upper beds of the formation can be utilized for supply, reducing the yield of wells to about 100 gpm. The Saginaw Formation along with the glacial aquifers should yield water adequate for demands during the next two decades, although additional wells may be needed.

VILLAGE OF OVID

The village of Ovid obtains its water supply from wells in the Saginaw Formation and in valley outwash along the Maple River. The iron content of the water is reduced by treatment.

The Saginaw Formation, although only moderately productive at Ovid, has considerable potential for additional development. The valley outwash also has considerable potential as it is highly productive owing to the availability of recharge from the Maple River. The principal limit on the yield of the valley outwash is the flow requirements of the river. The two aquifers at Ovid should provide for adequate water supplies for the next two decades.

CITY OF ST. JOHNS

St. Johns obtains its water from wells in the Saginaw Formation. The water is softened, and its iron content is reduced by treatment. The Saginaw is highly productive in the St. Johns area and has the potential to yield considerably more water than is presently being withdrawn. An increase in water use over the past 5 years, particularly during the summers, has resulted in a slight decline of ground-water levels in the vicinity of the municipal well field (fig. 29). That the water levels are declining in response to

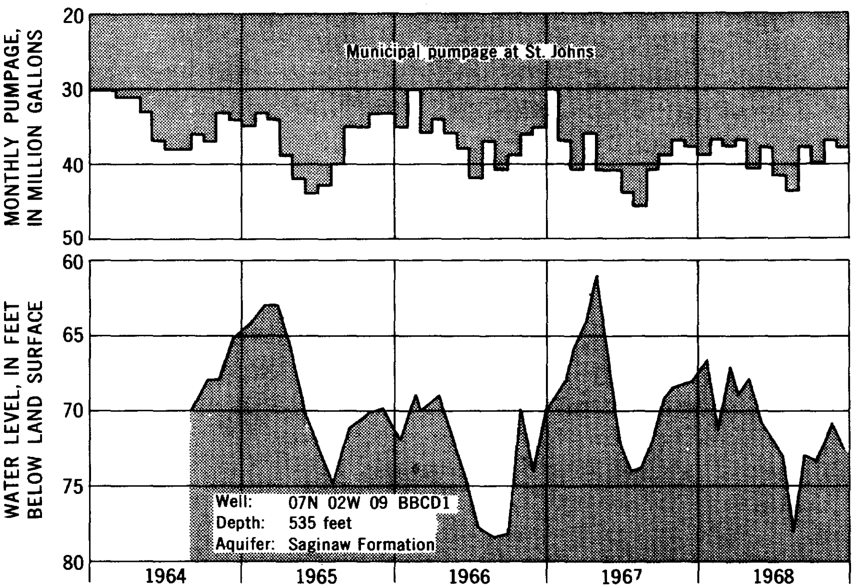

FIGURE 29.—Heavy pumpage during summer months at St. Johns is reflected in ground-water levels.

increases in the rate of withdrawal indicates that the rate of withdrawal is slightly in excess of the rate of recharge.

The Saginaw Formation should meet demands for additional water for the next two decades. Additional wells probably should be drilled half a mile or more from the existing well field in order to minimize well interference and provide for long-term maintenance of well yields.

Buried-outwash aquifers in the St. Johns area also can be utilized for additional water supply. The sites where the glacial deposits will yield large quantities of water will have to be located by additional test drilling. The area south of St. Johns appears to be most favorable for the development of buried-outwash aquifers.

SOUTHWESTERN CLINTON COUNTY

The southwestern part of Clinton County has abundant ground-water resources; the two principal sources are buried-outwash deposits and the Saginaw Formation. The Saginaw appears to be especially productive along the Looking Glass River. Deposits of buried outwash also have considerable potential for development of large supplies of water, especially where recharge can be induced from streams. Locally the sand and gravel aquifers directly overlie sandstones of the Saginaw Formation. The development of large water supplies from the Saginaw in some of these localities also would induce recharge from streams.

VILLAGE OF WESTPHALIA

The village of Westphalia obtains its water supply from the Saginaw Formation, which is moderately productive in the area of the village. As foreseeable future demands are fairly small, continued development of the Saginaw Formation should provide ample water for the next two decades.

SOUTHEASTERN CLINTON COUNTY

The southeastern part of Clinton County has fairly abundant water resources. The Looking Glass River, which flows through the central part of the area, has some potential for development as a source of water supply. However, its use for waste-effluent dilution at De Witt probably precludes withdrawal uses of the stream during periods of low flow.

Ground-water resources are fairly abundant, although locally the ground-water reservoirs are not highly productive. The Saginaw Formation and buried outwash are the chief aquifers. At the present time these aquifers, except for household wells, are largely undeveloped, but both have considerable potential for additional development. Water-supply problems may occur in some areas in southeastern Clinton County because productive aquifers do not coincide with areas of potential large demand.

BATH TOWNSHIP

The Saginaw Formation and buried outwash are the chief aquifers in Bath Township. The Saginaw yields large supplies of water in some parts of the township; however, in the central part it will yield less than 200 gpm to large diameter wells. Development of the Saginaw as a source of water for the township would call for several low-yield wells near areas of large demand or a few high-yield wells 2 or 3 miles away from the areas of large demand.

Continued development of ground-water reservoirs in the Lansing metropolitan area will eventually result in a lowering of water levels in the Saginaw Formation in the southeastern part of Clinton County. Interference between wells in the Saginaw Formation in Bath Township and in the Lansing metropolitan area can be reduced by locating large-capacity wells on the north side of the low-yield area extending across the central part of Bath Town ship (pl. 3).

CITY OF DE WITT

The city of De Witt does not have a public water-supply system at present (1969); however, a system is being planned. In the city, where the Saginaw Formation has the greatest potential for development, yields of at least 300 gpm can be expected. Because ontinued development of ground-water reservoirs in the Lansing metropolitan area will result in lowered ground-water levels in southern De Witt Township, wells supplying the city of De Witt should be as far north as practicable to reduce interference between the wells.

Buried-outwash aquifers have considerable potential for water-supply development in the De Witt area. Water-quality factors, however, indicate that development of the Saginaw Formation would be more advantageous than development of the glacial aquifers.

NORTHWESTERN EATON COUNTY

The northwestern part of Eaton County has limited water resources generally, although water resources are abundant locally. The Thornapple River has considerable potential for development of water supplies. At present (1969) it has not been developed for water supply in the region except for a small amount of irrigation.

Glacial deposits compose the chief aquifer in this area. Outwash deposits appear to have considerable potential for development of water supplies; the valley outwash along the Thornapple River is an example. Detailed test drilling and related studies are needed to define adequately the potential of glacial aquifers. The Saginaw and Michigan Formations, which are sources of water to many household wells, are not highly productive.

VILLAGE OF MULLIKEN

Residents of the village of Mulliken and surrounding areas obtain their water supplies from privately owned wells that tap glacial deposits or the Saginaw Formation. Neither of these aquifers appears to be highly productive; however, additional study is needed to determine if the glacial aquifers will yield moderate or large supplies of water. Such a study would help in determining whether a public supply system would be feasible or if development on an individual basis should be continued.

VILLAGE OF SUNFIELD

The village of Sunfield has a public water system supplied by a well tapping buried outwash. The extent of this buried-outwash deposit and its water-bearing potential cannot be defined on the basis of presently available data. The buried outwash in the area of the village, however, should supply the village for two decades of normal growth.

VILLAGE OF VERMONTVILLE

The village of Vermontville obtains its water supply from wells in buried outwash. This aquifer probably is capable of yielding adequate water for anticipated future demands. Although few data are available on the water-bearing characteristics of the valley outwash along the Thornapple River, these deposits should have considerable potential as an additional source of water supply for the village. Withdrawal of water from wells in the valley outwash would induce recharge from the river and would provide supplies adequate for long-term growth.

NORTHEASTERN EATON COUNTY

Most of the northeastern part of Eaton County does not have abundant water resources. The Grand River, which is the principal stream of the area, receives waste effluents from several municipalities and is not suitable for most uses without intensive treatment.

The principal aquifers of the area are the Saginaw Formation and the glacial drift. The Saginaw Formation is not highly productive over much of the area but will yield moderate to large supplies of water to wells in the southern parts of Windsor and Benton Townships and in the eastern part of Oneida Township.

Glacial aquifers in the area will also yield moderate to large supplies of water in several localities. The valley-outwash and buried-outwash aquifers along the Grand River in Windsor Township should be highly productive sources of water. Valley outwash along the Thornapple River also should yield moderate to large supplies of water.

CITY OF GRAND LEDGE

The city of Grand Ledge obtains its water supply from wells tapping the Saginaw Formation, which crops out along the Grand River at Grand Ledge. This area was formerly a point of natural discharge from the formation. Most water that is now being withdrawn from the municipal wells would have discharged naturally to the river if it were not discharged by wells. Water levels have remained nearly static during the past 20 years (fig. 30). Additional withdrawals will result in an expanded cone of depression that will cause an additional decrease in natural discharge and

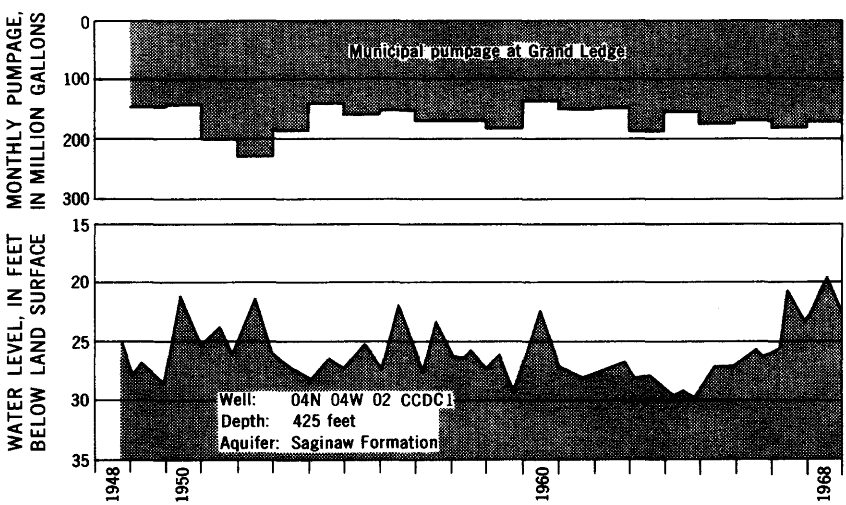

FIGURE 30.—Pumpage has not had significant effects on ground-water levels at Grand Ledge.

will induce additional recharge from the river. The Saginaw Formation should continue to supply the needs of the city for the next two decades, although increased withdrawals will call for additional wells and lower pumping levels.

VILLAGE OF POTTERVILLE

The village of Potterville obtains its water supply from the Saginaw Formation, which is moderately productive in the Potterville area. The present withdrawal rates are low. Anticipated demands for water during the next two decades can be met through installation of additional "Saginaw" wells.

WINDSOR TOWNSHIP

Windsor Township presently (1969) does not have a public water system, although its rapid urbanization may require that a public water system be initiated in the future. The two chief sources of water supply for the township are the Saginaw Formation and the glacial aquifers. The Saginaw is productive in the southern part of the township, but in most of the remaining part it yields less than 100 gpm per well. The glacial aquifers along the Grand River are potential sources of large water supplies for the township; withdrawals from these aquifers will induce recharge from the river. During periods of low flow the need for streamflow for sewage dilution at Lansing may conflict with large withdrawals of water from wells tapping stream-fed aquifers.

SOUTHWESTERN EATON COUNTY

The southwestern part of Eaton County as a unit does not have abundant water resources. Battle Creek, which flows through the southern part of the area, is utilized for the discharge of waste effluents from Charlotte, Olivet, and Bellevue. Thus, the stream is not of suitable quality for use as a source of water for public supply without extensive treatment.

The principal aquifers of this area are the glacial drift and the Marshall Formation. The Saginaw, Bayport, and Michigan Formations, which are tapped by household wells, generally are not sources of major water supplies.

The glacial aquifers, especially the valley-outwash aquifers, offer considerable potential for future development. Buried-outwash deposits also may be important sources of future water supply. These aquifers, however, underlie only a small part of the area. The Marshall Formation yields saline water in all but a few square miles of the southwestern part of the area (pl. 3). Locally, in the area where it yields fresh water, it will yield several hundred gallons per minute to wells.

CITY OF BELLEVUE

The city of Bellevue obtains its water from the Marshall Formation, which is moderately productive at Bellevue. The water, however, contains hydrogen sulfide, objectionable concentrations of iron, and 200 mg/l of chloride, which is near the recommended limit for public water supplies (250 mg/l). Increased withdrawals from the formation in time may result in an increase in chloride content. Hence, the long-term outlook for water supply at Bellevue is uncertain. As the glacial deposits are fairly thin within the city, their potential is small, but glacial deposits east of the city appear to have potential for development of moderate supplies.

CITY OF OLIVET

The city of Olivet obtains its water supplies from the Marshall Formation, which yields water of low chloride content at Olivet. However, one test well drilled into the Marshall at Olivet yielded water with objectionable concentrations of chloride. Apparently, water from the overlying Michigan Formation contaminated the water in this well.

The Marshall Formation should continue to provide water supplies adequate to meet the demands of the city during the next two decades. Some new supply wells, however, probably will have to be drilled outside the city limits. The chloride content of the water from the Marshall should be monitored to determine whether the chloride content increases as withdrawal rates increase.

SOUTHEASTERN EATON COUNTY

The southeastern part of Eaton County has moderately abundant water resources. The need for water for sewage dilution during periods of low flow, however, may conflict with development of the Grand River and Battle Creek as sources of major water supply unless storage reservoirs are created to compensate for withdrawals. The principal aquifers of the area are the glacial deposits, the Saginaw Formation, and, in the southern edge of the area, the Michigan Formation. The Saginaw Formation is highly productive in much of the northern half of the area but is not so productive in the southern half. The glacial deposits potentially are sources of large supplies of water in some localities but generally yield only a few gallons of water per minute to wells as does the Michigan Formation.

CITY OF CHARLOTTE

The city of Charlotte obtains most of its water supplies from wells tapping valley outwash along Battle Creek. It also obtains some water from a well tapping the Saginaw Formation. Water levels in the glacial aquifer have declined only a few feet during the past several years despite continued increases in the rate of withdrawal (fig. 31). The fact that the decline is small indicates

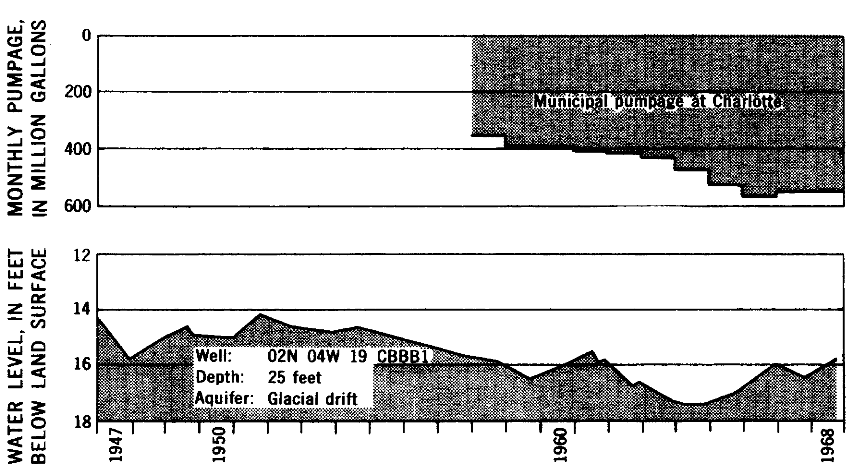

FIGURE 31.—Water levels at Charlotte have not declined significantly despite increased pumpage.

that the aquifer intercepted discharge and induced recharge from Battle Creek at a rate approximately equal to the withdrawal rate. Because the aquifer is recharged from the stream, considerable additional withdrawals are possible if adequate streamflow is available for recharge. For the same reason, the quality of water in the stream is an important factor in future development of the aquifer. The glacial and bedrock aquifers at Charlotte should easily supply the needs of the city for the next two decades.

CITY OF EATON RAPIDS

Eaton Rapids obtains its water supply from glacial outwash and the Saginaw Formation; both sources yield fairly large supplies of water. The water is very hard and contains objectionable quantities of iron, which are reduced by treatment. The aquifers in and adjacent to the city will yield adequate water for future growth, but softening is needed to provide a water satisfactory for domestic use.

ORTHEASTERN INGHAM COUNTY

The northeastern part of Ingham County does not have abundant water resources. The Red Cedar River, the principal stream, presently offers little potential as a source of water supply as all its flow is needed during low-flow periods for dilution of waste effluents. With storage, however, the stream has some water-supply potential.

The glacial deposits and the Saginaw Formation, the principal aquifers of the area, are not highly productive over much of the area. They will yield moderate to large supplies of water in some localities. Streamflow data indicate, however, that the valley-outwash deposits along Coon Creek in Williamston Township may be a source of large water supplies.

CITY OF WILLIAMSTON

The city of Williamston obtains most of its water supply from two wells in the Saginaw Formation, although it has one well which taps sand and gravel beds of an esker in the western part of the city. The Saginaw Formation is not highly productive in the Williamston area, but two Saginaw wells have supplied most needs of the city for almost two decades. These wells yield water that is relatively soft and of low iron content in contrast to the glacial well, which yields water that is hard and of high iron content. Thus, the Saginaw Formation is preferred as a source of water, and plans are being made to install additional Saginaw wells southwest of the city. The Saginaw Formation is moderately produc-

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tive south of Williamston, and this aquifer should provide adequate supplies for the next two decades. The glacial deposits along the small creek that flows through the northwestern part of the city could provide additional water.

VILLAGE OF WEBBERVILLE

The village of Webberville obtains its water supplies from wells tapping the Saginaw Formation. The Saginaw is highly productive in the Webberville area and should provide sufficient water for foreseeable growth during the next two decades.

SOUTHWESTERN INGHAM COUNTY

The southwestern part of Ingham County has relatively abundant water resources, the chief sources being the Saginaw Formation and the glacial aquifers. Although the Saginaw will yield less than 50 gpm to a well in the northeastern part of Vevay Township, the aquifer is highly productive over most of the area. The glacial deposits also are potential sources of moderate or large supplies over rather extensive areas.

CITY OF MASON

The city of Mason obtains its water supplies from the Saginaw Formation and the beds of sand and gravel associated with the Mason esker. Increased withdrawals from the Saginaw Formation have resulted in a decline in water levels since 1948 (fig. 32).

The aquifers at Mason are capable of yielding considerable additional water, but the long-term needs for water probably will call for expansion of the well system beyond the present city limits. The Saginaw Formation west of the city appears to be most favorable for the development of large supplies of water. Beds of sand and gravel associated with the Mason esker south of the city also have potential as additional sources of water.

VILLAGE OF LESLIE

The village of Leslie obtains its water supplies from the Saginaw Formation, which is moderately productive within the village. Apparently the Saginaw becomes more productive northwest of the city. Demands for water during the next two decades can be met through further development of the Saginaw aquifer.

SOUTHEASTERN INGHAM COUNTY

The southeastern part of Ingham County has moderately abundant water resources, the chief aquifers being the Saginaw Forma-

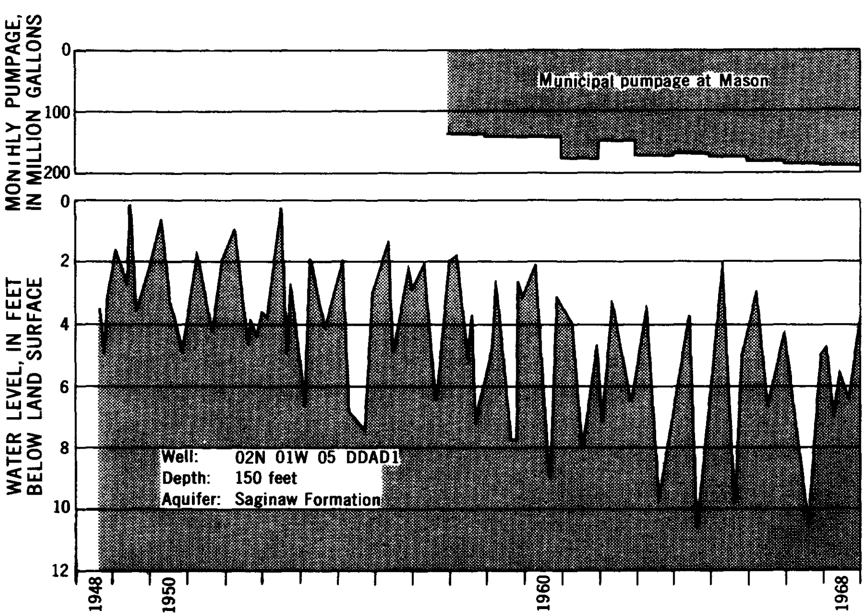


FIGURE 32.—Ground-water pumpage has caused a decline in water levels at Mason.

tion and the glacial drift. The Saginaw, although moderately productive in some parts of the area, yields less than 100 gpm to wells over most of the area. The productivity of the glacial deposits in the area has not been adequately defined, but these deposits appear to have considerable potential. Beds of sand and gravel underlying the outwash plains and the valley outwash should yield moderate to large supplies of water throughout a large part of the area.

VILLAGE OF STOCKBRIDGE

The village of Stockbridge obtains its water supplies from the Saginaw Formation. The formation is not very productive over much of Stockbridge Township, but at the village it yields several hundred gallons per minute to wells. The iron content of the water is reduced by treatment. The area south and west of the village appears to be most favorable for the future development of the Saginaw, and the formation should provide adequate water for growth during the next two decades.

LANSING METROPOLITAN AREA

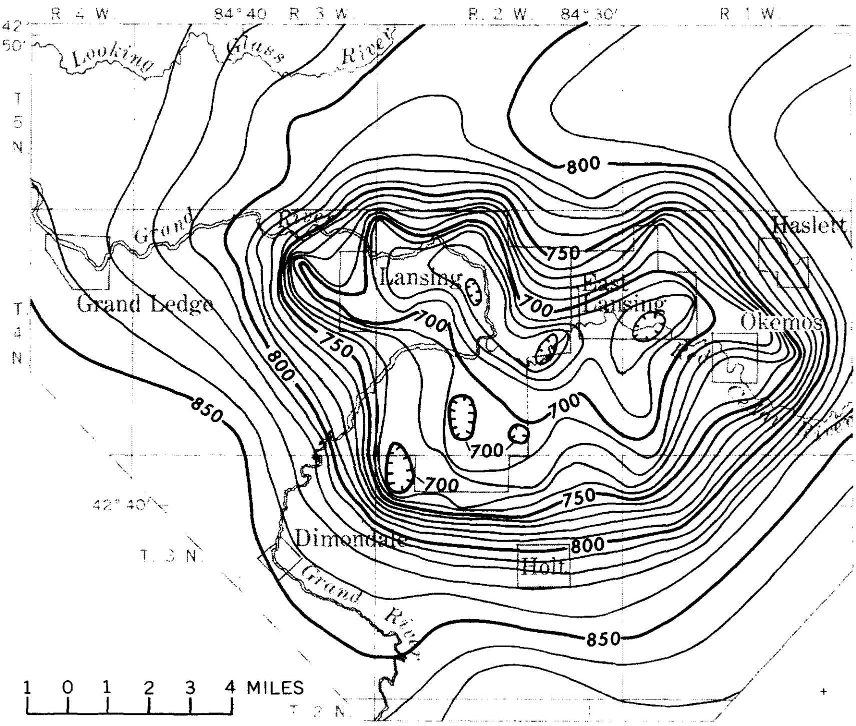
Local sources of water for the Lansing area are the Saginaw Formation, the glacial-drift aquifers, and the Grand and Red

Cedar Rivers. These sources have provided adequate supplies of water for residents in the Lansing area for over a century. During the past 60–70 years, most water used in the area has been supplied by public water systems. The evolution of municipal water supplies since about 1910 has consisted of development of an initial water system supplied by a few wells and expansion of the system by addition of wells. Pumps capable of lifting water from ever-increasing depths also were needed to compensate for declining ground-water levels. Most of the water is conditioned to reduce hardness and iron content.

The city of Lansing has expanded its water-supply system by taking advantage of the induced-recharge potential of the glacial-drift aquifers. Other municipalities in the metropolitan area have been able to obtain adequate supplies from wells tapping the Saginaw Formation.

Although development of water supplies through continued addition of wells to municipal systems has been adequate to meet the increased needs for water during previous decades, future development of local water sources will call for intensive water management programs. The objective of such programs will be the utilization of streams in combination with ground-water reservoirs. The following types of programs of local-water-resources development can be utilized to meet the needs for the periods 1970–85 and 1986–2000.

For the period 1970–85, continued addition of new wells to existing systems, including wells in the glacial aquifers which will receive induced recharge from streams, will provide sufficient water to meet most demands. Under this type of management, the combined average yield of the aquifers of the area is estimated to be about 70 mgd. Withdrawal of water from the Saginaw Formation at a 52-mgd rate necessary to provide the combined yield of 70 mgd will result in considerable drawdown in the potentiometric surface of the Saginaw Formation by 1985. The configuration of the potentiometric surface at that time and a drawdown of the potentiometric surface between 1935 and 1985 as determined from an analog-model study (Vanlier and Wheeler, 1968) of the region are shown in figures 33 and 34. The analog simulation predicts that the altitude of the potentiometric surface in the Lansing metropolitan area will generally range from 660 to 870 feet in 1985; this indicates a drawdown of as much as 150 feet in the period 1935–85. The simulated withdrawal rates used to obtain this drawdown are shown in figure 35. The analog study indicates that 52 mgd is about the maximum practical rate of withdrawal from the Saginaw Formation in the metropolitan area by 1985



EXPLANATION

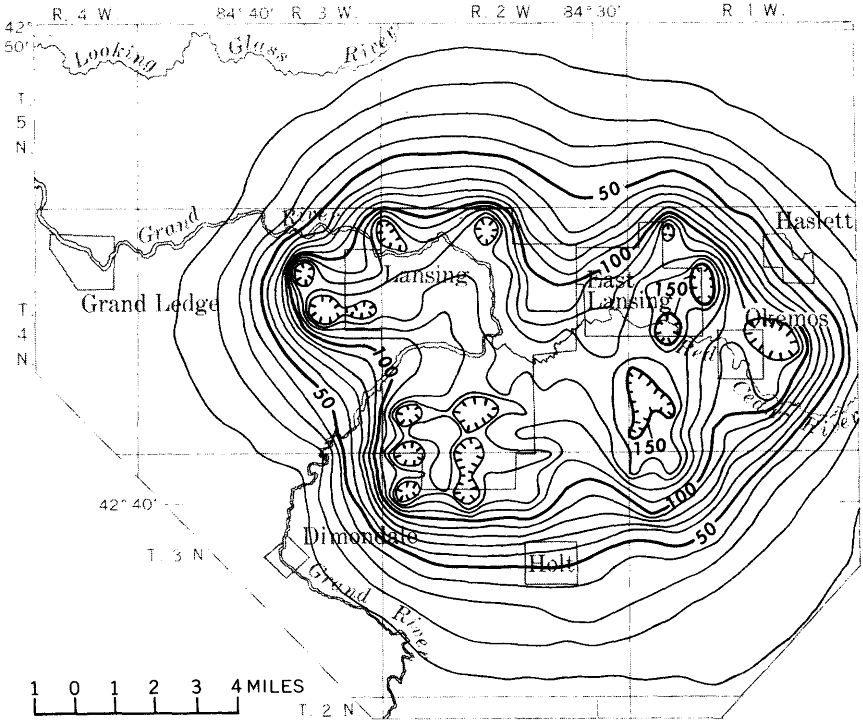
——850——

Potentiometric contour

Shows simulated altitude of potentiometric surface in 1985. Contour interval, 10 feet. Datum is mean sea level. Hachures indicate depressions

FIGURE 33.—Analog simulation predicts that the altitude of the potentiometric surface in 1985 in the Lansing metropolitan area will generally range from 660 to 870 feet.

without provision for artificial recharge. Withdrawal at average rates of 52 mgd by 1985 (fig. 35) will cause significant decline in water levels. Withdrawal rates significantly greater than those indicated in figure 35 would cause dewatering of a considerable part of the formation, resulting in a decline in the yields of individual wells. Although such decline could be compensated for through the installation of additional wells, each new well would reduce the yield of adjacent wells. The total increase in yield would be relatively small and the cost of additional wells would be large. Hence, the yield of 52 mgd by 1985 is an estimate of practical maximum yield.



EXPLANATION

—— 50 ——

Line of equal decline in the potentiometric surface from 1935 to 1985

Interval 10 feet. Hachures indicate depressions

FIGURE 34.—Drawdown of as much as 150 feet may occur in the potentiometric surface in the Lansing metropolitan area between 1935 and 1985 as determined by analog simulation.

For the period 1986–2000, some municipalities in the Lansing metropolitan area will not have sufficient water to meet demands unless wells are added outside the metropolitan area. Most of the highly productive aquifers within the area should be fully developed by 1985. However, demands for several decades can be met by importing water from outlying areas where water levels have not been lowered by ground-water withdrawals. Such development by individual governmental units, however, could be prevented or restricted by legal and political factors.

If water cannot be imported from outlying areas, water-supply development in the period 1986–2000 will involve complex water-management programs. Use of streams for water supply would be

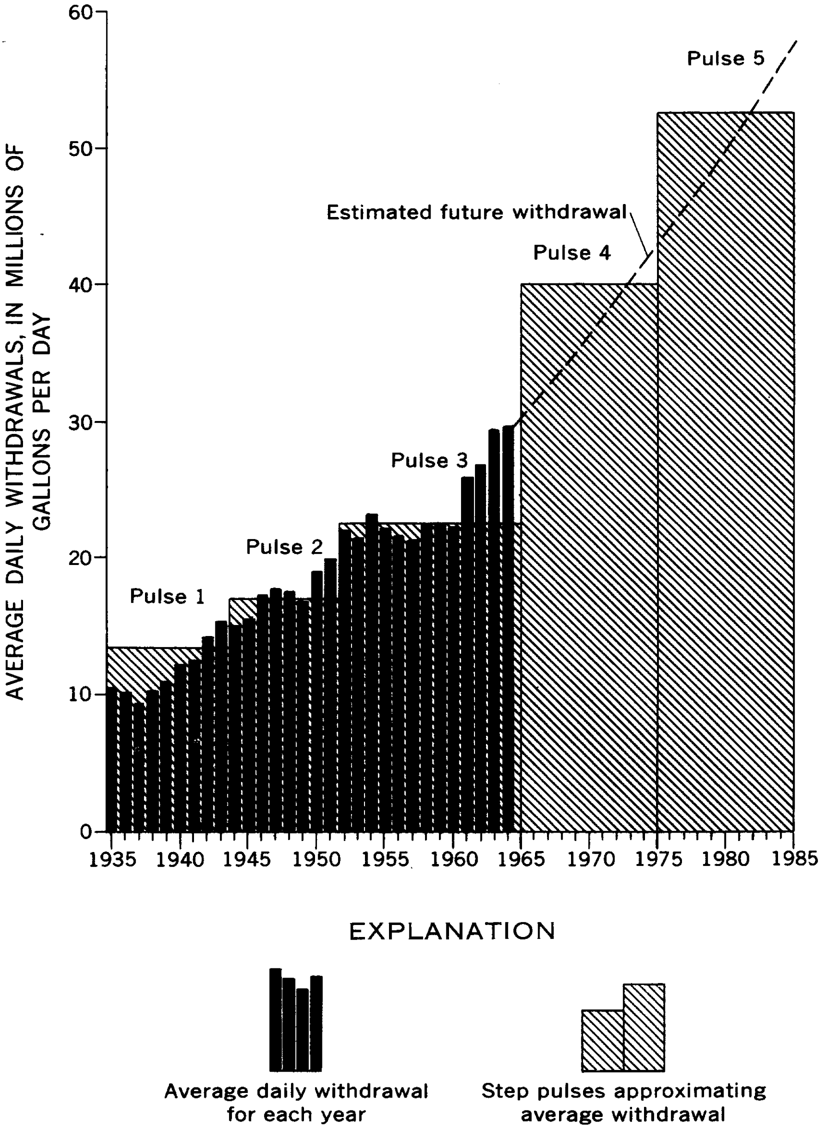


FIGURE 35.—Average daily withdrawal rates from the Saginaw Formation will increase to 52 million gallons by 1980.

a significant part of such programs. The streams of the area could be utilized for water supply during periods of ample flow, and during periods of low flow, water could be obtained from wells. During periods of ample flow, the streams also could be used to supply water for artificially recharging the Saginaw Formation. Use of large quantities of water from the streams will call for water-management programs to control streamflow and to protect and improve the quality of stream water. These objectives can be obtained through improvement of waste- and sewage-treatment techniques to prevent degradation of water quality and through construction of reservoirs for storage of surplus flows. (Such reservoirs can also be managed to provide flood control and other benefits.) Utilization of these programs is envisioned in preliminary plans for development of the water resources of the Grand River basin. Sewage from upstream communities could also be transported to points below potential intakes for water systems in the Lansing area. With such programs, the combined flows of the Grand and Red Cedar Rivers could be utilized for water supply during periods of ample streamflow.

Through utilization of artificial-recharge and induced-recharge facilities, the aquifers of the area could sustain an average yield of about 140 mgd for a period of 150 days. During the remainder of the year the Grand and Cedar Rivers could, under proper management, provide at least 140 mgd of water of good quality. Thus, with comprehensive management, the sustained yield from local sources would be about 140 mgd.

The long term needs of the area can be met also through a supply system which would utilize the water resources of the entire region. The Saginaw Formation and the glacial aquifers of the region could provide adequate supplies for the Lansing metropolitan area for at least four decades.

It should be recognized that these more complex water-development and water-management programs would raise the unit cost of water considerably above that of present programs. Thus, through time, importation of water from the Great Lakes will become increasingly attractive from an economic standpoint (fig. 27).

If water is to be imported from the Great Lakes, local sources can be utilized for water supply during the planning and construction period. The most economical means for obtaining water in this interim period probably will be to utilize the water in storage in the Saginaw Formation.

After completion of the importation system, existing wells, pumps, and related facilities could be used to provide emergency water supply and if necessary to augment the importation system during periods of peak demand.

CITY OF LANSING

The city of Lansing obtains nearly all its water from the Saginaw Formation. Some water is also obtained from outwash along the Grand River.

Future demands for water can be met in part through the installation of additional wells in the Saginaw Formation in the southern part of the city. The formation is believed to be highly productive in the southeastern part of the city.

Continued development of glacial aquifers, especially along the Grand River and Sycamore Creek in the southeastern part of the city, will also be needed to meet future demands. Withdrawal of water from these glacial deposits will result in depletion of streamflow, which may interfere with other water uses during dry weather periods. During periods of ample streamflow, however, the glacial aquifers can be fully utilized and withdrawals from the Saginaw Formation can be decreased. This would allow for increased withdrawal from the Saginaw during periods of dry weather.

Artificial recharge can be used to increase the yield of the Saginaw Formation. The most promising location for artificial recharge of the Saginaw Formation is in the vicinity of the bridge over the Red Cedar River on Pennsylvania Street. At this location, dewatered beds of sand and gravel overlie beds of dewatered sandstone. Artificial recharge could be accomplished by constructing pits in the glacial sand and gravel deposits and then diverting water from either the Red Cedar River, or Grand River, or Sycamore Creek into the pits during periods of ample streamflow.

The quality of water is generally good and with proper precautions should remain that way in the future. Care must be taken, however, to prevent conditions around abandoned brine wells from deteriorating. Poor-quality water from these wells should be contained either through proper plugging of the wells or by raising the potentiometric surface of the Saginaw through recharge or decreased pumpage in the area. Also, wells could be drilled and the poor-quality water pumped into the Grand River. This procedure could effectively stop the enlargement of the contamination area. Water quality of the Grand River probably would not be adversely affected because the large volume of streamflow would provide a large dilution factor.

With continued development, under intensive management including large-scale artificial recharge, the Saginaw Formation and the glacial aquifers within or adjacent to the city should provide adequate water supplies for the city for the next two decades.

EAST LANSING AND MERIDIAN TOWNSHIP

East Lansing and Meridian Township obtain their water supplies from the Saginaw Formation. Although the two communities have separate distribution facilities, they are planning to use a common water-supply system.

The chief aquifer in these communities is the Saginaw Formation. The formation is highly productive in the southern and western parts of Meridian Township but is far less productive along the eastern edge of the area. Withdrawals from the Saginaw Formation in the Okemos area will induce recharge from the Red Cedar River. Other potential sources of major water supply are the buried-outwash deposits in the northern part of the township and the sand and gravel beds along the esker that runs along the eastern edge of East Lansing.

The aquifers of the area should provide adequate water supplies for the next two decades. However, estimates of future water demands for these two communities range widely. If demands are as large as some population projections indicate, additional water-management programs, such as artificial recharge, may be needed to meet demands after 1985.

LANSING TOWNSHIP

Lansing Township obtains its water supply from the Saginaw Formation, which is fairly productive in the township area. However, withdrawal of water by the township and by neighboring communities has already resulted in considerable decline in water levels. This decline will continue and accelerate during the next decade and will result in a decrease in the yield of township wells. By 1980–85 the decline in water levels may become acute. An increasing number of wells will be needed to obtain the same quantity of water from the formation. Buried-outwash deposits may have some potential as sources of water supply in the township; however, detailed geophysical and test-drilling studies are needed to determine the potential of these deposits.

The fact that the township is encompassed by other municipalities that also are developing local water resources to their full extent seriously restricts the township's area of potential development. The problem of providing adequate water supplies will become increasingly difficult if the township is forced to rely only upon those resources within its boundaries.

DELTA TOWNSHIP

Delta Township's public water system is supplied from the Saginaw Formation. This formation has considerable potential for additional development, especially in the northern part of the township. Another possible source of large water supplies is the buried outwash, but detailed studies are needed to determine the potential of the glacial aquifers of the township. It appears that the needs of the township can be met for the next two decades through continued development of the Saginaw Formation and glacial aquifers.

DELHI TOWNSHIP

Delhi Township presently (1969) is in the process of developing a public water-supply system, which is to be supplied by the city of Lansing. The Saginaw Formation is highly productive in the township. Apparently the formation is hydraulically connected to beds of glacial sand and gravel which in turn are fed by streams. Hence, the rate of recharge to the formation is high. However, continued development of the Saginaw Formation by other communities in the area will cause a lowering of water levels in the northern part of the township.

MICHIGAN STATE UNIVERSITY

Michigan State University obtains its water supply from the Saginaw Formation, which is highly productive in the campus area. The needs of the University can be met until about 1985 through the continued addition of wells in the Saginaw Formation, although water-level declines during this period will significantly decrease the yield of existing wells. After 1985 it will be difficult to meet needs for water through the continued addition of Saginaw wells.

Glacial aquifers capable of yielding moderate to large supplies of water are present along the Red Cedar River within the campus area. Other sand and gravel aquifers which will yield moderate to large supplies of water undoubtedly are also present in the campus area. However, test drilling and related studies are needed to define their potential.

SUMMARY AND CONCLUSIONS

The Tri-County region has fairly abundant water resources; large quantities of water are available from several aquifers, and additional water supplies could be developed from several streams.

The Saginaw Formation is the major source of water supplies in the region. It is a highly productive aquifer, but only in the Lansing metropolitan area has it been extensively developed for water supplies. Over most of the region, the Saginaw has been utilized only to supply water to farms and other rural households. In many of these areas, the formation has good potential for the development of municipal water supplies.

Productive glacial aquifers, especially the surficial and buried outwash, underlie more than 100 square miles of the region. These aquifers appear to have considerable potential for development for municipal water supplies; however, test drilling, aquifer tests, and related studies are needed to define adequately the potential of the buried-outwash deposits.

Other aquifers of the region also are potential sources of water supplies. The Grand River Formation is a minor source of water in Clinton County, and the Bayport, Michigan, and Marshall Formations in southeastern Ingham County and in the southwestern part of Eaton County are sources of fresh water.

The availability of water in the region relates not only to the natural hydrologic and geologic characteristics of the region but also to the type and degree of water management utilized. Estimates of regional water availability on a sustained-yield basis generally range from 200 mgd under minimum management to 400 mgd under intensive management. In addition a large volume of water is stored in the ground-water reservoirs of the region. Thus, if all the water resources of the region could be utilized under a comprehensive management program, the needs of the region could be served for many decades to come.

The backbone of an intensive management program is the utilization of streams in combination with ground-water reservoirs. The following steps will eventually be needed in this management program to provide adequate water supplies:

1. Protection and improvement of the quality of water in streams to provide for reuse of water.
2. Storage of excess flows to augment low flows.
3. Use of ground-water reservoirs during periods of low flow and use of streams during periods of excess flow.
4. Artificial recharge of aquifers.

Although local resources generally will be adequate to meet future needs, the possibility exists of serious water-supply problems developing within the next few decades. Such problems could result from the fact that the chief area of large water demand, the Lansing metropolitan area, encompasses only a small part of the area of potential water supply. If water supplies for this area have to be provided from the ground-water resources within the corporate limits of the communities in the metropolitan area, major problems in developing adequate municipal supplies will develop—for some communities by 1985 and for most communities by 1990. The fact that serious water-supply problems may not occur simultaneously for all communities in the metropolitan area may mask the common nature of the problem.

Another source of water supplies to the Lansing metropolitan area is the Great Lakes. The decision as to whether the local water resources should continue to be utilized for water supply or whether water should be imported from the Great Lakes should be based primarily on economic factors, as it is feasible from hydrological and engineering standpoints to utilize either source. Systems analysis is needed to determine the relative advantages of the alternative water-supply systems.

The development of the optimum water-supply system for the Lansing metropolitan area is a major challenge to the region. The development of such a system will call for the cooperative action of the largest water users in the region.

Communities outside the metropolitan area will be able to develop adequate water supplies from local sources for the next several decades. Some communities, however, may have to expand the area of potential development to 1 or 2 miles from their existing corporate boundaries.

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