Water for a Rapidly Growing Urban Community--

GEOLOGICAL SURVEY
WATER-SUPPLY PAPER 2000

Oakland County, Michigan

Water for a Rapidly Growing Urban Community-- Oakland County, Michigan

By F. R. TWENTER
and R. L. KNUTILLA

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A study of the occurrence, quality, and availability of water as it relates to the rapidly growing industrial and domestic needs of Oakland County

Prepared in cooperation with Oakland County and the State of Michigan

UNITED STATES DEPARTMENT OF THE INTERIOR

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DEFINITION OF TERMS

Acre-foot (acre-ft). The quantity of water required to cover 1 acre to a depth of 1 foot; equal to 43,560 cubic feet or 325,851 gallons.

Aquifer. A formation, group of formations, or part of a formation that is water bearing. Also called groundwater reservoir.

Artesian water. The occurrence of ground water under sufficient hydrostatic head to rise above the upper surface of the aquifer.

Base flow. Discharge entering stream channels as effluent from the groundwater reservoir; the fair weather flow of streams.

Bedrock. In this report, designates the consolidated rock underlying the glacial deposits.

Coefficient of transmissivity. A term used to express the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer under a gradient of 100 percent.

Cubic feet per second (cfs). A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, whose velocity is 1 foot per second; equivalent to 448.8 gallons per minute or about 0.65 million gallons per day.

Cone of depression. A conical depression, on a water table or piezometric surface, produced by pumping.

Drawdown. Lowering of the water table by pumping or artesian flow.

Effluent seepage (effluent flow). Flow of water from the ground into a surface-water body.

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 Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plant transpiration, no attempt being made to distinguish between the two.

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Gravity yield. The ratio of the volume of water which a rock or soil unit, after being saturated, will yield by gravity to its own volume.

Ground water. Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.

Ground-water runoff. That part of streamflow which consists of water discharged into a stream channel by seepage from the ground-water reservoir; same as base flow.

Hydrograph. A graph showing changes in stage, flow, velocity, or other aspect of water with respect to time.

Infiltration. The flow of a fluid into a substance through pores or small openings.

Low-flow frequency curve. A graph showing the magnitude and frequency of minimum flows for a period of given length.

Partial-record station. A site where limited streamflow data are collected systematically over a period of years for use in hydrologic analyses.

Permeability. The capacity of a material to transmit a fluid.

Recharge. Addition of water to an aquifer by infiltration of precipitation through the soil, by seepage from streams or other bodies of surface water, by flow of ground water from another aquifer, or by pumpage of water into the acquifer through recharge wells; also, the water added by these processes.

Recurrence interval (return period). The average interval of time within which the given flood will be equaled or exceeded once; also, the average interval of time within which a flow equal to or lower than a given low flow will occur once.

Runoff. The water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Soil moisture. Water diffused in the soil or in the upper part of the zone of aeration from which water is discharged by the transpiration of plants or by soil evaporation.

Subcrop. In this report, a bedrock formation or rock unit that occurs directly under the glacial deposits and that would be exposed at land surface if all the glacial deposits were removed.

Water table. The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Zone of saturation. The zone in which the functional permeable rocks are saturated with water under hydrostatic pressure.

WATER FOR A RAPIDLY GROWING URBAN COMMUNITY—OAKLAND COUNTY, MICHIGAN

By F. R. Twenter and R. L. Knutilla

ABSTRACT

Oakland County, an area of 899 square miles, is in southeastern Michigan. The southern part of the county is overlapped by the suburbs of the city of Detroit.

In 1970, about 850,000 people were living in the county and using about 100 million gallons of water a day. More than 80 percent of the water used for large industrial and municipal supplies came from Detroit's water system.

The average annual rate of streamflow from the county is about 370 million gallons per day (575 cubic feet per second). Median annual 7-day low flows range from 0 to 0.25 cfs per square mile. Low flows can be augmented by more than 60,000 acre-feet of water captured during high streamflow by construction of small reservoirs at 21 inventoried sites.

Glacial deposits and the Marshall Sandstone are the prime sources of ground water. Most wells that penetrate the full thickness of glacial deposits in the northwestern part of the county will yield at least 50 gpm (gallons per minute), and many will yield more than 400 gpm. The Marshall Sandstone, which occurs only in the Holly area, is capable of yielding more than 1,000 gpm.

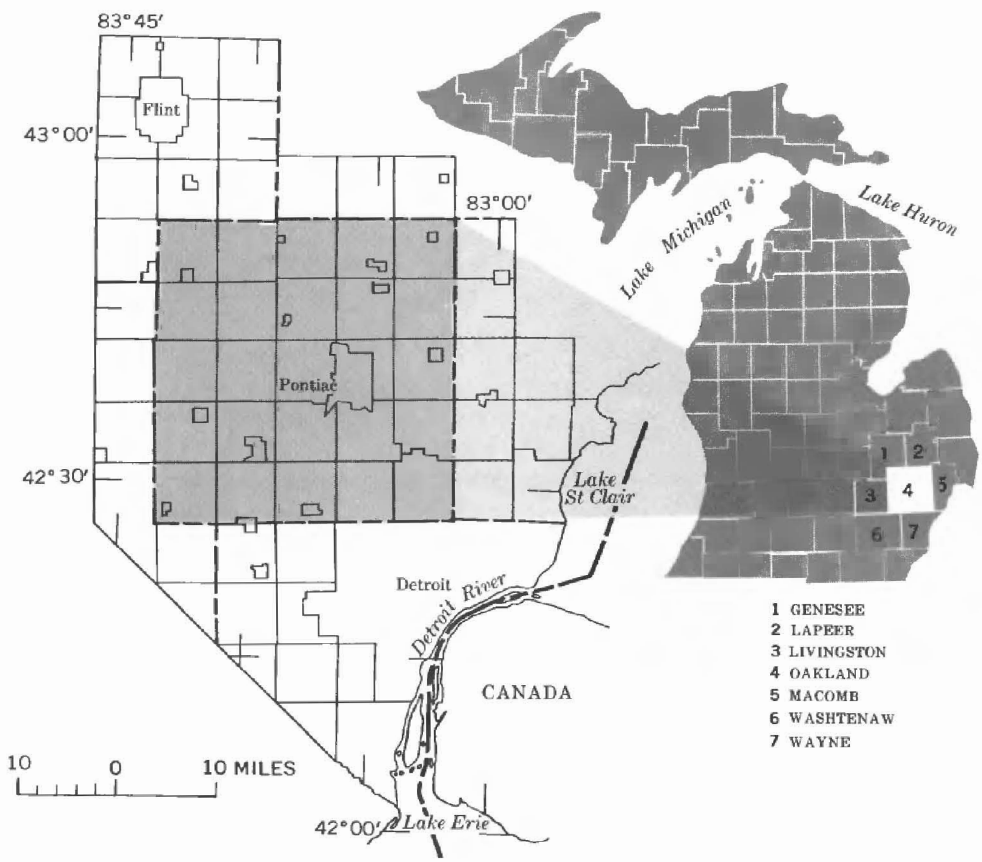
The chemical quality of both surface and ground water is relatively good throughout the county. Only in the southern part of the county is the dissolved solids above the acceptable standard of 500 milligrams per liter.

1. Oakland County

LOCATION

Oakland County is in the southeastern part of Michigan's Lower Peninsula (fig. 1). It is relatively close to two of the Great Lakes—Lake Erie, about 25 miles to the southeast, and Lake Huron, about 35 miles to the northeast.

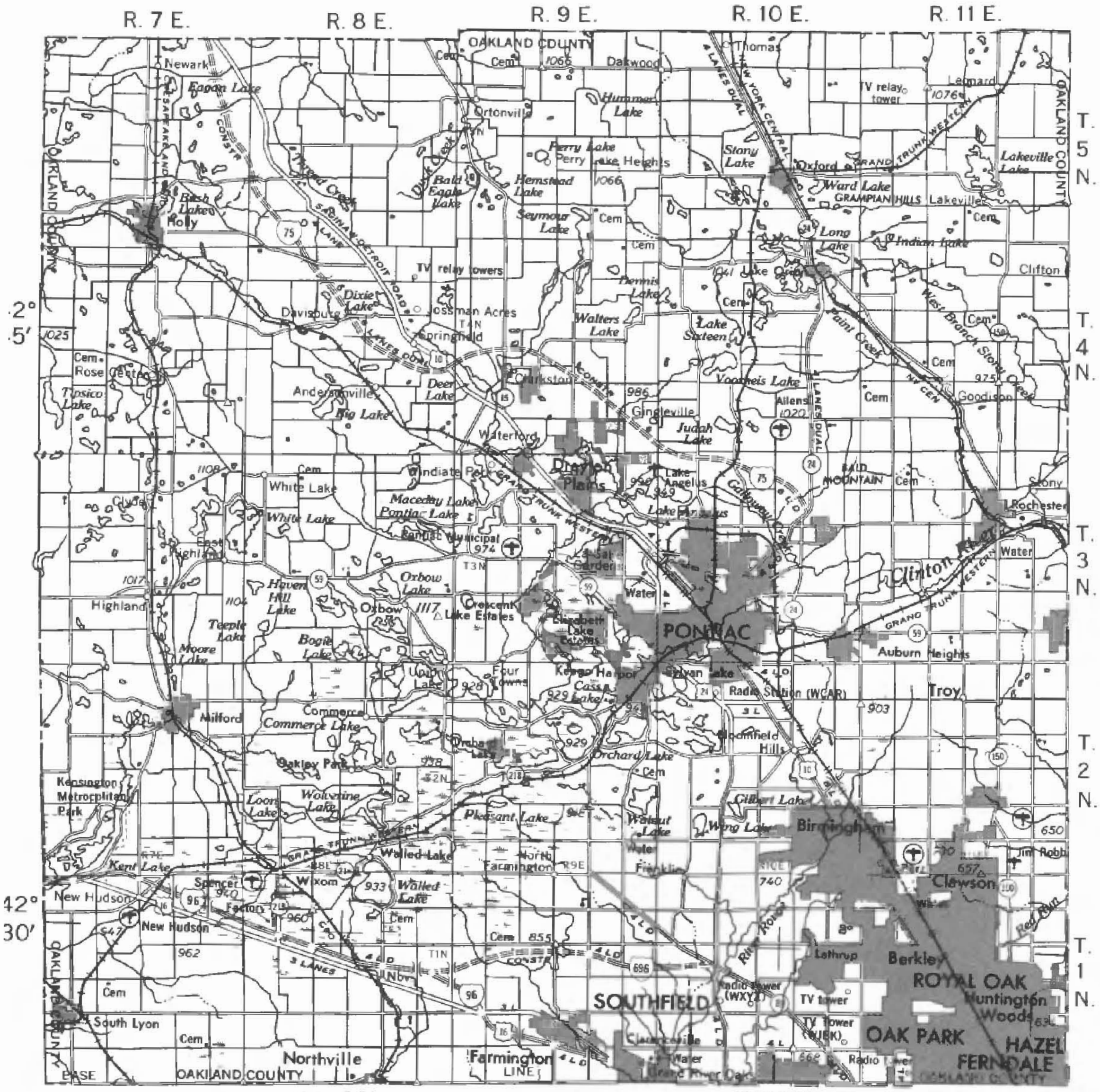
Pontiac, the largest city in the county, is in the economic and population corridor between Detroit and Flint (fig. 2). With the continuous increase in population, the northern suburban area of Detroit has overlapped into the southeastern corner of Oakland County and has merged with communities in the suburbs of Pontiac. In the future, urbanization from the cities of Detroit and Pontiac will wedge northward and merge with Flint to form one large metropolitan complex.



Oakland County—899 square miles of Michigan. FIG. 1

WATER—THE PURPOSE OF THIS REPORT

Water is an important part of everyday living in Oakland County. The hundreds of lakes that dot the county (fig. 3) are highly valued for year-round recreation and esthetics. Also highly valued for similar purposes are the five major perennial streams and their tributaries.

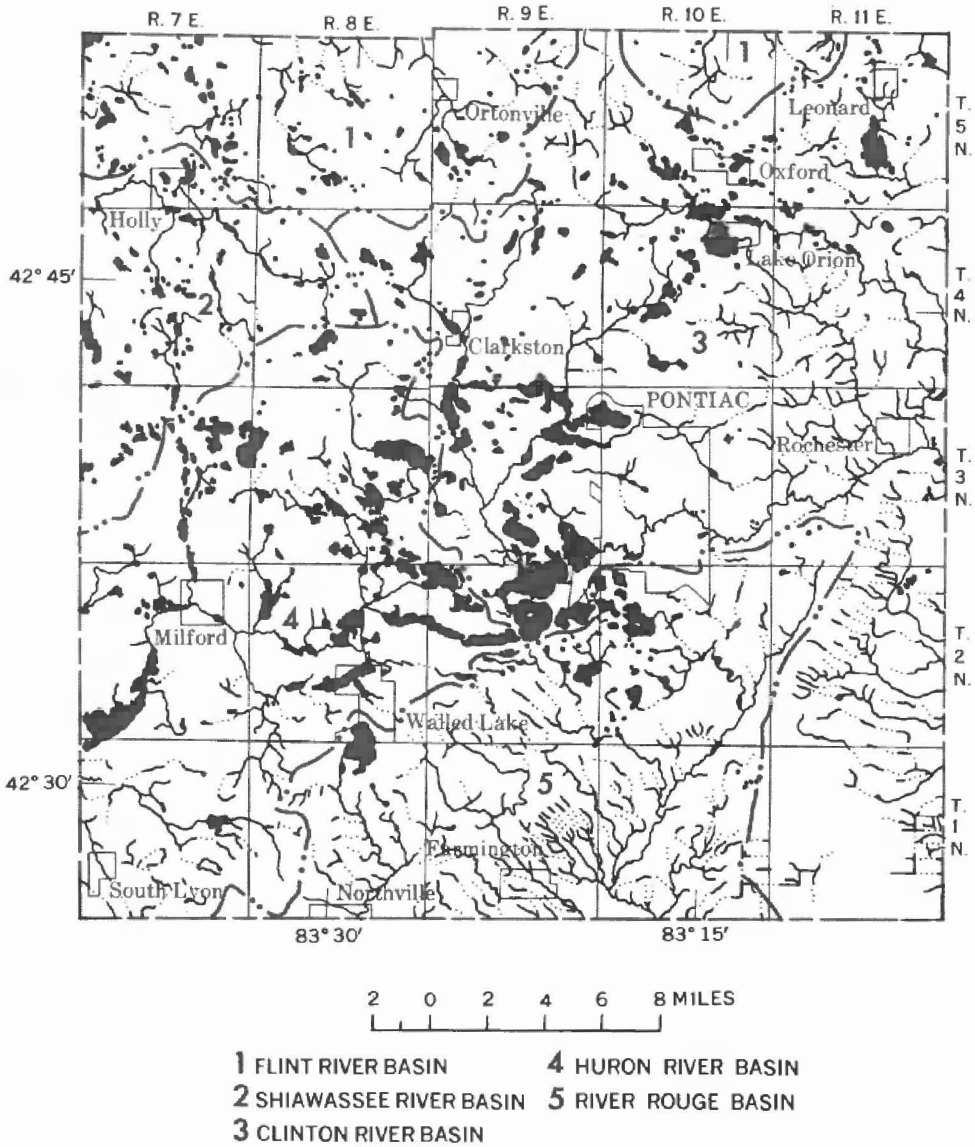


Base from U.S. Geological Survey; 1:250,000; Detroit, 1965

5 0 5 MILES

Index map of Oakland County. FIG. 2

As the city of Pontiac expands and as suburban Detroit extends farther northward, the esthetic, recreational, and homesite value of water in the streams and lakes will become increasingly important. Streams and lakes will serve also as a source of water for irrigation, cooling, and waste dilution. Ground water will con-



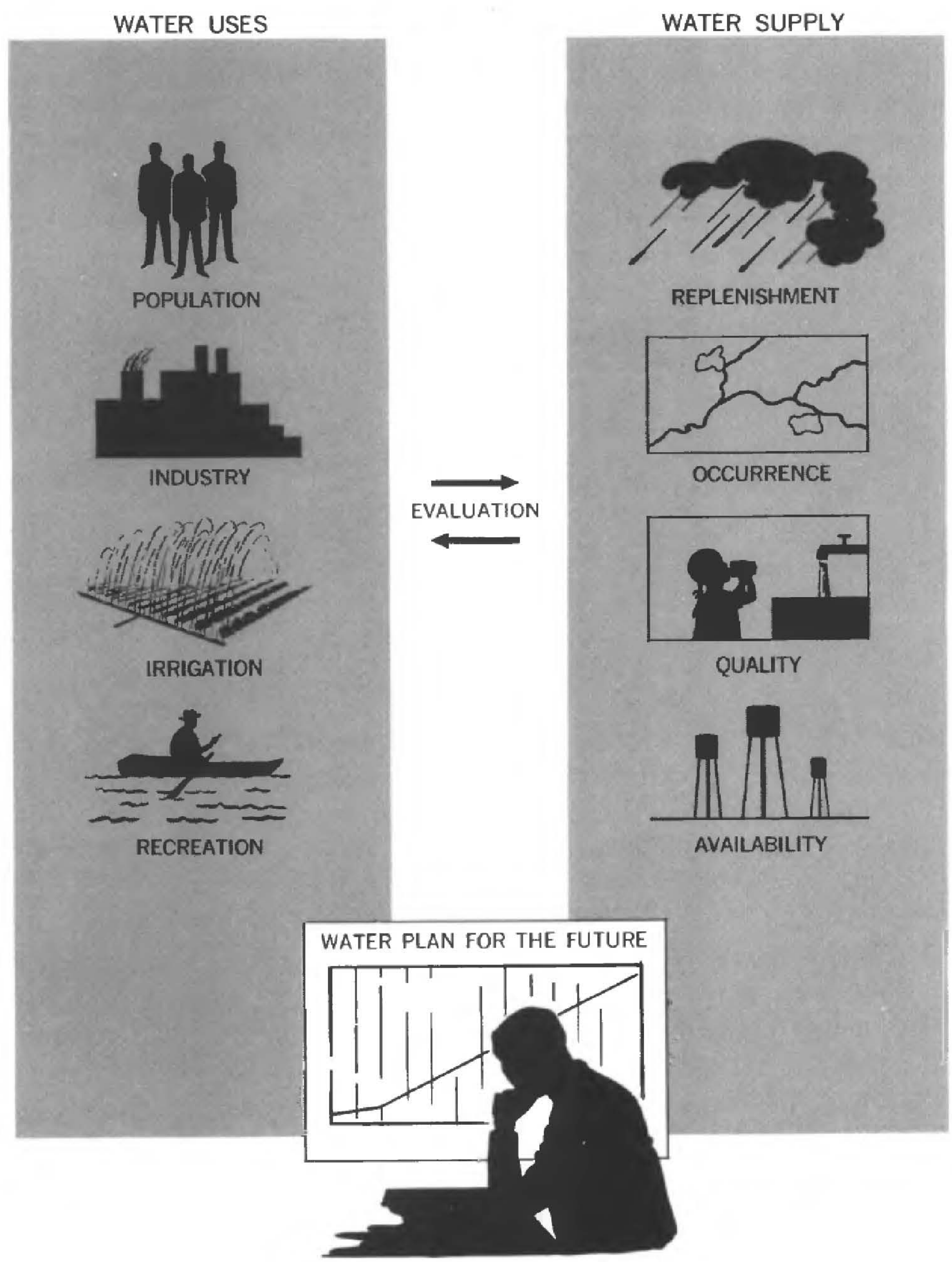
A land of abundant lakes and streams. FIG. 3

tinue to be an important source for many water-supply needs. In order that these water-related needs may continue to be met without undue cost and effort, water facts are necessary. Thus, this report is intended to provide a factual basis for planning and management of the water resources as they apply to these needs and to the growth and economic development of Oakland County.

SPHERE OF INVESTIGATION

The basis for this report is a 3-year (1966–68) study of all facets of water in Oakland County. This study is supplemented by results from earlier studies, published and unpublished, concerning various aspects of the water situation, not only locally but on a national scale.

Any study of water resources in Oakland County involves two factors—water supply and water use (fig. 4). Both are of prime importance. Without people's use of water there would be few



Essential elements of a water-resources study for Oakland County. FIG. 4

water problems. Therefore, the people situation was analyzed. Data on population and population growth were collected in an effort to predict future populations. The use of water was defined —how much is used, where it is used, and who uses it—so that future demands could be estimated.

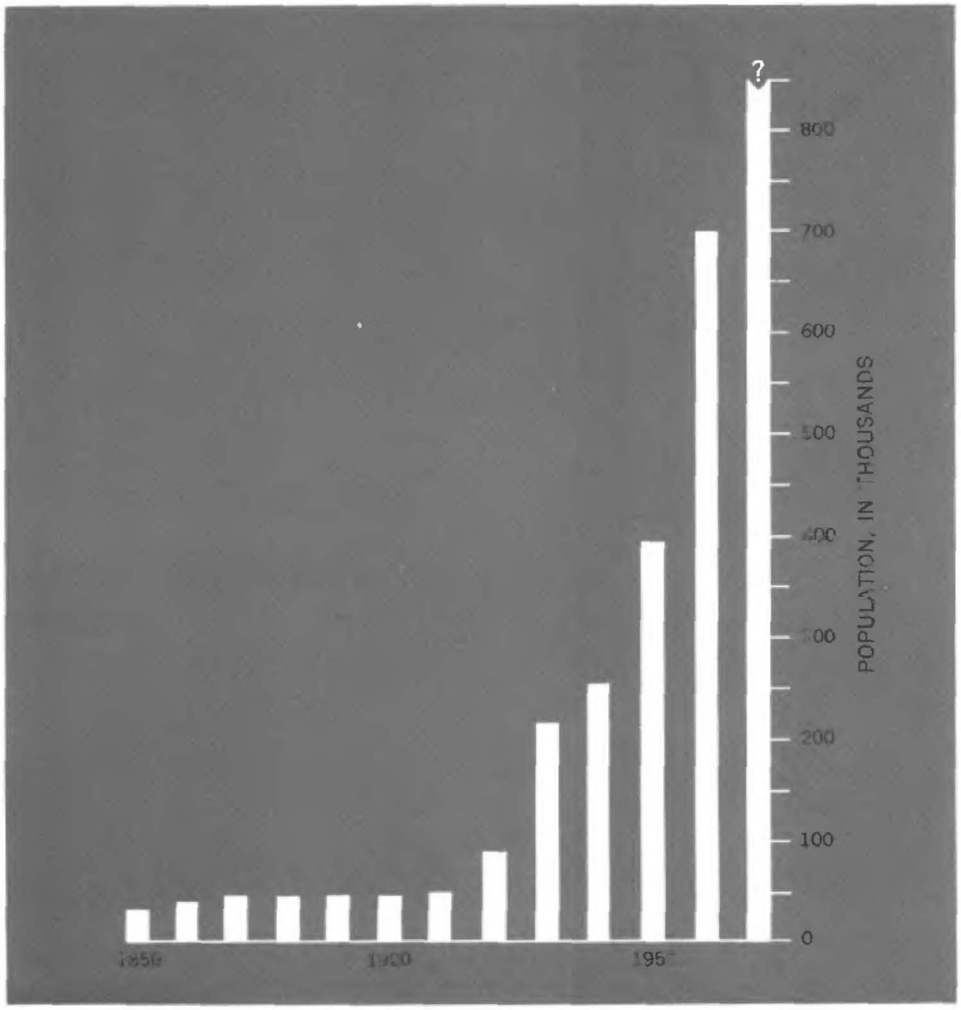
Secondly, the water itself was analyzed—its replenishment, its occurrence, its quality, and its availability. To do this, data on climate, evapotranspiration, and soils were obtained to determine the water's physical and chemical makeup. Streams and lakes were measured during different stages so that predictions could be made of future streamflow and lake levels. Water levels in wells were recorded to establish a basis for determining any future rise or fall. Geologic data were obtained from rocks at the earth's surface, from drillers records, and from new wells so that the framework of the container in which water occurs could be defined. Finally, these data were analyzed and their relationships were established to form a basis for making the future more predictable.

2. The Changing Scene

POPULATION

The population of Oakland County increased gradually from 1850 until about 1910–20 (fig. 5). Subsequently, the population growth rate accelerated owing to the expansion of suburban Detroit into the southeastern corner of the county. Today the county has more than 800,000 people (fig. 6), most of whom live in five townships.

If the land in Oakland County were planned and completely developed to single-family housing, an urban developer might select a maximum suitable unit density of about 2.7 homes per acre. This would provide for an average lot size of 80 by 135 feet and a 35 percent allowance for streets, parks, recreational areas, churches, and shopping facilities. Assuming a population of 4 per dwelling, an acre of land provides housing for 11 people. Thus, a population density of about 7,000 per square mile could be considered a well-developed area. A population much greater than this would probably necessitate multiple housing units. At the present rate of growth it will be several hundred years before all areas in



Past population—a rapid increase since 1910. FIG. 5

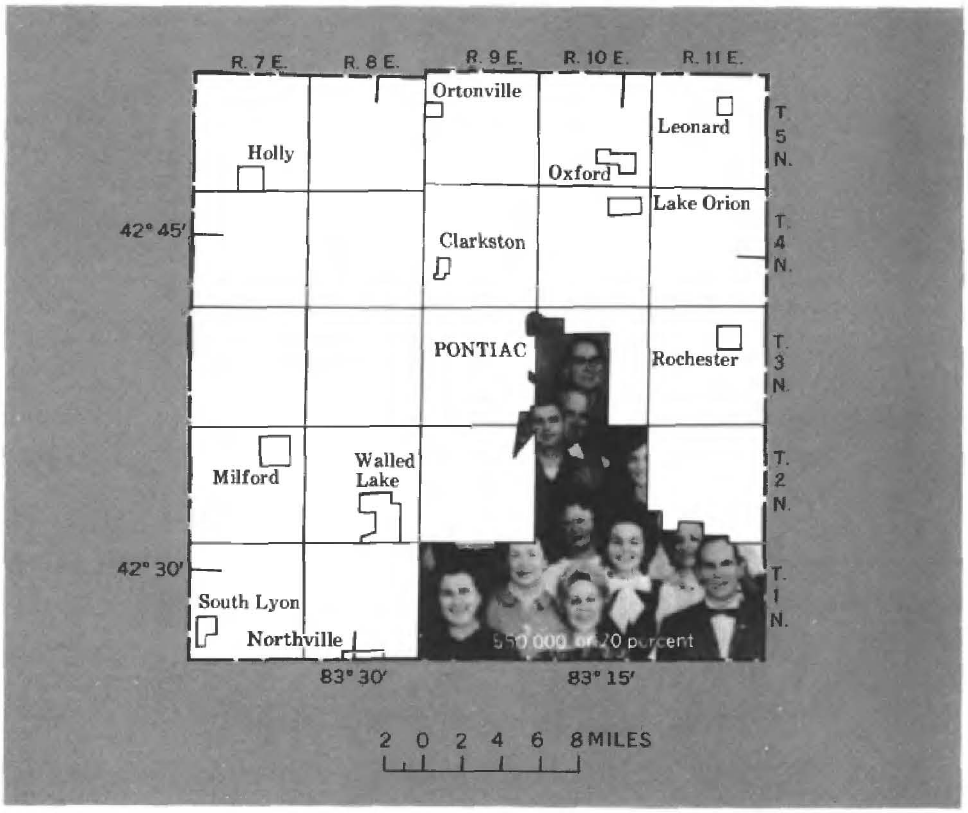
the county reach this level of development. Of greater significance, however, is the fact that some areas in the southeastern part of the county have already reached, or are nearing, a population level that could be considered overly developed (fig. 7).

Because of excellent building sites, rolling terrain, lakes, and streams, it is expected that the population will continue to increase rapidly. By the year 2000 the estimated population, on the basis of present trends, will be about 1,600,000 (fig. 8).

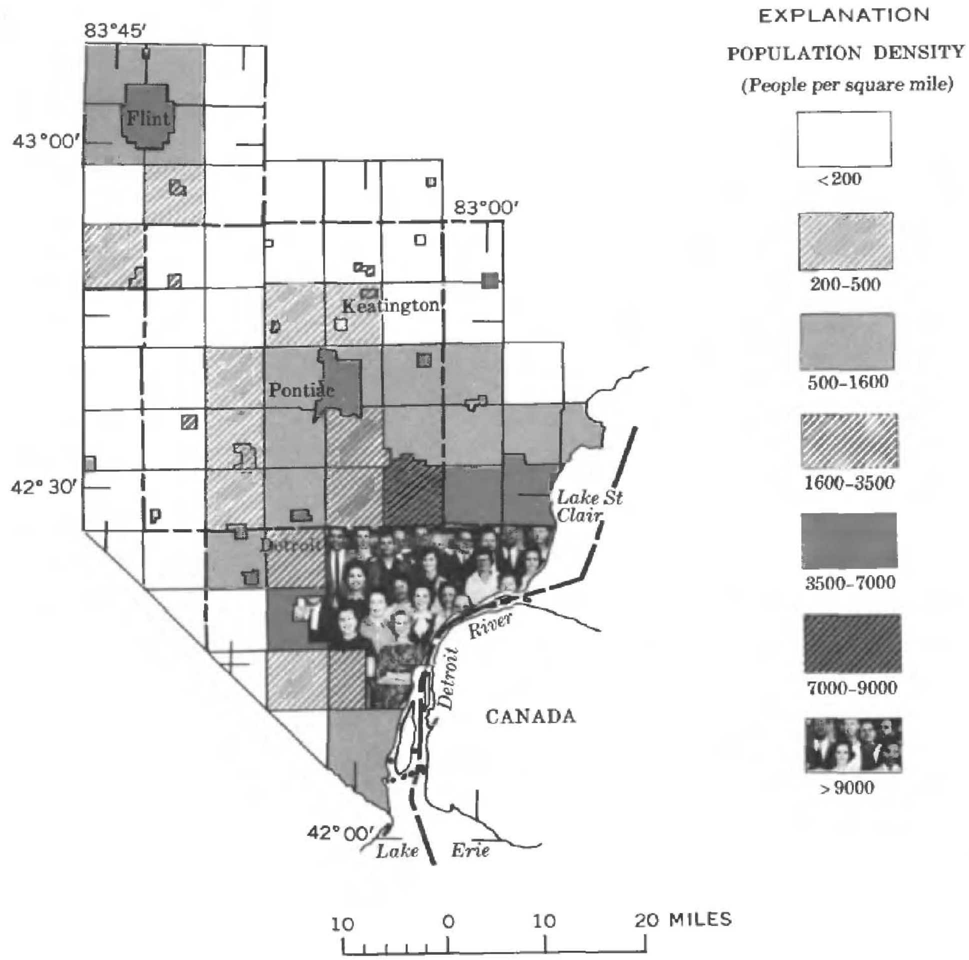
THE SHIFTING POPULATION

Along with the population increase, there is evolving a change in land use. The small farms and homesteads of yesteryear are giving way to the modern subdivisions of today. An area that once housed only a single family now houses several hundred families. Of the many examples of this change in Oakland County, the largest probably is at Keatington. Here, on an undeveloped 3,200-acre tract of land and lakes, a new town is being built—a town that will, within a few years, house about 25,000 people. With this type of change in land use comes an increase in water use.

Throughout Oakland County some aspects of this changing scene are affecting all the people. Several decades ago when most daylight hours were consumed by work, little time was left for relaxation and enjoyment of outdoor recreation. Lakes and streams were used primarily by ardent naturalists and fishermen. The water remained fresh and clean. Today, with more free time and better means of transportation, many people escape city life by swimming, boating, and fishing in lakes and streams. Others find relaxation by living along the shores and beaches. More water is being used, often without concern about future needs. Thus, the water becomes less fresh and clean. What the future



About 70 percent of the people lives on 20 percent of the land. FIG. 6



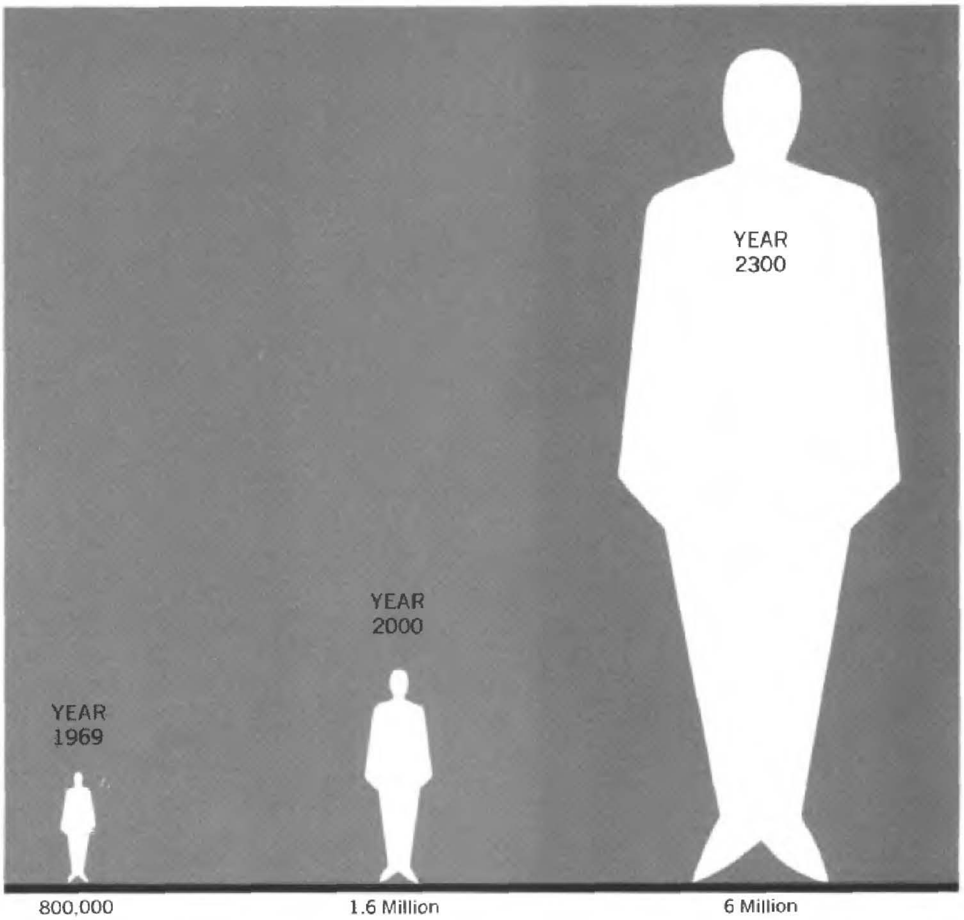
The greatest concentration of people is in the Detroit-Pontiac area. FIG. 7

holds is not completely predictable. However, with the possibilty of a shorter workday and the certainty of an increased population, we can be sure that more use will be made of our water resources. The quantity of water available per capita will be reduced and, unless pollution is eliminated, the quality of water will deteriorate.

3. Water Use

MORE PEOPLE—MORE WATER

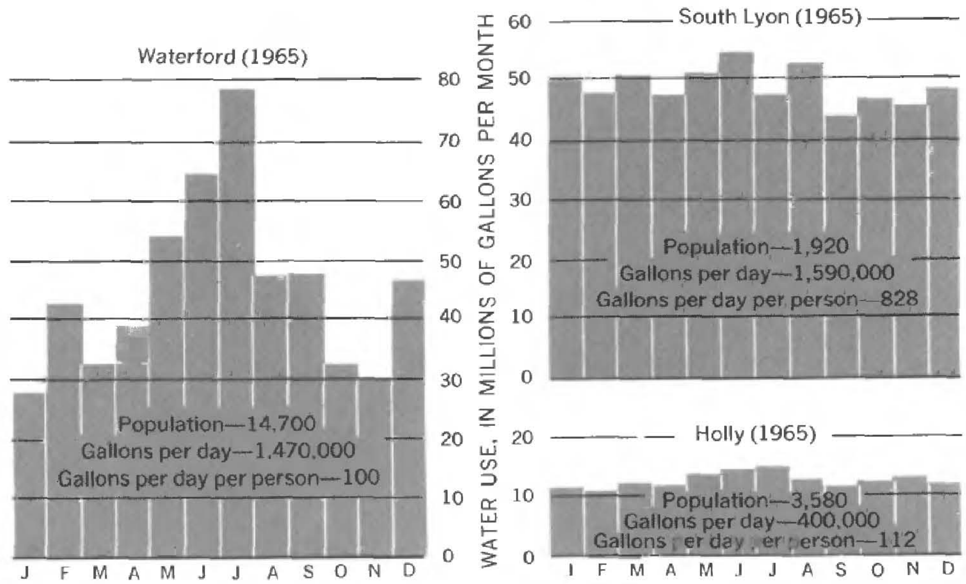
One method for predicting water use has as its basis the relation between population and per capita use. Logically, more people use more water. That is, if a community with 50 people



Projected population—1.6 million and upward. FIG. 8

used water today at the rate of 3,000 gpd (gallons per day) then, on a straight-line basis, that same community with 5,000 people should use 300,000 gpd. However, this method alone produces erroneous results, for it requires stability in not one but several trends. Not only must the trend in per capita domestic use remain stable but also the trends in population and industry. In actual situations, we find little stability. Per capita domestic use varies from house to house and from day to day. Population increases slowly one decade, rapidly the next. Industry that is absent from the scene today may arrive tomorrow. Because of these factors, we find that the total quantity of water used varies considerably between communities. This variance is well illustrated by the pumpage data shown in figure 9.

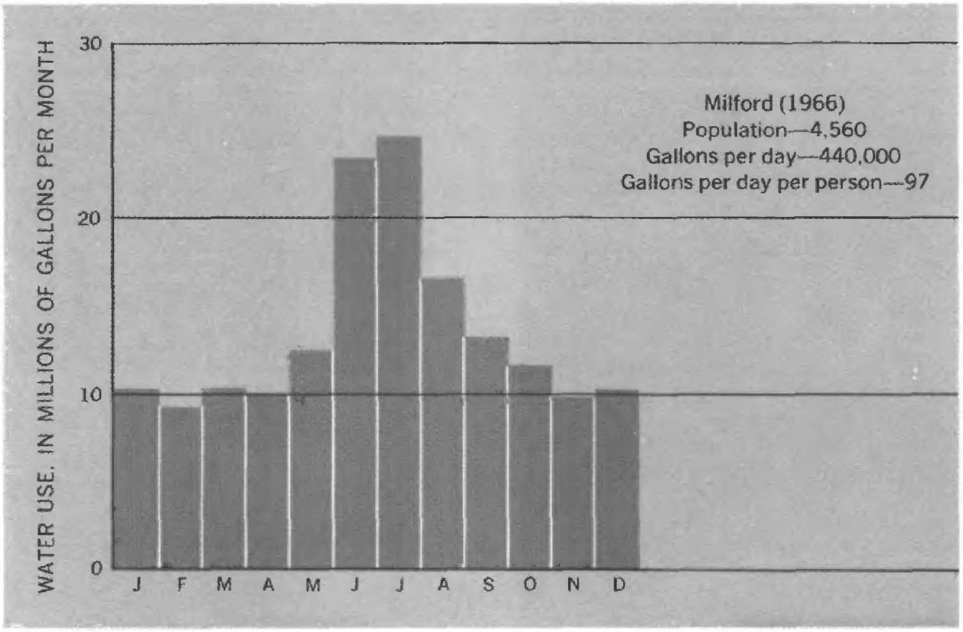
As can be seen, South Lyon has fewer people than Holly or Waterford, yet daily water use is greater. Waterford used nearly



Great differences exist in water use between communities. FIG. 9

three times as much water in July as in January and Holly had a slight seasonal increase in water use during the summer. Water use in South Lyon showed no seasonal trend. Thus, one significant fact emerges from the data on the graphs—water use predictions can be no more than an educated estimate based on conditions relative to the local situation. This estimate, if continually updated, will provide the water manager a basis for designing a city's future water supply.

The community of Milford is typical of the smaller communities that have no major water-using industries. Monthly water use is relatively stable or on the uptrend during the first part of the year but shows a downtrend during the latter part of the year (fig. 10). The peak demand for water is during the growing season when temperatures and evapotranspiration rates are high. Because water use in Milford is principally domestic, the per capita use here, which was 97 gpd in 1966, probably is representative of per capita domestic use in other communities. However, two things should be kept in mind. First, this figure includes not only water used for drinking, washing, and lawn irrigation, but also that used by the city to prepare the water for use, to keep water mains flushed and clean, and to offset losses suffered through leakage in transmission. Secondly, more water is used during a dry year than a wet one; 1966, although not a dry year, had less than average rainfall.

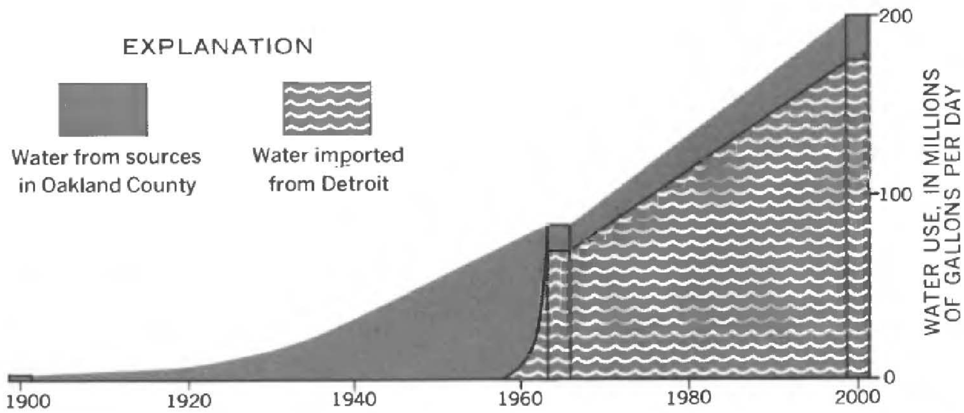


Water use in Milford—a typical picture for communities without big water-using industries. FIG. 10

Per capita water use in Milford compares favorably with that in Holly (112 gpd) and Oxford (114 gpd). Also, per capita use in the part of Oakland County supplied by Detroit water is about 130 gpd, industry included. Therefore, it is assumed that a per capita consumption of 100 to 110 gpd is typical of domestic use in

Oakland County. Communities having considerably higher use ratios than this, such as 150 or 200 gpd per person, reflect water-using industry, tourist areas, or communities having large residential lots. Use of water in rural homes or in communities of less than 500 population is reported to be between 50 and 60 gpd per person.

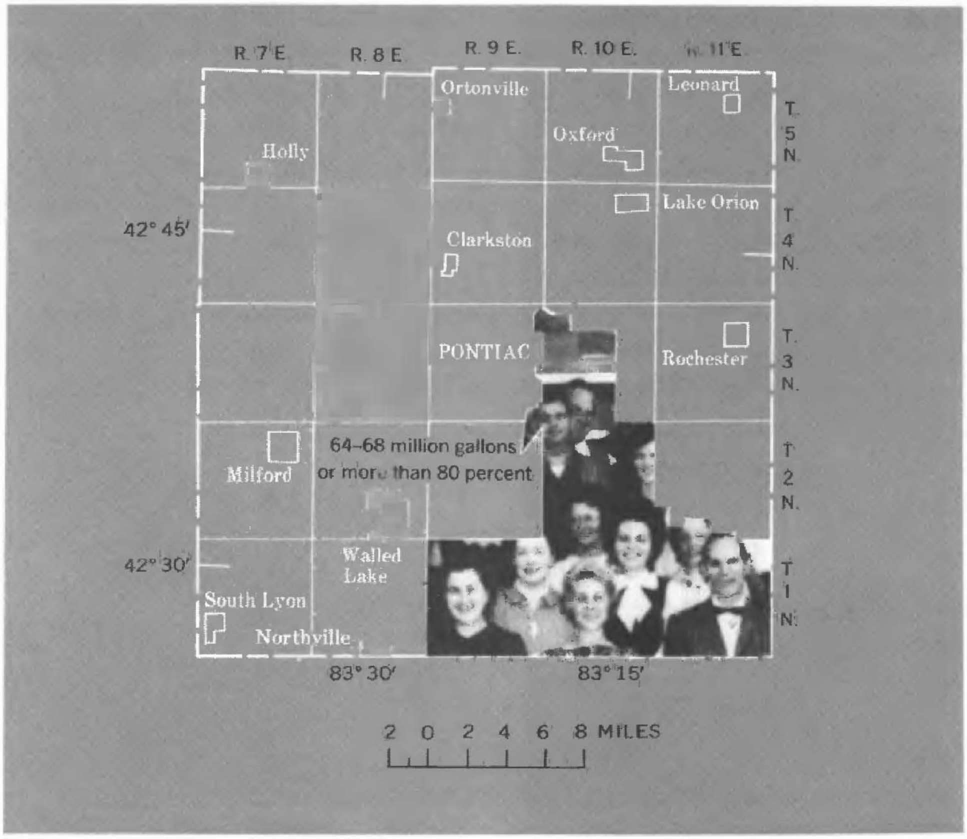
Using the above data and population figures shown in an earlier section we can estimate trends in water use. Shortly after the turn of the century, when the population was about 50,000 and mostly rural, water use was about 3 million gpd, most of which was ground water from within the county (fig. 11). In 1965, with



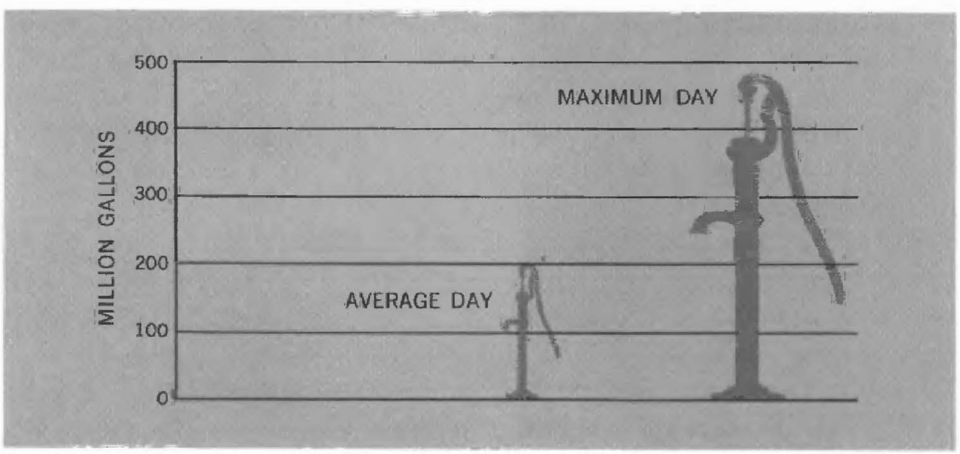
Water taken from sources within Oakland County today is only a small part of the total water used. FIG. 11

a much greater population and a considerable number of water-using industries, daily water use in the county averaged between 80 and 85 million gallons. Much of this water came from Detroit and was used in five southeastern townships (fig. 12), serving 70 percent of the county population. By the year 2000, if projected figures are correct, water use will average about 200 million gpd. Most of this water will be used in eight or nine southeastern townships and will be supplied by Detroit.

We should keep in mind, however, that no water-supply system can be planned solely on average use, for, in fact, water use varies from day to day. Therefore, the system must be planned so that it is capable of meeting the maximum demands placed on it. Demands for water during the summer months increase considerably and on days of maximum demand water use may be two to 2.5 times greater than the average (fig. 13). Thus, by the year 2000 there may be days when total use will exceed 500 million gallons.



More than 80 percent of the water used in 1965 was used in the southeast part of the county, the area of greatest population density. FIG. 12

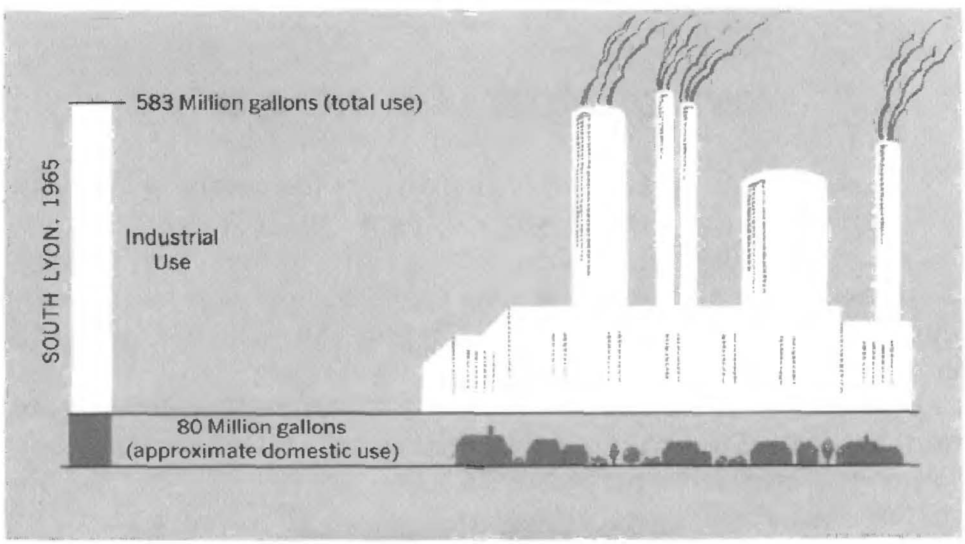


Maximum daily demands for water placed on the supply system, in general, will be at least double the average demand. FIG. 13

INDUSTRIAL WATER USE

Water use by industry varies greatly. Use may be large or small depending on size of plant, number of employees, and type of processing. In some plants little or no water is used in product processing—here the primary use is for air conditioning and domestic needs. Although the quantity of water used per year for air conditioning may not be great, the effect of the periodic demand for this use on the supply system may be tremendous. For several months during the summer, large quantities of water may be required, whereas during the rest of the year the requirements are small. Thus, the supply system must be designed to produce large quantities of water even though the system may be used at full capacity for only several days during some years. A supply of water and a supply system for these types of use often can be developed best by use of water from local sources.

In some plants, large quantities of water are used in product processing; generally little of this water is incorporated into the product. Thus, it is necessary to have not only an adequate source of supply but a disposal system capable of handling large quantities of waste water. Data for South Lyon, discussed earlier in this section, reflects the effect of industrial water use on a community's water picture (fig. 14). Here there is little evidence of seasonal trends in use or little percentage variation from month to month.



Industry may determine supply requirements. FIG. 14

Industry plays an important role in estimates of future water use. However, estimates of industrial use should be related to the availability of water. To illustrate, where unlimited amounts of water are available, such as in the area supplied by the Detroit system, estimates of industrial water use is in relation to the treatment and transmission of water rather than to the available supply. In communities, where limited amounts of water are available, estimates of possible industrial use are limited to the available local water supply. A supply that is sufficient to sustain only domestic demands could not meet the demands of water-using industry.

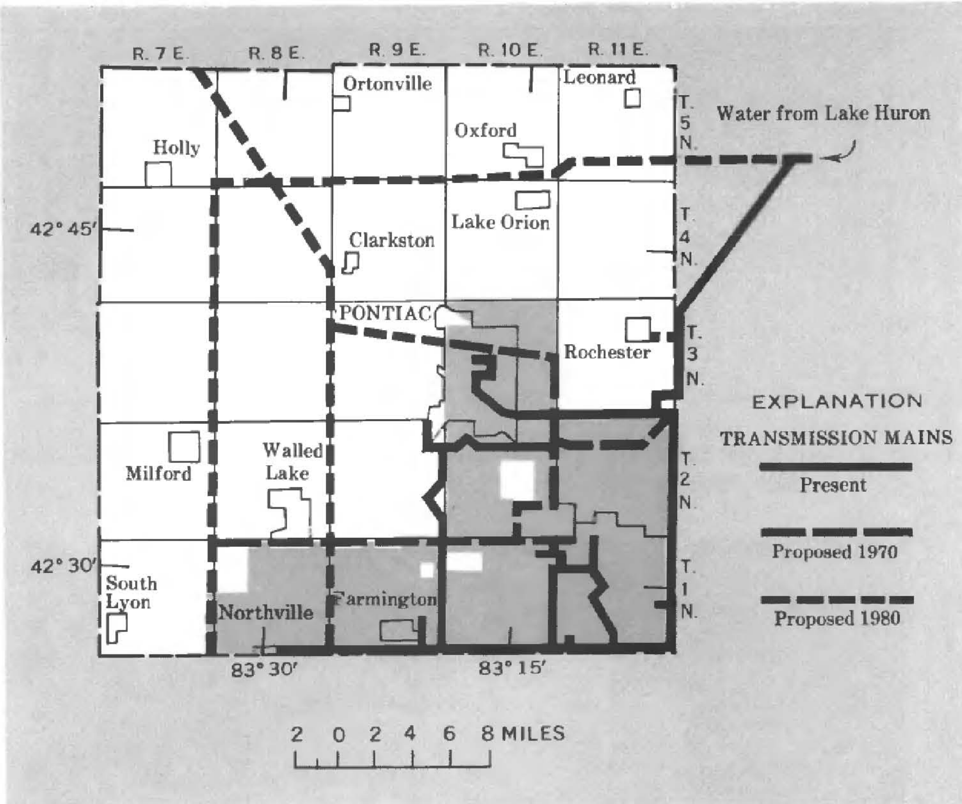
IRRIGATION WATER

Irrigation in Oakland County does not appear as a major water use in 1968 or in the future. The acreage in crops being irrigated at present is very small and has been on the decrease in recent years. Because there is little evidence to the contrary, it appears that this decreasing trend will continue.

Substantial quantities of water are used to maintain healthy and green grass in parks, golf courses, and lawns. The quantity of water required for this type of irrigation usually is computed as a part of the per capita requirement for the community. As such, irrigation does not appear to have a significant role in estimates of future water requirements.

WATER FROM LAKE HURON

One significant factor involved in water-use analysis for Oakland County is the Detroit water system (fig. 15). Through this system "any village, township, city, county or industry, through its representative governmental agency, can obtain any amount of water capacity it wants * * *" (Detroit Department of Water Supply, 1966, p. 3). Thus, in areas where the population increases rapidly and becomes concentrated and where local water supplies cannot produce the quantity and quality of water needed, Detroit water will be readily available. In those areas where the population increase has been slower and where it appears that this trend will continue, local water sources will be sufficient to supply most demands for several decades.



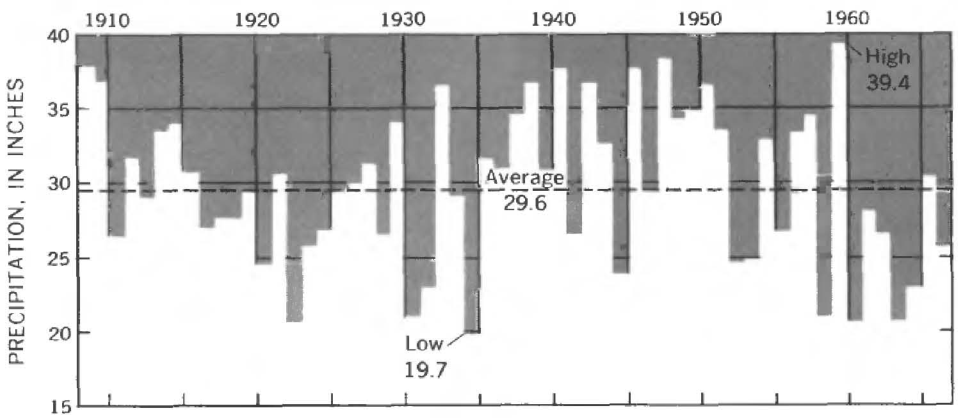
Most of southeastern Oakland County (shaded area) is now served by water from Lake Huron via the Detroit water system. FIG. 15

4. A Replenishable Resource

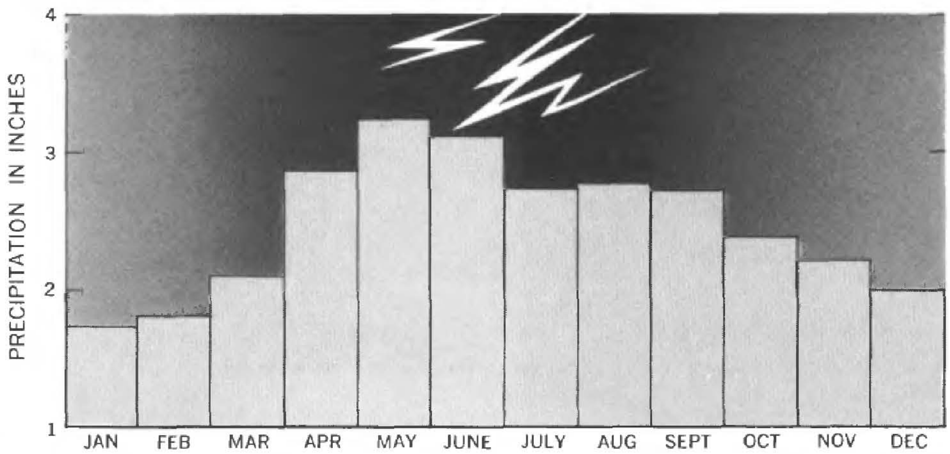
PRECIPITATION

Precipitation replenishes the water resources in Oakland County. It is well known that snow and rainfall replenish lakes and streams; not as well known is the fact that precipitation also is the primary replenishment for ground water within the county. Thus, data on precipitation gives some insight into the status of the local water resources.

The amount of precipitation varies from year to year, month to month, and day to day. Sixty years of records at Pontiac indicate that the yearly precipitation there ranges from less than 20 to about 40 inches (fig. 16). January is the dryest month; May is the wettest (fig. 17). Many of our water problems arise during



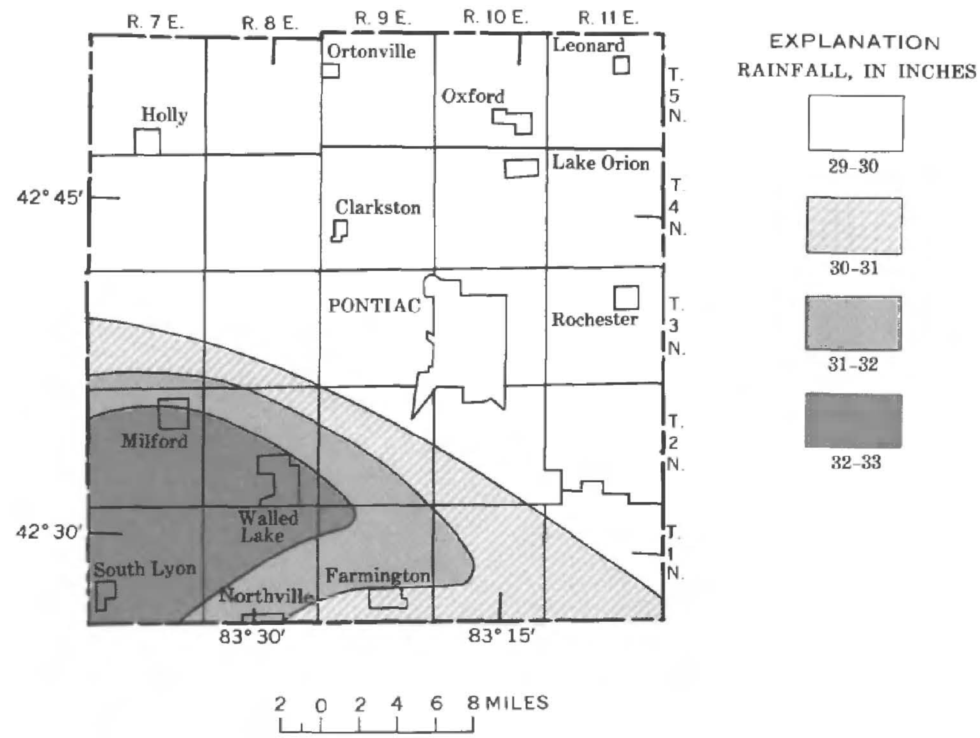
Average yearly precipitation for the past 60 years is nearly 30 inches—considerable variation can occur from one year to the next. FIG. 16



Wettest months of the year are May and June. FIG. 17

dry years when too little water causes droughtlike conditions or during wet years when an overabundance of water produces flooding. When precipitation is near normal, water problems are reduced. Daily and hourly variations in precipitation occur often and are sometimes quite great, but their time of occurrence defies long-range predictability.

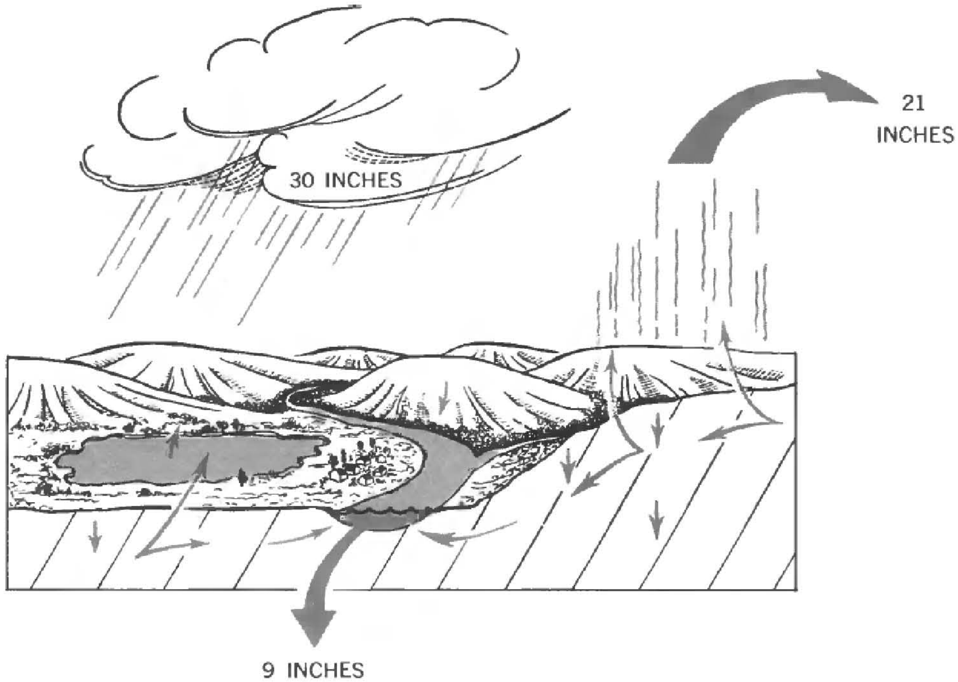
Precipitation varies not only with time, but with locality. Within Oakland County, however, the normal yearly variation is relatively small, ranging between about 29 and 33 inches (fig. 18), a variation which probably is not of great significance in relation to the overall water resources picture. More important is the fact that most of the county receives, on the average, about 30 inches of rain and snow each year—an amount equivalent to about 815,000 gallons per acre.



Average yearly precipitation ranges from 29 to 33 inches. FIG. 18

HYDROLOGIC CYCLE

The amount of water that falls on the county, if diverted to complete controlled use, would be adequate for most needs. Present technology, however, precludes such control. Therefore, any estimates of available water or any water budget must take into account not only precipitation, but the distribution, use, and loss of water. If we consider the hydrologic cycle, we find that water from precipitation is distributed along two main paths—evapotranspiration (the combined processes of evaporation and transpiration) and runoff—paths along which water is used and is often lost (fig. 19). Evapotranspiration is the greatest consumer of water, returning about 70 percent (21 inches) of the water from precipitation back to the atmosphere during an average year. The remaining 30 percent (9 inches) goes to surface runoff and in the process replenishes our lakes. In reaching the two major paths of distribution some precipitation percolates to ground-water reservoirs and subsequently seeps to streams or returns to the atmosphere by evapotranspiration. During an average year, about 5 inches of the water from precipitation takes this route. A budget

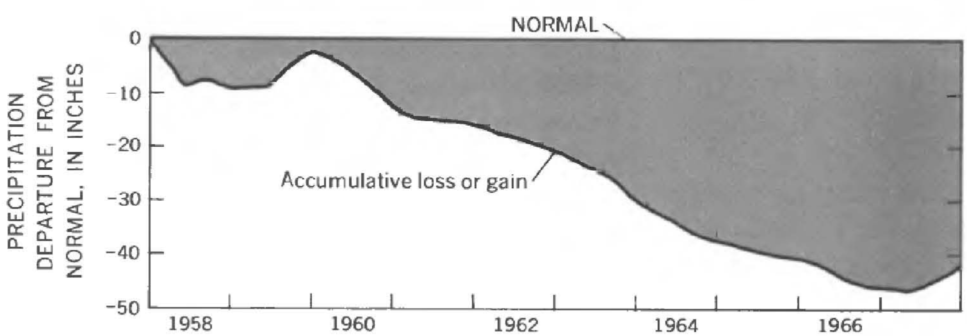


Water from precipitation follows varied routes of distribution. FIG. 19

evaluating several of these parameters is defined later in this report.

THE SOURCE IS REPLENISHED

The quantity of water that goes to runoff and percolation may seem to be a rather small part of the total precipitation. Yet, throughout most of the area, it has been enough to maintain water levels in streams, lakes, and wells (except in areas of heavy pumping). During extended periods of reduced precipitation, such as between 1960 and 1966, considerably less water is available for recharge and water levels may decline (fig. 20). With the return



More than 40 inches of water was "lost" from 1960 to 1966 because of reduced precipitation. FIG. 20

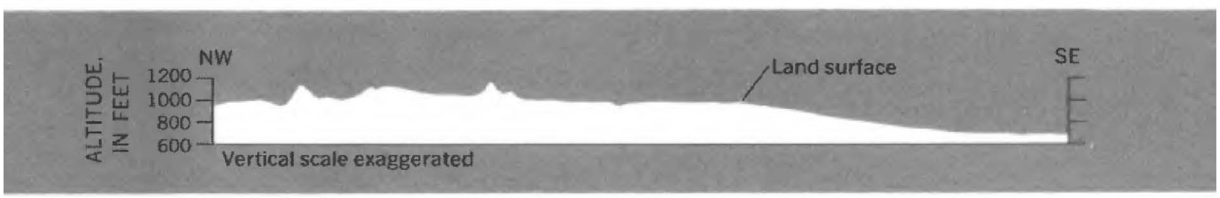
of average or above-average precipitation, such as in 1966–67, water levels soon return to normal. Thus, streams that become stagnant and sometimes dry up are flushed out and replenished when it is wet. Lakes that appear to be dying are rejuvenated when precipitation increases. And wells that go dry during droughtlike conditions will often yield sufficient water again after a year or two of above normal precipitation.

5. An Interwoven System

LAND AND WATER

Water has many forms of occurrence. It occurs in the air, on land, and in the ground. Although each mode of occurrence is unique, in many respects they are interwoven and form a highly complex system. The surface of the land, its makeup and configuration, plays an important role as a part of this system.

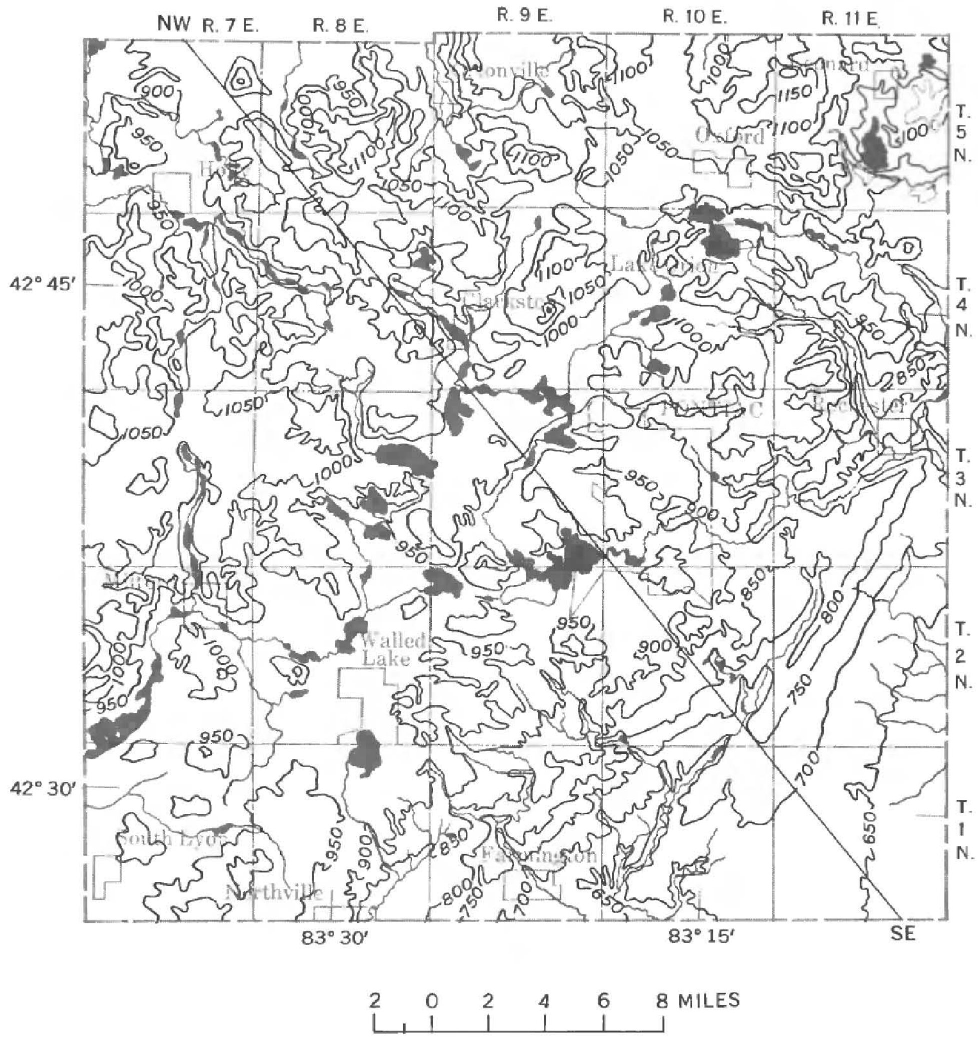
In Oakland County the land surface exhibits a variety of differences, especially as to difference in altitude and configuration. In the relatively flat southeastern corner of the county, the altitude of the land surface is at its lowest—about 630 feet above sea level (fig. 21). Northward, the surface is increasingly higher until



The altitude of the land surface ranges between 600 and 1,200 feet above mean sea level. (See fig. 22 for location of section.) FIG. 21

it reaches its highest altitudes, just over 1,200 feet, in the rolling and hilly stretch between the west-central boundary and the northeast corner. In the northwest corner the surface altitude decreases until again it is less than 1,000 feet.

Surface-water drainage exhibits the influence of the land surface. This drainage radiates outward from the high terrain (fig. 22) eventually merging into one of the major streams which flow from the county. Because of the irregular configuration of the land, water is trapped in many areas to form numerous lakes and swamps.



EXPLANATION

——— 800 ———

Contour line of the land surface showing altitude above mean sea level; contour interval 50 feet except in areas of high relief where the interval is 100 feet

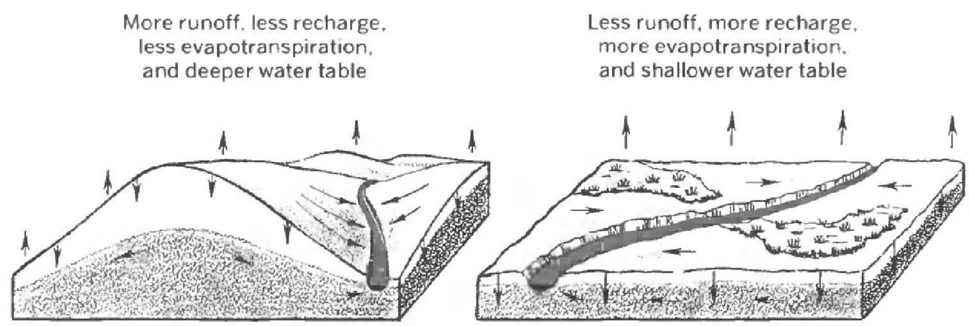
Line of section

The land surface is relatively flat in some areas but quite hilly in others.
FIG. 22

Water in the ground also is affected by the land surface in the respect that it always seeks a lower altitude. It may either flow to streams within the county and be carried away, or it may flow underground toward lower altitudes outside the county.

SOME INTERRELATIONSHIPS

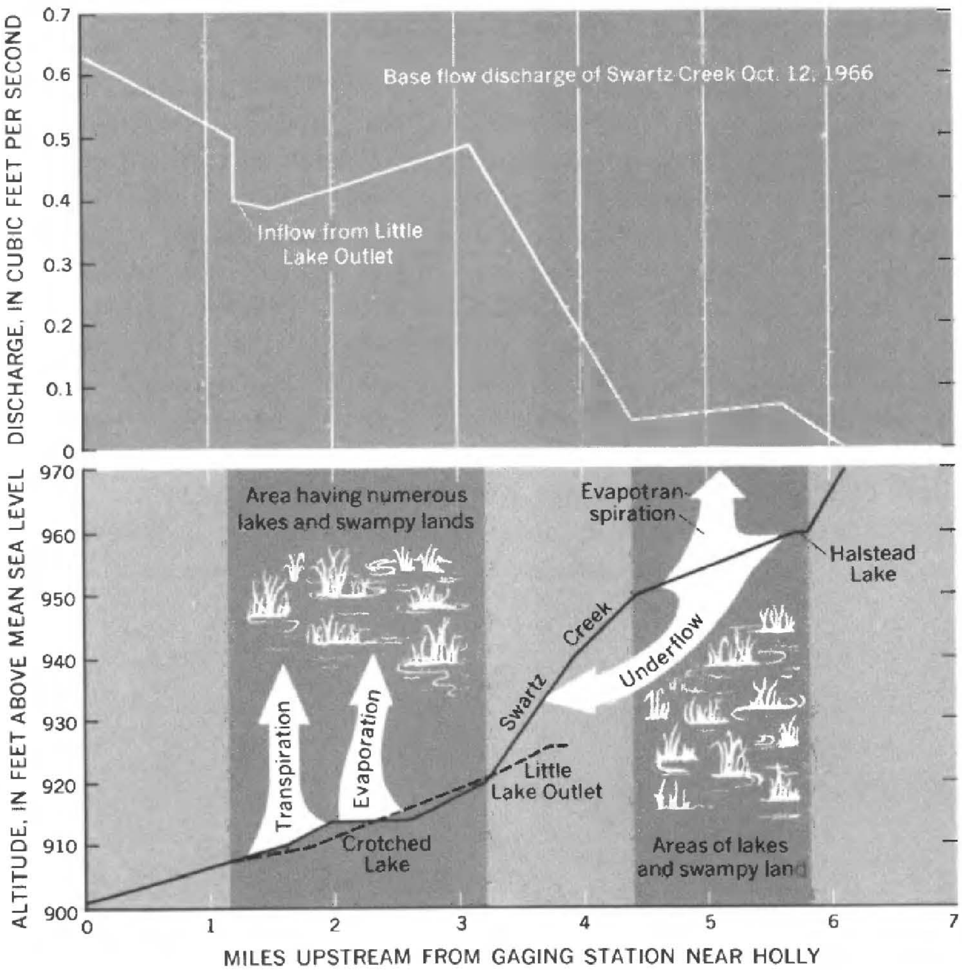
Examples of the relationship between the land surface and the occurrence of water are provided throughout this report. We should keep in mind, however, that this relationship implies another relationship—one that exist's between water in all its various forms. In this report, we place water into general categories so that it can be logically discussed; however, no such neat subdivisions actually exist. In nature, all water is related. An example of water's interwoven nature and how it is affected by the land surface is shown by the relationship between runoff, recharge, and evapotranspiration. Comparing water in an area where the surface is rolling or hilly to an area where it is relatively flat, other conditions being equal, we find that the interrelationships shown in figure 23 are common. An actual example as it occurs in Oakland County is demonstrated in the Swartz Creek basin.



The configuration of the land surface and the occurrence of water are related. FIG. 23

Seepage measurements were made in the Swartz Creek basin on October 12, 1966; the discharge is shown in figure 24. This was during a period of dry weather and the measurements represent base flow, wherein runoff was principally ground water. Although the measurements were made in the fall, some transpiration probably took place, and with temperatures of more than 60°F, evaporation losses were significant.

Significant differences in ground-water seepage in the upper reaches of Swartz Creek are noted although the glacial materials throughout the basin are fairly uniform in hydrologic properties. Ground-water seepage is substantially greater in the reach of stream from miles 3.1 to 4.4 where the stream gradient is also greater (fig. 24). The steeper gradient of the water table in this area, as reflected by stream gradient, water-table contours, and



Base flows reflect basin physiography. FIG. 24

the slope of the surrounding land surface, results in increased ground-water flow; the amount of flow being directly proportional to slope of the water table. In the reach of stream from about miles 4.4 to 5.7, a decrease in discharge is noted. The decrease is attributed, in part, to evapotranspiration; and although no data are available to substantiate this, some water probably infiltrated into the ground in this reach and returned to the stream between miles 3 and 4.

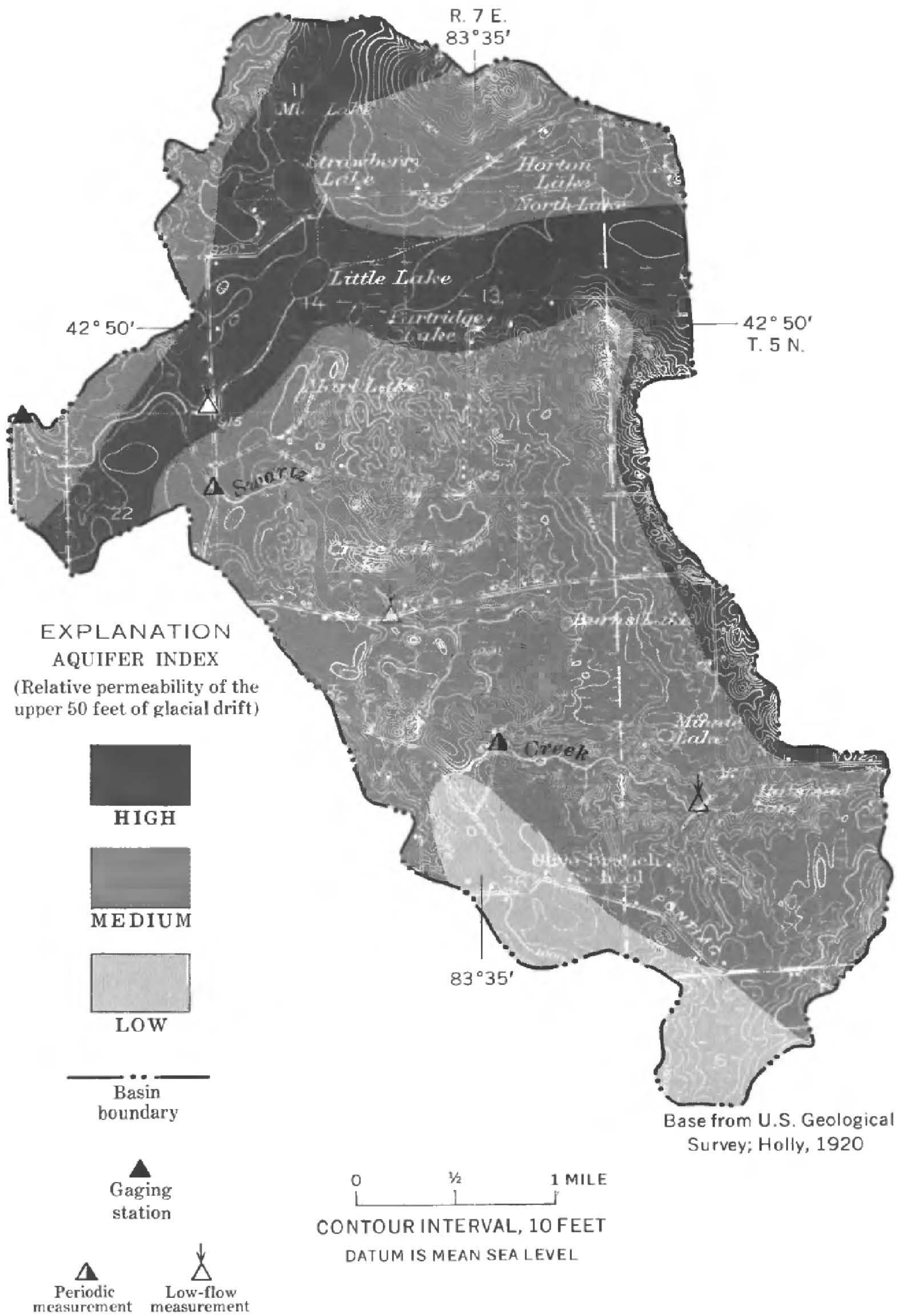
The decrease in streamflow between miles 1.2 and 3.1 can be attributed to evaporation from the several lakes in this area and to transpiration from swamps. In both reaches were streamflow decreases (between miles 1.2 to 3.1 and 4.4 to 5.7) stream gradients are small, and the areas of wet swampy lands are substantially greater; these conditions are conducive to greater evapotranspiration losses.

As can be seen, gains and losses to streamflow within the upper reaches of the creek are directly attributable to the influence of land-surface configuration. Downstream, near mile 0, the composition of materials at land surface come into play and the increase in flow here can be attributed, in part, to permeable glacial materials which transmit water to the stream more readily (fig. 25). However, stream gradient still appears to have an important influence. To illustrate this, the same permeable materials that cross Swartz Creek near mile 0 extend into the headwaters of Little Lake Outlet to the north. Yet, runoff from this basin is small. Inspection of the land-surface configuration in the basin indicates very low stream gradients (fig. 25) with resultant swamps and lakes; these are conditions that favor high evapotranspiration and reduced runoff. Thus, it appears that, in this area, the influence of the relatively flat land surface overrides the influence of the permeable material.

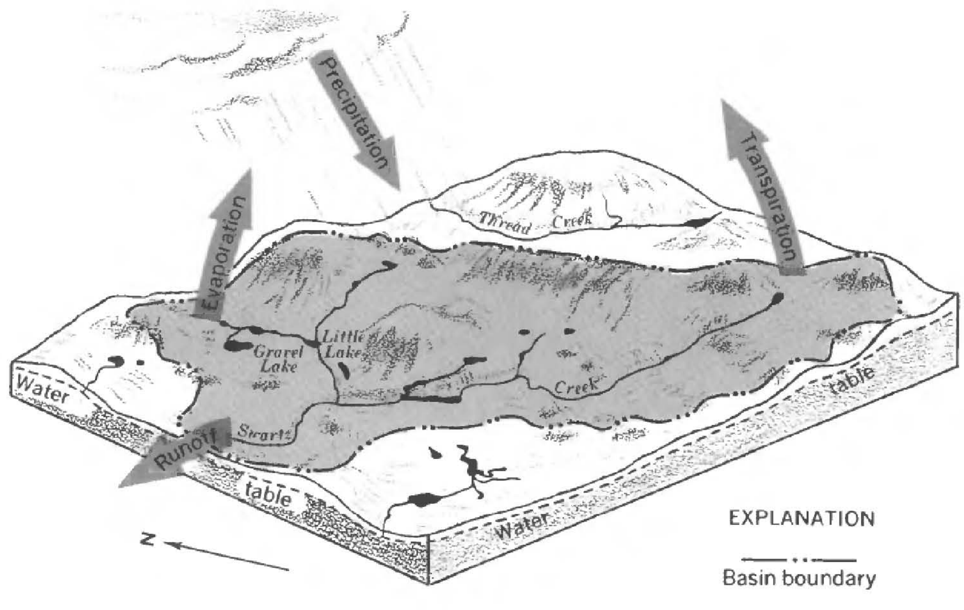
As demonstrated, the configuration of the land surface plays an important role in the nature and occurrence of water in a river basin. Analysis of streamflow data illustrates certain patterns of behavior between land and water and suggests an interrelationship between water flowing in streams or that is stored in lakes and water in the ground. The existence of an interrelationship between surface water and ground water is demonstrated in nature by the sustained flow of streams during periods of dry weather. Water issuing from the ground as springs and seeps forms the rills which add to and maintain the flow of streams. The balance that exists between surface and ground water and other elements of the hydrologic cycle may be demonstrated through a water-budget analysis. Data collected in the Swartz Creek basin provide a basis for illustrating a typical budget. The budget and method of analysis are given in the following section.

A WATER BUDGET FOR A SMALL BASIN

The hydrologic cycle, a continuing phenomenon, may for the purpose of analysis be considered to begin with precipitation. As man envisions it, precipitation is the source of water for streams; it replenishes soil moisture, recharges ground-water reservoirs, supplies water for storage in lakes and other depressions, and provides the water needed for plant growth (fig. 26). The apportionment of precipitation may be expressed in the water-budget equation, $P=R+\Delta S+L$, where P (precipitation) represents input,



Physiography and aquifer characteristics that influence base flows in Swartz Creek basin. FIG. 25

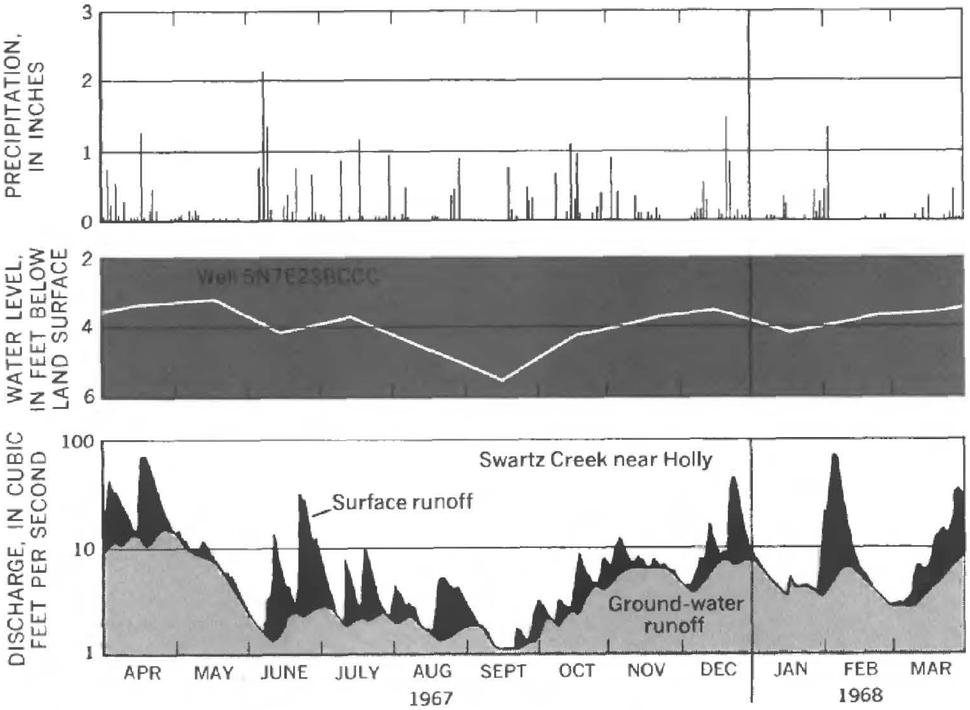


Nature's water budget in Swartz Creek basin. FIG. 26

and R (runoff), ΔS (change in storage), and L (losses through evaporation and transpiration; collectively, evapotranspiration) represent output. Other elements such as interbasin underflow, change in soil moisture, diversion of water into or out of the basin, and consumptive use of water by man, often are included in a water-budget analysis. However, in this basin study, these elements, along with the change in surface-water storage, were small and their net effect on the overall budget was negligible. Measurement of precipitation, streamflow, and ground-water levels, therefore, provide the data necessary for solving the equation.

An understanding of the principal elements in the budget equation provides an insight to the interwoven system in which water occurs. Precipitation, an integral part of the equation, was covered in chapter 4 and needs no further emphasis here. Of the other elements in the equation, runoff is most readily perceived; however, the complexity of this element is not always recognized.

Runoff is made up of two principal components; overland flow or surface-water runoff, and effluent seepage or ground-water runoff. The proportionment of these components reflects basin characteristics, principally basin geology. A delineation of the relative proportions of each component can be accomplished by an analysis of streamflow records. Figure 27 illustrates the separation of streamflow into its components for the period April 1967 to



Surface and ground-water runoff are governed by precipitation and ground-water levels. FIG. 27

March 1968, a period for which both water level and streamflow data are available. The solid area represents the surface-water component, and the remaining or shaded area of the hydrograph is ground-water contribution to streamflow. Table 1 shows a

TABLE 1.—*Nearly half the total runoff in the Swartz Creek basin comes from ground-water sources*

Month	Runoff, in inches			Ground-water runoff as a percentage of total runoff
	Total	Surface	Ground	
1967				
April	3.12	1.97	1.15	37
May	.80	.12	.68	85
June	.91	.73	.18	20
July	.46	.25	.21	46
August	.33	.17	.16	48
September	.16	.04	.12	75
October	.45	.18	.27	60
November	.72	.19	.53	74
December	1.37	.83	.54	39
1968				
January	.59	.20	.39	66
February	1.70	1.31	.39	23
March	1.19	.79	.40	34
Total	11.80	6.78	5.02	43

month-by-month summary of runoff and the totals for the 12-month period. As shown, about 43 percent of the streamflow was derived from ground-water sources.

The significance of the proportions of surface-water runoff and ground-water runoff may best be demonstrated by a comparison of flow for basins having varied runoff characteristics. A comparison was made for three such basins in Oakland County (table 2).

TABLE 2.—*The proportions of surface-water runoff and ground-water runoff vary between basins and from year-to-year within each basin*

Year	Runoff, in inches			Ground-water runoff as a percentage of total runoff
	Total	Surface	Ground	
Swartz Creek near Holly				
1964	3.01	1.23	1.78	59
1966	5.63	2.65	2.98	53
1967	9.48	5.12	4.36	46
River Rouge at Birmingham				
1964	1.69	0.93	0.76	45
1966	3.09	1.73	1.36	44
1967	4.68	2.48	2.20	47
Huron River at Milford				
1964	4.85	1.16	3.69	76
1966	6.01	1.56	4.45	74
1967	8.64	3.11	5.53	64

The percentage of ground-water runoff shown in the table reflects variations in permeability of the glacial deposits in the three basins; higher percentages of ground-water runoff indicate more permeable deposits. In some areas, basin physiography and urbanization will significantly affect the proportions of surface- and ground-water runoff.

As can be seen, the ground-water portion of streamflow is greatest in the Huron River basin and is lowest in the River Rouge basin; that in Swartz Creek basin is intermediate. The permeabilities that are reflected by these streamflows correlate, in general, with the geology in the basins. The principal glacial deposits at land surface in the Huron basin are outwash (usually permeable); whereas, in the Rouge basin, deposits of clay lake beds (usually impermeable) predominate. Deposits in the Swartz Creek basin are composed of both permeable and impermeable materials; outwash predominates in the downstream part of the basin and impermeable till makes up most of the headwater deposits.

The proportions of surface- and ground-water runoff vary also within each basin from year-to-year depending upon climatic conditions. These differences are shown in table 2, where runoff ranging from dry to wet conditions are included. In wet years ground-water runoff is relatively large, but it makes up a smaller proportion of the total flow.

The second element on the output side of the budget equation —that is, change in storage—was evaluated on the basis of records of ground-water levels and a computed value of gravity yield (gravity yield times change in ground-water level equals change in storage). The value of gravity yield was determined from data for two short-term periods—September 5–14, 1967, and January 1–15, 1968. Resultant values of gravity yield were 0.05 for the September period and 0.10 for the January period; the differences probably are due to the necessity of having to analyze short periods of record and in defining ground-water levels on monthly measurements. Because the data for the September period are more reliable and because evaluation of pumping test data indicate that the lower value of gravity yield is more representative, the value 0.05 was used in computing the change in ground-water storage.

Losses are not evaluated independently in the budget equation but are shown as a residual after equating the other elements. The budget analysis for the 12-month period April 1967 to March 1968 is shown in table 3. Some monthly values may be in error,

TABLE 3.—*Evaluation of nature's water budget in the Swartz Creek basin*
[Units in inches]

Month	$P = R + \Delta S + L$
1967	
April	3.90 = 3.12 + 0.32 + 0.46
May	.65 = .80 + .04 − .19
June	8.40 = .91 + .05 + 7.44
July	2.39 = .46 − .04 + 1.97
August	3.59 = .33 − .20 + 3.46
September	1.82 = .16 − .11 + 1.77
October	4.06 = .45 + .17 + 3.44
November	2.13 = .72 + .13 + 1.28
December	3.94 = 1.37 + .11 + 2.46
1968	
January	1.44 = .59 − .12 + .97
February	1.84 = 1.70 + .23 − .09
March	1.26 = 1.19 + .04 + .03
Totals	35.42 = 11.80 + .62 + 23.00

especially those for losses—losses which include lag between precipitation, runoff, and change in ground-water storage. As an example, May and February show negative losses which is impossible in nature. However, annual totals are in the correct order of magnitude for the period studies.

Although it represents only a short period of time, the water budget shown above does define the relative apportionment of precipitation to the three principal output elements in the budget. A more reliable budget could be constructed if long-term records were available; however, such is not the case for all elements. Records for precipitation indicate a long-term average of about 30 inches, somewhat below that for the 1967–68 year. Also, annual runoff for a long-term period as indicated by records for the Swartz Creek gaging station is about 8 inches or about 4 inches less than that shown above. The difference between long-term precipitation and long-term runoff is about 22 inches, a figure which represents the average annual water loss by evapotranspiration. Over a long-term period, changes in storage are negligible. Data are insufficient to assign more exacting values to either of these elements.

HOW MAN CAN CHANGE NATURE'S BUDGET

The Swartz Creek basin lies in a sparsely settled area. Within the basin, homes are widely scattered and the land is forest covered or is used for agricultural purposes. The interrelationships of surface water, ground water, and precipitation as shown in the preceding sections therefore reflect conditions little affected by man. But, what might happen when man develops and populates an area? How could he affect nature's apportionment of water? What imbalances might he cause? One example of what might happen is shown in the following hypothetical situation.

Among man's immediate needs when he arrives on the scene is water. In a basin such as Swartz Creek, ground-water aquifers probably would be selected as the chief source for a water supply. The first step, therefore, is to put down a well. As more families move into the area, additional wells are installed. Eventually, there are subdivisions and industries that need water and large diameter wells are constructed. As this situation multiplies, pumpage soon greatly exceeds the rate at which the aquifers are being recharged—water levels begin to decline. The water is being "mined."

At first this may not be considered a serious problem. However, other elements in the water picture soon begin to suffer. Streams, which depend on ground-water to maintain their flow during periods of dry weather, soon become dry or recede to undesirable low flows. These streams, rather than receiving water from ground water sources as they once did, now are supplying the aquifers. This problem of reduced flow may be of lesser significance for those streams to which water, once used, is returned. The returned water often is of poorer quality, however, and will alter the streams' usefulness. Lakes and other bodies of water which are within the cone of influence caused by pumping also feel the effects. They, also, are recharging the aquifers and their levels begin to decline. During periods when streamflow and lake levels are high this induced recharge may be a beneficial use of surplus water. However, this benefit cannot override the ill effects of reduced streamflow and lower lake levels during dry periods.

Along with urbanization, other problems, perhaps less readily perceived, also arise. Asphalt and concrete roads and parking lots, sidewalks, and buildings restrict infiltration of water which would otherwise percolate to ground-water reservoirs. In so doing, overland runoff is facilitated. Water from precipitation and snow melt can reach the streams readily, reducing times of concentration and resulting in greater peak discharges and consequent flood problems. Thus, with pumpage and urbanization, changes occur in nature's water budget. The proportions of surface- and ground-water runoff in streamflow are changed, and runoff volumes, particularly where pumpage constitutes a diversion of water, are altered.

Man, however, is not necessarily limited in his move toward urban growth and development by these changes in the hydrologic situation. Methods can be adopted to arrest ground-water depletion, flood problems, and reduced lake levels and streamflow. Recharge wells, recharge galleries, and other systems of water spreading might be employed to induce recharge during periods of surplus streamflow and precipitation. In some cases water may be pumped from aquifers to augment streamflow. Also, as discussed later in this report, lake levels can be restored by various methods and reservoirs may be used to augment low-flow and reduce flood flows.

6. Water on the land

SURFACE WATER—A PRIME ASSET

In Oakland County, water on the land is a major feature and a prime asset. This water provides esthetic, recreational, and utilitarian benefits that are unequaled in most other parts of the

State. Water occurs on the land in several forms; however, the most obvious and most valued are the streams and lakes that exist in abundance throughout the county. Although streams and lakes have some characteristics in common, each group also has its own distinguishable characteristic and are discussed as separate entities.

STREAMS

Oakland County is an upland area where streams are small and runoff is generally inadequate for any major water-development project. Rising in the county are the headwaters of five major river systems (fig. 28), four of which rise in the higher altitudes of the northern two tiers of townships and the fifth rises near the south-central part of the county. The Shiawassee and Flint Rivers drain the northwestern and northern part of the county, respectively, and flow westward and northward to Saginaw Bay. The Clinton River drains most of the central and eastern parts of the county and flows generally eastward to Lake St. Clair. River Rouge and the Huron River drain the southern and southwestern parts of the county respectively; they flow into the Detroit River and Lake Erie, respectively.

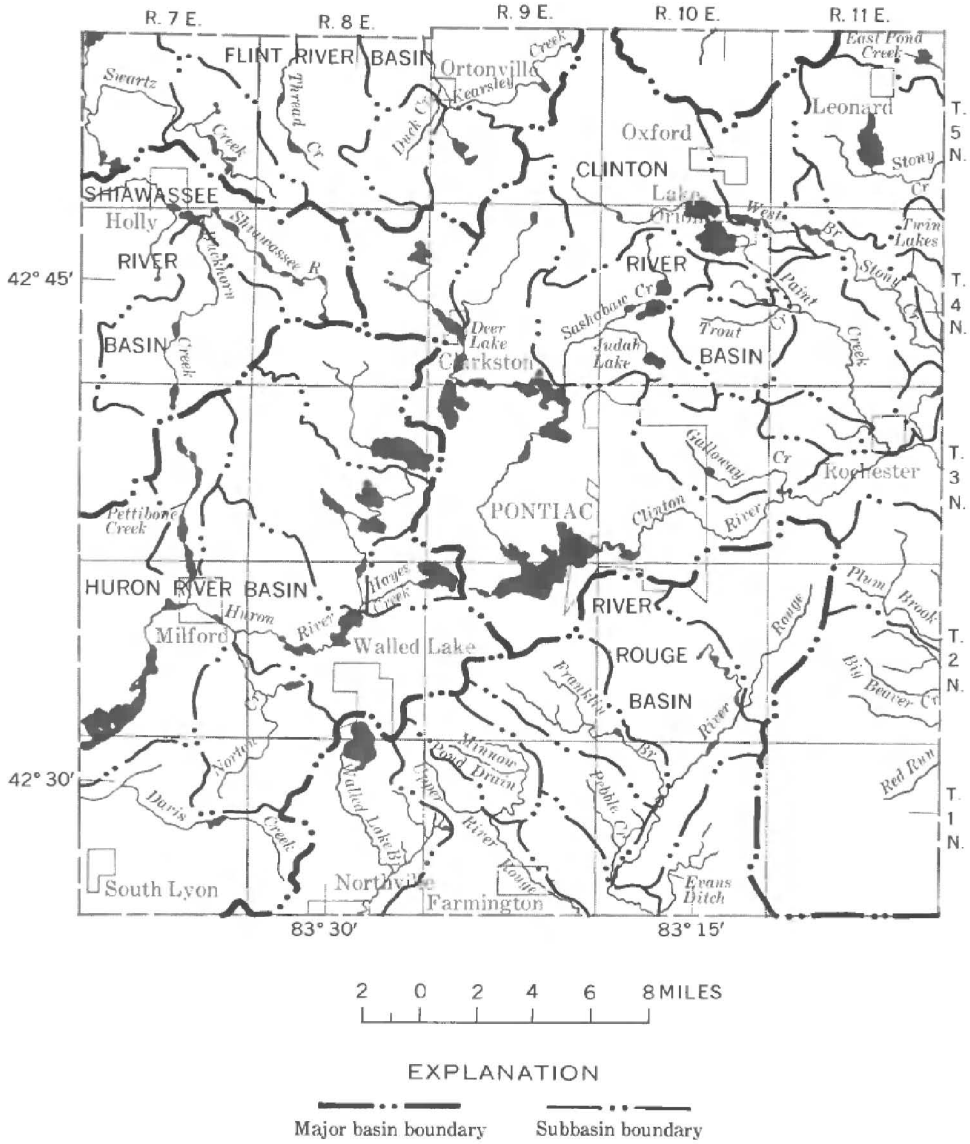
In a broad sense the pattern of drainage has been dictated by the shape of the bedrock surface; the general direction of flow follows the slope of this surface. In a stricter sense, though, the stream network was determined by drainage patterns developed during glacial and recent time.

Stream valleys are generally broad and often contain lakes of considerable size. Gradients are gentle and average falls of less than 20 feet per mile (table 4). In some reaches, however, slopes well in excess of 20 feet per mile are common, and many smaller streams have even higher average gradients.

Streams, as sources of water supply, have been relatively untapped to date (1968). Their principal use, other than for recreation, has been to carry off wastes. However, use of streams for lake-level augmentation, irrigation, and esthetic purposes has been important also. Except for irrigation or waste dilution, most uses are nonconsumptive and do not seriously alter the quality of water.

Streamflow

The average annual discharge of streams in the county (fig. 29), is about 575 cfs. This supply is adequate to meet most current and future needs, especially where quality requirements are



The headwaters of five major river systems rise in Oakland County. FIG. 28

not critical and where the water may be reused downstream. The average flow represents the upper limit or maximum developable supply. It is the limit of the potential water available if it were possible to store it all in reservoirs and release it at a uniform rate. Without storage, however, dependable supplies are limited to the low flows of summer and fall.

Streamflow varies widely from day-to-day and from year-to-year. At times streams contain little water and some smaller streams become dry. At other times, streams become torrents

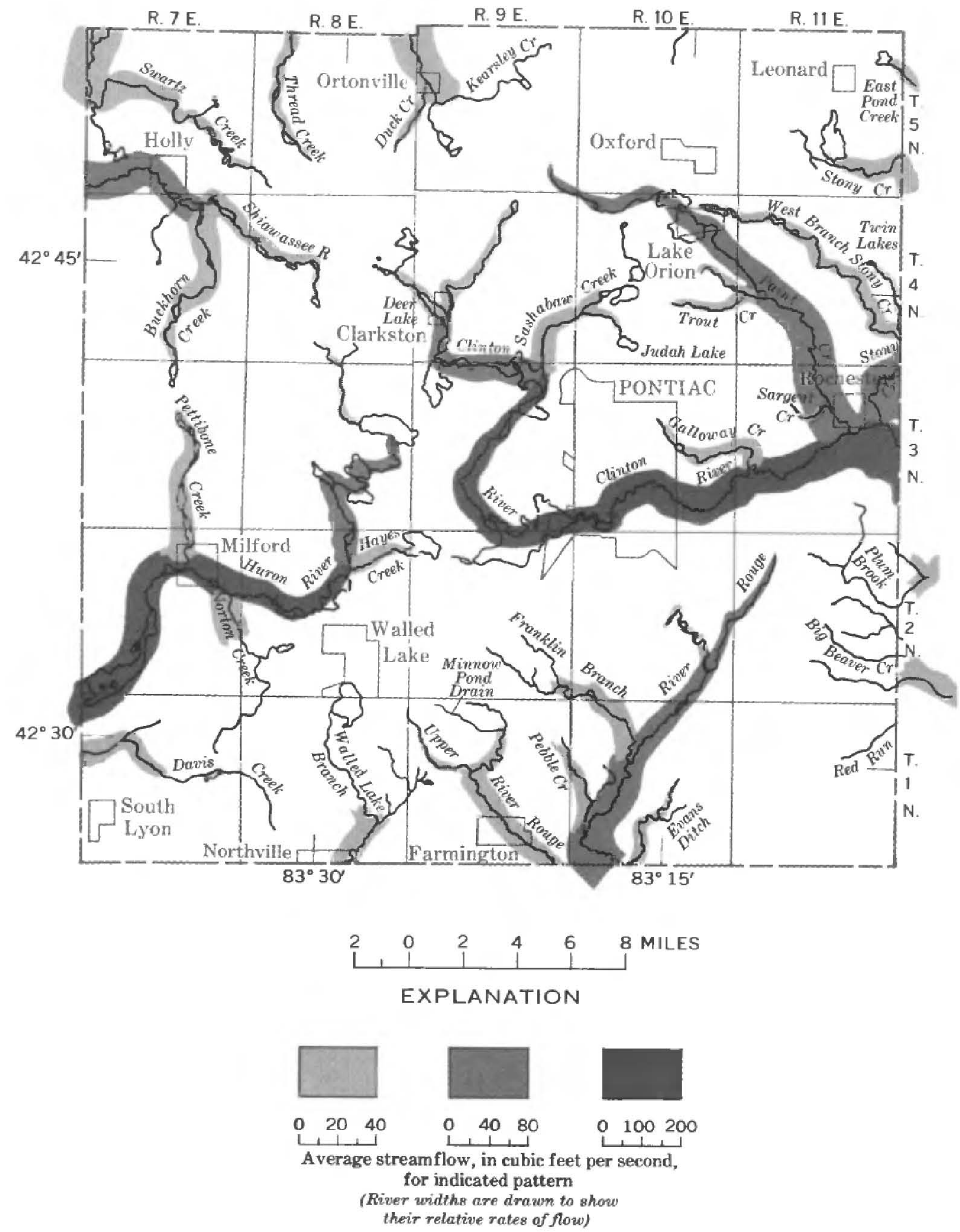
TABLE 4.—*Stream slope in Oakland County ranges between 4 and 39 feet per mile*

Streams	Length (miles)	Altitude, in feet: At source	Altitude, in feet: At mouth or county line	Average slope (feet per mile)
Buckhorn Creek	8.7	1,017	923	10.8
Shiawassee River	12.5	1,017	897	9.5
Duck Creek	4.3	1,023	929	21.9
Kearsley Creek	7.0	1,048	910	19.7
Swartz Creek	14.1	970	842	9.1
Thread Creek	6.8	1,008	883	18.4
Deer Lake Outlet	3.7	1,047	967	21.6
Sashabaw Creek	7.5	998	957	5.5
Galloway Creek	7.8	947	808	17.8
Trout Creek	5.3	989	868	22.8
Sargent Creek	5.2	961	761	38.5
Paint Creek	23.4	1,050	713	14.4
Twin Lakes Outlet	3.3	898	795	31.2
West Branch Stony Creek	12.7	967	781	14.6
Stony Creek	19.0	998	682	16.6
Clinton River	48.2	1,039	666	7.7
Big Beaver Creek	5.9	780	627	25.9
Quarton Lake Outlet	9.0	910	721	21.0
Franklin Branch	11.6	968	644	27.9
Pebble Creek	10.3	993	619	36.3
River Rouge	20.3	798	608	9.4
Evans Ditch	8.6	740	610	15.1
Minnow Pond Drain	9.6	969	755	22.1
Upper River Rouge	11.0	946	635	28.3
Walled Lake Branch	7.8	933	806	16.3
Norton Creek	8.8	939	903	4.1
Pettibone Creek	6.9	999	901	14.2
Huron River	36.0	1,028	869	4.4

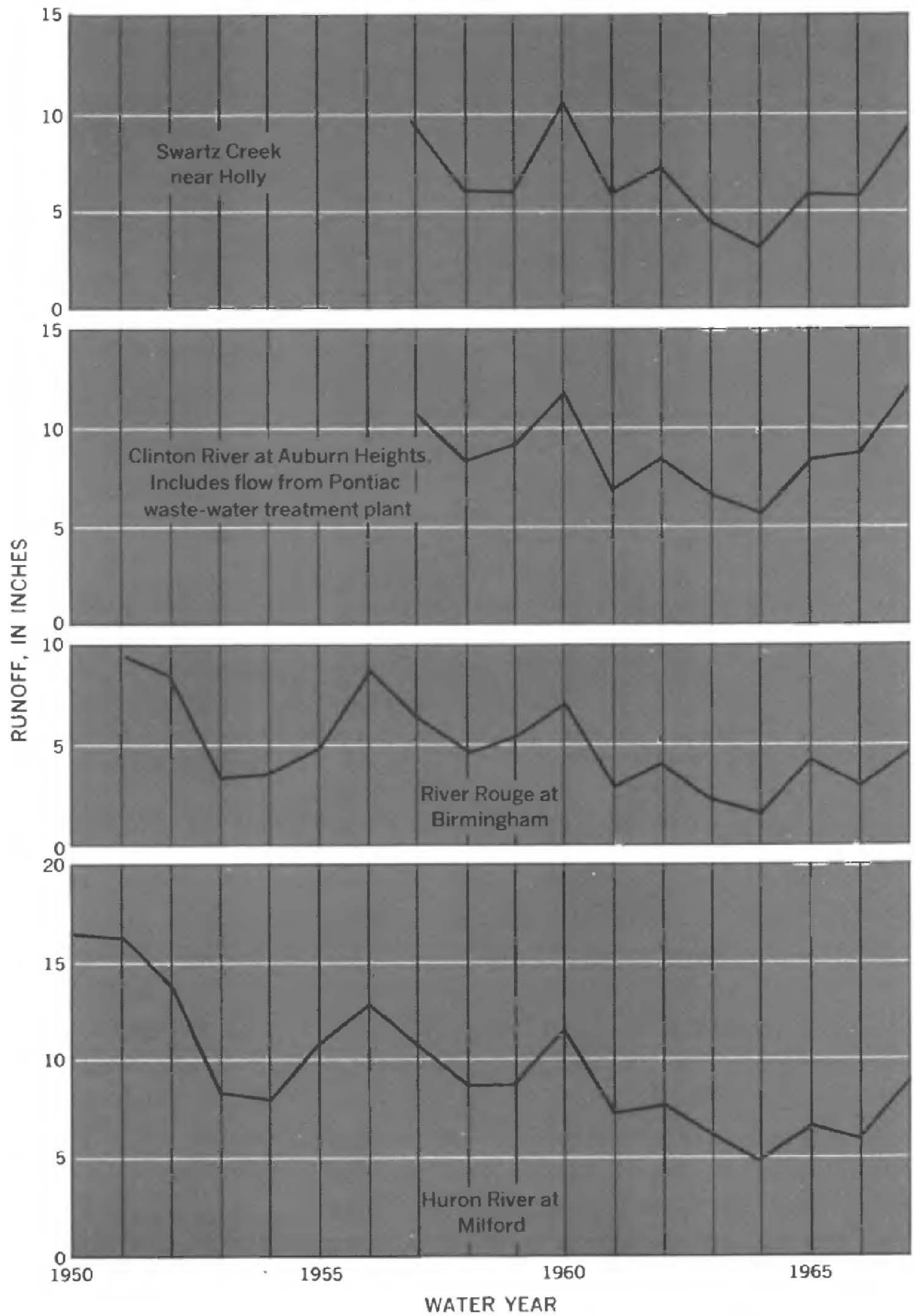
with raging waters causing destruction to properties within their reach. Total annual runoff, although greater in some basins than in others, has parallel trends (fig. 30). Similarly, a within-year cyclical variation in streamflow—with generally higher flows in late winter and spring months followed by a recession to lower flows in late summer and early fall—is similar between basins.

Day-to-day fluctuations in streamflow reflect day-to-day changes in climatic conditions, whereas annual runoff reflects, in part, precipitation for more than 1 year. For example, the low runoff of 1964 (fig. 31) is a culmination of precipitation deficiencies beginning about 1960. Similarly, the high runoff of 1952, a year of below normal precipitation, is a reflection of the above normal precipitation during the years 1949–51.

Fluctuations in streamflow are controlled chiefly by precipitation and temperature. During the winter, precipitation, in the form of snow, accumulates on the ground to be subsequently released when temperatures rise above freezing. Sudden changes in temperature during these periods, coupled with rain, may result in flooding, since infiltration of water is impeded by frozen soils and resistance to overland runoff to streams is minimal. During other seasons runoff from a given storm is dependent on soil conditions, soil moisture content, and vegetative cover.

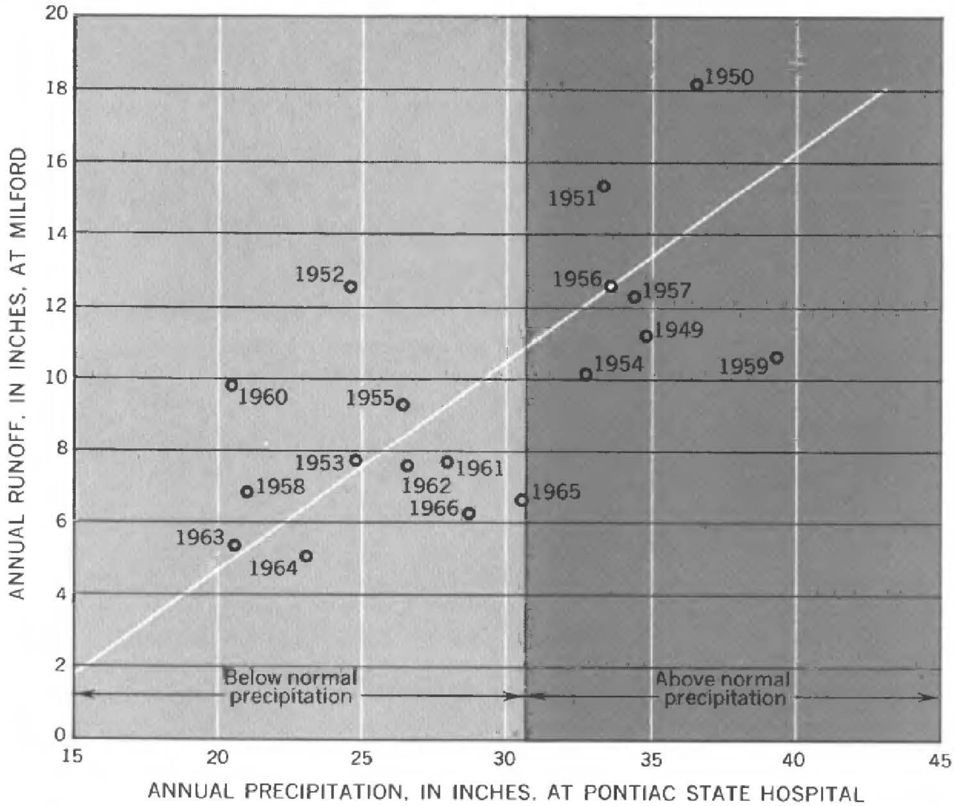


Average streamflow ranges from less than 10 to more than 200 cubic feet per second. FIG. 29



Runoff varies widely from year-to-year but has similar trends in adjoining basins. FIG. 30

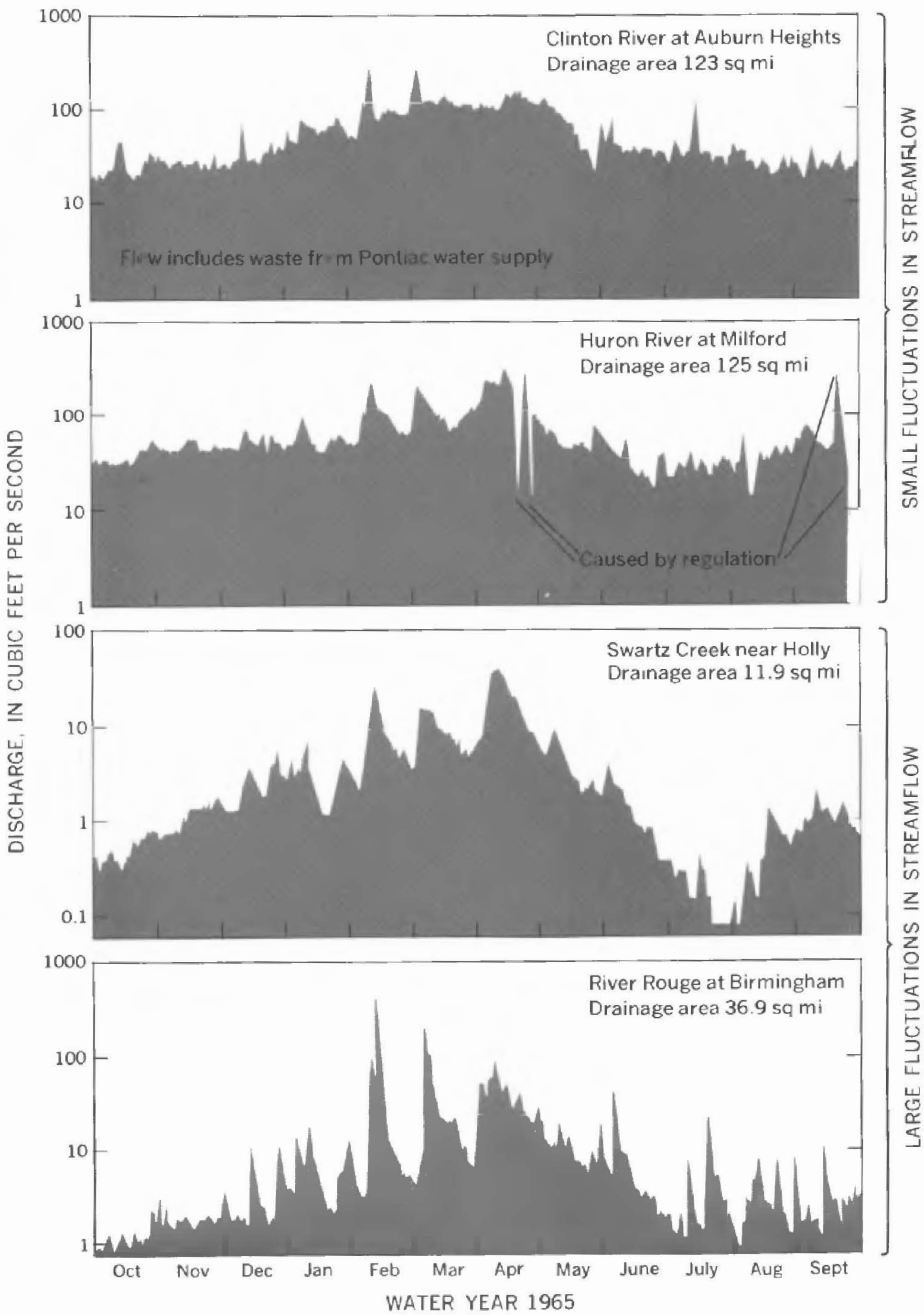
Although precipitation and temperature are fundamental in triggering a change in streamflow, basin physiography and geology largely govern the degree of change. River basins having



Annual runoff reflects not only annual precipitation but also the precipitation of preceding years. FIG. 31

combinations of such physical features as small slopes, large lakes and swamps, pervious soils, and dense vegetation will have lower peak flows per unit area, maintain higher base flows, and generally have a more nearly uniform flow throughout the year. Most streams in the Clinton, Shiawassee, and Huron River basins reflect these properties (fig. 32). River basins having hilly terrain, steep slopes, intense urbanization, and impervious soils permit rapid overland runoff, have higher peak flows, recede quickly to low flows, and have low sustained or base flows. Swartz Creek, most streams in the River Rouge basin, and streams in the southeastern part of the county which are tributary to Clinton River have these properties.

The flow of streams is constantly changing and is subject to the whims of nature and man; therefore, streams must be monitored (fig. 33) to evaluate their suitability for an intended use. The monitoring may consist of collection of records on a continuous or periodic basis, or as occasional spot sampling. Monitoring of streamflow began in Oakland County as early as 1935; however,



Precipitation's effect on streamflow is influenced by basin physiography and geology; this effect is reflected in records from streams in two different physical environments. FIG. 32

it was not until after 1955 that the program was expanded to provide adequate areal coverage (figs. 34 and 35). These early

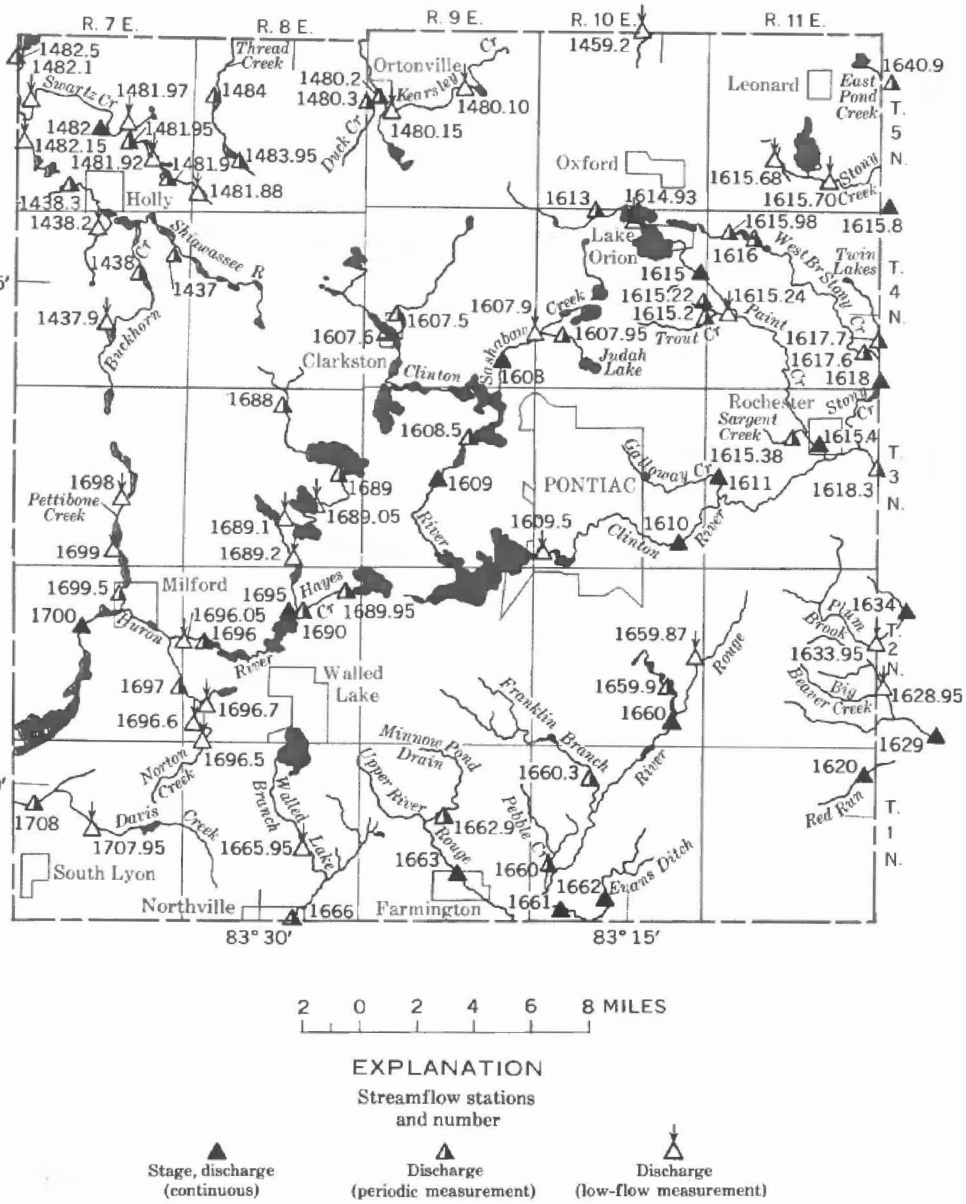
Records of streamflow are obtained from gaging stations such as this on the Huron River at Milford. FIG. 33

records, and those obtained as a part of this project, provide the basis for evaluating the characteristics of streamflow made in this report.

Records collected at long-term continuous-record stations both within and outside the county are the nucleus for streamflow analyses. Statistical correlation between these records and those for short-term continuous record stations and partial-record stations provided the basis for defining streamflow characteristics.

Flow duration

The variability of streamflow is most easily shown as a cumulative-frequency or flow-duration curve. Such a curve combines into a single unit the complete record of discharge and indicates the percentage of time specific discharges were equaled or exceeded. As an example, duration curves for Huron River at Milford are shown in figure 36. One curve is for the actual period of record and the second is for a period extended on the basis of correlation with nearby long-term stations. (Flow-duration data for the Milford gage and other stations in the county were adjusted to the 1931–66 period for defining flow characteristics.) Table 5 shows duration data for each continuous and partial-record station in the county. Data for partial-record stations, or stations which



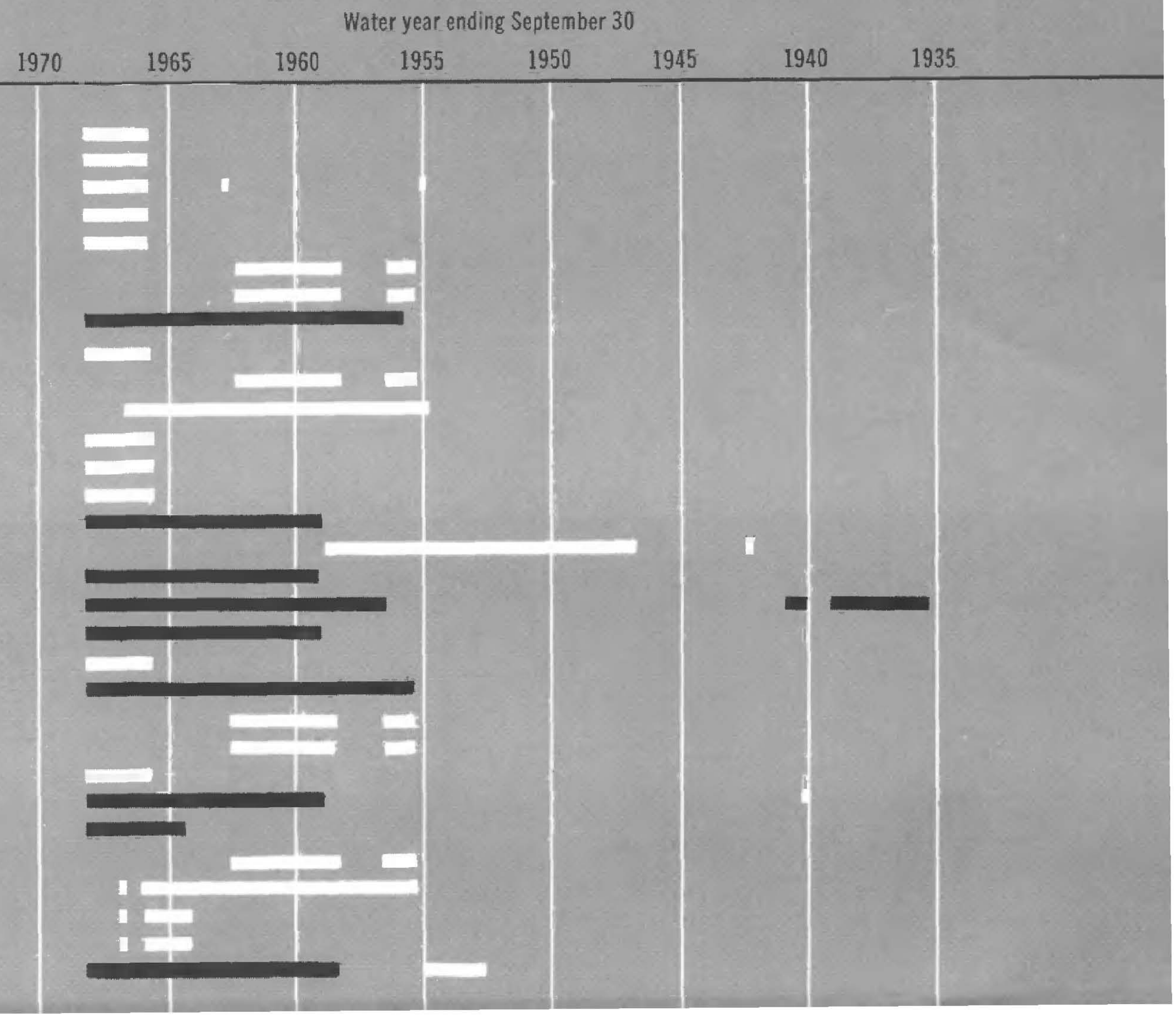
Streamflow data are available for 85 stations. FIG. 34

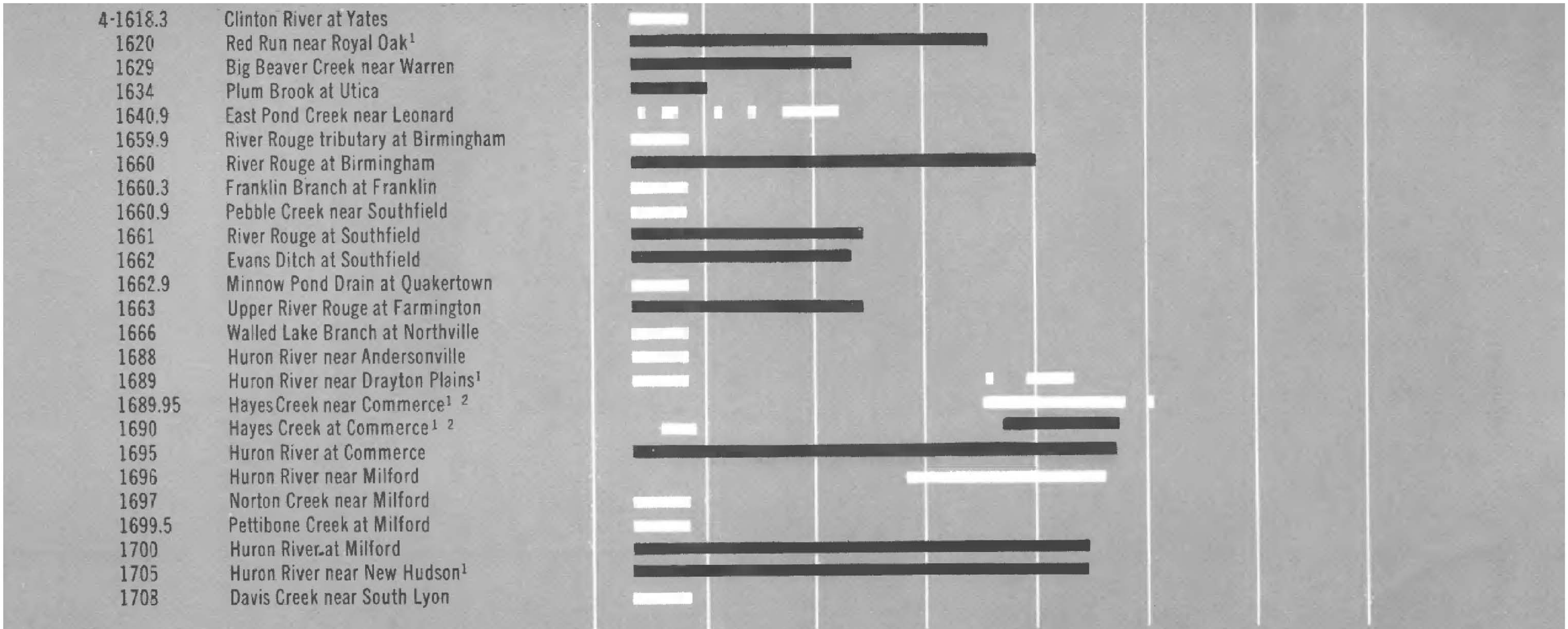
have been in operation for only a few years (fig. 35), are less reliable than those for stations having long-term records.

Duration curves are commonly used to make comparisons of the flow characteristics of different streams. A comparison of four streams in Oakland County is shown in figure 37. Discharge for these streams is plotted in cubic feet per second per square

NEXT PAGE: Monitoring of streamflow began in Oakland County as early as 1935. FIG. 35

Station No.	Station Name
4-1437	Shiawassee River near Davisburg
1438	Buckhorn Creek near Holly
1438.3	Shiawassee River at Holly
1480.2	Kearsley Creek at Ortonville
1480.3	Duck Creek at Ortonville
1481.9	Swartz Creek near Five Points
1481.95	Swartz Creek at Five Points
1482	Swartz Creek near Holly
1482.5	Swartz Creek near Bayport Park
1483.95	Thread Creek near Davisburg
1484	Thread Creek near Holly
1607.5	Clinton River at Clarkston
1607.6	Deer Lake Outlet at Clarkston
1607.95	Judah Lake Outlet near Eames
1608	Sashabaw Creek near Drayton Plains
1608.5	Clinton River at Drayton Plains
1609	Clinton River near Drayton Plains
1610	Clinton River at Auburn Heights
1611	Galloway Creek at Auburn Heights
1613	Paint Creek Drain near Oxford
1615	Paint Creek near Lake Orion
1615.2	Trout Creek near Lake Orion
1615.22	Trout Creek tributary near Lake Orion
1615.38	Sargent Creek at Rochester
1615.4	Paint Creek at Rochester
1615.8	Stony Creek near Romeo
1615.98	West Branch Stony Creek near Lake Orion
1616	West Branch Stony Creek near Lakeville
1617.6	West Branch Stony Creek near Washington
1617.7	Twin Lakes Outlet near Washington
1618	Stony Creek near Washington





EXPLANATION

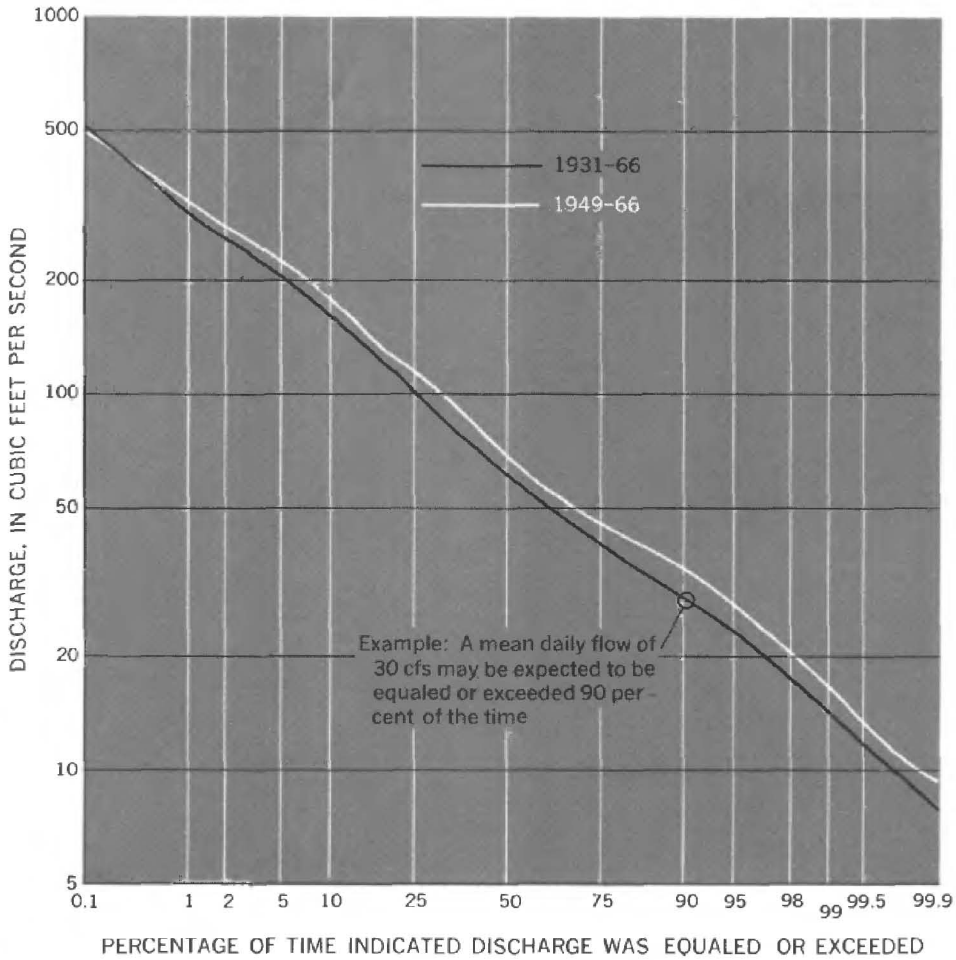
Occasional discharge measurement (partial-record station)

Continuous streamflow records

[1] Affected by regulation

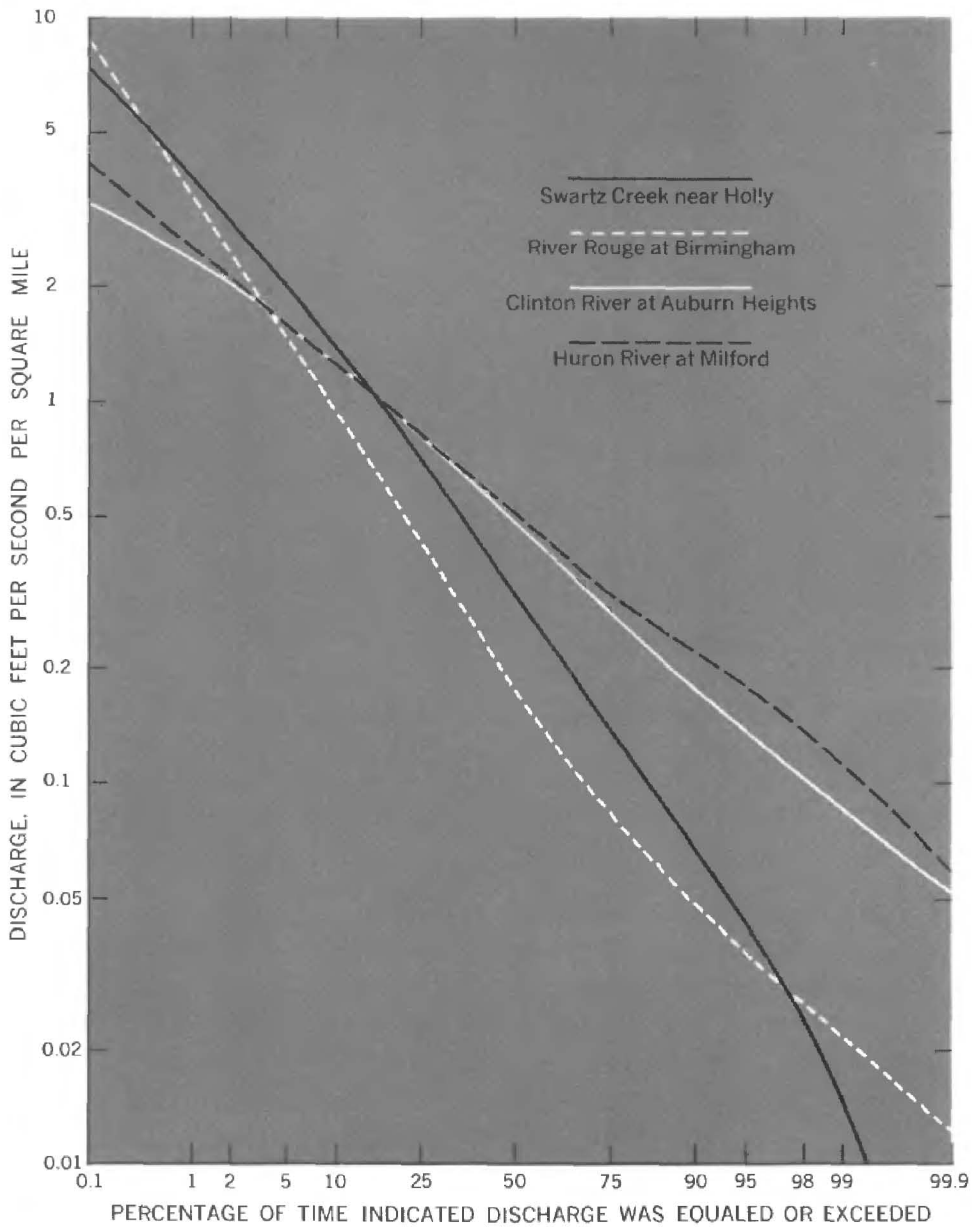
[2] Drainage area indefinite

NOTE: Station numbers conform to the numbering system used for the national network of gaging stations in the U.S. Geological Survey's annual report on surface-water supply since 1958. Lowflow measurement sites not included in listing.



Variability of streamflow is easily shown by flow-duration curves such as that for the Huron River at Milford. FIG. 36

mile (cfs per sq mi) to eliminate most of the effects of basin size. The relative shapes and positions of the curves present a generalized picture of the hydrologic characteristics of the drainage basins and suggest variations in basin runoff. The high-flow end of a duration curve is governed principally by climate and basin physiography. The low-flow end is indicative of ground-water contributions to streamflow. Steeply inclined curves, such as those for Swartz Creek near Holly and River Rouge at Birmingham, indicate rapid overland runoff, steeper stream gradients, more compact soils, and small contributions from ground-water sources. Flatter duration curves, such as those for Clinton River at Auburn Heights and Huron River at Milford, indicate higher retention of flood waters, either as ground-water storage or as surface storage in lakes, swamps, or stream channels. Flatter curves also indicate well-sustained low flows and more permeable soils. A duration curve which is concave upward at the low-flow end indicates a release of ground water to base flow with increased proportions. A bending downward of the low-flow end (Swartz Creek) indicates a proportionate decrease in the release



Duration curves for four streams in Oakland County illustrate variations in flow characteristics. FIG. 37

TABLE 5.—*Summary of flow-duration data for continuous*
[Discharge in cubic feet per second; discharge in

Station		Drainage area (sq mi)	Discharge which was equaled or exceeded for indicated percentage of time			
			30	50	70	90
4–1437.	Shiawassee River near Davisburg.	11.6	7.8 (.67)	5.9 (.51)	4.6 (.40)	3.2 (.28)
1438.	Buckhorn Creek near Holly	22.0	12 (.54)	7.5 (.34)	5.1 (.23)	3.0 (.14)
1438.3.	Shiawassee River at Holly	49.2	30 (.61)	20 (.41)	14 (.28)	9.2 (.19)
1480.2.	Kearsley Creek at Ortonville	19.7	13 (.66)	8.0 (.41)	4.9 (.25)	2.7 (.14)
1480.3.	Duck Creek at Ortonville	7.23	4.0 (.55)	2.9 (.40)	2.2 (.30)	1.6 (.22)
1481.9.	Swartz Creek near Five Points.	2.48	.9 (.36)	.5 (.20)	.3 (.12)	.1 (.04)
1481.95.	Swartz Creek at Five Points	6.17	3.0 (.49)	1.7 (.28)	1.0 (.16)	.5 (.08)
1482.	Swartz Creek near Holly	11.9	7.0 (.59)	3.7 (.31)	2.0 (.17)	.8 (.07)
1482.5.	Swartz Creek near Bayport Park.	27.9	24 (.86)	11 (.39)	4.6 (.16)	1.3 (.05)
1483.95.	Thread Creek near Davisburg.	7.56	2.0 (.26)	1.5 (.20)	1.2 (.16)	.8 (.11)
1484.	Thread Creek near Holly	12.2	4.7 (.39)	3.3 (.27)	2.3 (.19)	1.5 (.12)
1607.5.	Clinton River at Clarkston	11.5	7.0 (.61)	4.1 (.36)	2.5 (.22)	1.3 (.11)
1607.6.	Deer Lake Outlet at Clarkson.	15.0	8.0 (.53)	6.0 (.40)	4.7 (.31)	3.4 (.23)
1607.95.	Judah Lake Outlet near Eames.	4.39	1.5 (.34)	.3 (.07)	.1 (.02)	0 (0)
1608.	Sashabaw Creek near Drayton Plains.	21.0	11 (.52)	5.0 (.24)	2.0 (.10)	.7 (.03)
1608.5.	Clinton River at Drayton Plains.	74.7	49 (.66)	27 (.36)	15 (.20)	7.5 (.10)
1609.	Clinton River near Drayton Plains.	79.5	50 (.63)	28 (.35)	16 (.20)	8.5 (.11)
1610.	Clinton River at Auburn Heights.	123	85 (.69)	57 (.46)	38 (.31)	22 (.18)
1611.	Galloway Creek at Auburn Heights.	17.8	6.8 (.38)	1.5 (.08)	.4 (.02)	.2 (.01)
1613.	Paint Creek Drain near Oxford.	18.3	12 (.66)	6.7 (.37)	3.6 (.20)	1.8 (.10)
1615.	Paint Creek near Lake Orion.	38.9	22 (.57)	12 (.31)	6.9 (.18)	3.5 (.09)
1615.2.	Trout Creek near Lake Orion.	7.38	4.6 (.62)	2.7 (.37)	1.7 (.23)	.9 (.12)
1615.22.	Trout Creek tributary near Lake Orion.	2.35	2.3 (.98)	1.7 (.72)	1.2 (.51)	.7 (.30)
1615.38.	Sargent Creek at Rochester	4.69	2.3 (.49)	.9 (.19)	.4 (.09)	.2 (.04)
1615.4.	Paint Creek at Rochester	71.3	43 (.60)	27 (.38)	18 (.25)	11 (.15)
1615.8.	Stony Creek near Romeo	25.6	11 (.43)	5.8 (.23)	3.0 (.12)	1.6 (.06)

See footnotes at end of table.

and partial-record stations in Oakland County
cubic feet per square mile shown in parentheses]

Variability index (Q_{30}/Q_{90})	Lowest average discharge for indicated period of consecutive days and for recurrence interval shown						Average discharge
	7 days			30 days			
	2 yr	10 yr	20 yr	2 yr	10 yr	20 yr	
2.4	2.9	1.8	-------	3.3	2.1	-------	7.9
--------	(.25)	(.16)	-------	(.28)	(.18)	-------	(.68)
4.0	2.4	1.1	-------	3.0	1.4	-------	12
--------	(.11)	(.05)	-------	(.14)	(.06)	-------	(.54)
3.3	7.7	3.5	-------	9.3	4.5	-------	30
--------	(.16)	(.07)	-------	(.19)	(.09)	-------	(.61)
4.8	2.1	.9	-------	2.6	1.2	-------	14
--------	(.11)	(.05)	-------	(.13)	(.06)	-------	(.71)
2.5	1.3	.8	-------	1.5	1.0	-------	4.1
--------	(.18)	(.11)	-------	(.21)	(.14)	-------	(.57)
9.0	.1	.03	-------	.1	.04	-------	.9
--------	(.04)	(.01)	-------	(.04)	(.02)	-------	(.36)
6.0	.3	.1	-------	.4	.2	-------	3.1
--------	(.05)	(.02)	-------	(.06)	(.03)	-------	(.50)
8.8	.5	.1	.1	.7	.2	.2	6.9
--------	(.04)	(.01)	(.01)	(.06)	(.02)	(.02)	(.58)
18.5	.8	.1	-------	1.3	.2	-------	25
--------	(.03)	(.004)	-------	(.05)	(.007)	-------	(.90)
2.5	.7	.5	-------	.8	.5	-------	2.0
--------	(.09)	(.07)	-------	(.11)	(.07)	-------	(.26)
3.1	1.3	.8	-------	1.5	.9	-------	4.8
--------	(.11)	(.07)	-------	(.12)	(.07)	-------	(.39)
5.4	1.1	.5	-------	1.3	.6	-------	7.2
--------	(.10)	(.04)	-------	(.11)	(.05)	-------	(.63)
2.4	3.1	2.0	-------	3.5	2.3	-------	8.1
--------	(.21)	(.13)	-------	(.23)	(.15)	-------	(.54)
--------	0	0	-------	0	0	-------	1.5
--------	(0)	(0)	-------	(0)	(0)	-------	(.34)
15.7	.5	.1	.05	.7	.2	.1	11
--------	(.02)	(.005)	(.002)	(.03)	(.01)	(.005)	(.52)
6.5	6.3	2.5	-------	8.0	3.3	-------	51
--------	(.08)	(.03)	-------	(.11)	(.04)	-------	(.68)
5.9	7.0	3.0	2.3	9.0	3.9	3.2	52
--------	(.09)	(.04)	(.03)	(.11)	(.05)	(.04)	(.65)
3.9	20	10	7.8	25	13	10	80
--------	(.16)	(.08)	(.06)	(.20)	(.11)	(.08)	(.65)
34.0	.1	.03	.02	.2	.06	.04	8.2
--------	(.006)	(.002)	(.001)	(.01)	(.003)	(.002)	(.46)
6.7	1.4	.6	-------	1.8	.7	-------	13
--------	(.08)	(.03)	-------	(.10)	(.04)	-------	(.71)
6.3	2.8	1.2	.8	3.7	1.6	1.3	24
--------	(.07)	(.03)	(.02)	(.10)	(.04)	(.03)	(.62)
5.1	.7	.4	-------	.9	.5	-------	4.7
--------	(.09)	(.05)	-------	(.12)	(.07)	-------	(.64)
3.3	.6	.3	-------	.7	.4	-------	2.4
--------	(.26)	(.13)	-------	(.30)	(.17)	-------	(1.02)
11.5	.1	0	0	.1	0	0	2.5
--------	(.02)	(0)	(0)	(.02)	(0)	(0)	(.53)
3.9	9.7	5.9	5.1	12	7.0	6.1	45
--------	(.14)	(.08)	(.07)	(.17)	(.10)	(.09)	(.63)
6.9	1.3	.5	.4	1.6	.7	.6	12
--------	(.05)	(.02)	(.02)	(.06)	(.03)	(.02)	(.47)

TABLE 5.—*Summary of flow-duration data for continuous*
[Discharge in cubic feet per second; discharge in

	Station	Drainage area (sq mi)	Discharge which was equaled or exceeded for indicated percentage of time			
			30	50	70	90
1615.98.	West Branch Stony Creek near Lake Orion.	11.7	3.5 (.30)	2.0 (.17)	1.2 (.10)	.6 (.05)
1616.	West Branch Stony Creek near Lakeville.	14.8	5.0 (.34)	2.8 (.19)	1.6 (.11)	.6 (.04)
1617.6.	West Branch Stony Creek near Washington.	22.5	7.3 (.32)	3.4 (.15)	1.6 (.07)	.7 (.03)
1617.7.	Twin Lakes Outlet near Washington.	3.63	1.5 (.41)	1.0 (.28)	.6 (.17)	.4 (.11)
1618.	Stony Creek near Washington.	68.0	32 (.47)	20 (.29)	13 (.19)	8.2 (.12)
1618.3.	Clinton River at Yates	299	200 (.67)	120 (.40)	74 (.25)	43 (.14)
1620.	Red Run near Royal Oak [1]	36.5	------	------	-----	-----
1629.	Big Beaver Creek near Warren.	23.5	12 (.51)	4.6 (.20)	1.6 (.07)	.5 (.02)
1634.	Plum Brook at Utica	16.1	9.5 (.59)	3.2 (.20)	1.0 (.06)	.3 (.02)
1640.9.	East Pond Creek near Leonard.	9.49	4.5 (.47)	1.5 (.16)	.2 (.02)	0 (0)
1659.9.	Endicott Lake Outlet	21.5	3.7 (.17)	2.2 (.10)	1.5 (.07)	.9 (.04)
1660.	River Rouge at Birmingham.	36.9	13 (.35)	6.5 (.18)	3.6 (.10)	1.8 (.05)
1660.3.	Franklin Branch at Franklin.	15.4	11 (.71)	6.2 (.40)	3.8 (.25)	2.0 (.13)
1660.9.	Pebble Creek near Southfield.	10.3	5.5 (.53)	2.7 (.26)	1.5 (.15)	.7 (.07)
1661.	River Rouge at Southfield	87.9	41 (.47)	22 (.25)	13 (.15)	6.7 (.08)
1662.	Evans Ditch at Southfield	9.49	4.8 (.51)	2.4 (.25)	1.3 (.14)	.7 (.07)
1662.9.	Minnow Pond Drain at Quakertown.	9.18	5.0 (.54)	1.1 (.12)	.3 (.03)	.06 (.007)
1663.	Upper River Rouge at Farmington.	17.5	8.7 (.50)	4.5 (.26)	2.6 (.15)	1.4 (.08)
1666.	Walled Lake Branch at Northville.	22.1	10 (.45)	4.6 (.21)	2.2 (.10)	1.0 (.05)
1688.	Huron River near Andersonville.	14.0	4.5 (.32)	2.0 (.14)	1.0 (.07)	.4 (.03)
1689.	Huron River near Drayton Plains.[1]	20.8	------	------	-----	-----
1689.95.	Hayes Creek near Commerce.[1 2]	3.11	3.5 (1.13)	2.0 (.64)	1.4 (.45)	.8 (.26)
1690.	Hayes Creek at Commerce [1 2]	7.55	10 (1.32)	6.8 (.90)	5.0 (.66)	3.6 (.48)
1695.	Huron River at Commerce	49.6	35 (.71)	20 (.40)	14 (.28)	9.0 (.18)
1696.	Huron River near Milford	76.0	56 (.74)	33 (.43)	24 (.32)	15 (.20)
1697.	Norton Creek near Milford [3]	17.9	16 (.89)	11 (.61)	8.3 (.46)	6.0 (.34)

See footnotes at end of table.

and partial-record stations in Oakland County—Continued
cubic feet per square mile shown in parentheses]

Variability index (Q_{30}/Q_{90})	Lowest average discharge for indicated period of consecutive days and for recurrence interval shown						Average discharge
	7 days			30 days			
	2 yr	10 yr	20 yr	2 yr	10 yr	20 yr	
5.8	.4	.2	-------	.6	.3	-------	3.5
--------	(.03)	(.02)	-------	(.05)	(.03)	-------	(.30)
8.3	.4	.1	-------	.6	.2	-------	5.2
--------	(.03)	(.007)	-------	(.04)	(.01)	-------	(.35)
10.4	.5	.2	-------	.7	.3	-------	8.0
--------	(.02)	(.009)	-------	(.03)	(.01)	-------	(.36)
3.8	.4	.2	-------	.5	.3	-------	1.6
--------	(.11)	(.06)	-------	(.14)	(.08)	-------	(.44)
3.9	7.0	4.0	3.4	8.3	5.0	4.2	35
--------	(.10)	(.06)	(.05)	(.12)	(.07)	(.06)	(.51)
4.7	40	20	-------	48	24	-------	210
--------	(.13)	(.07)	-------	(.16)	(.08)	-------	(.70)
--------	-------	-------	-------	-------	-------	-------	--------
--------	-------	-------	-------	-------	-------	-------	--------
24.0	.3	.1	0	.6	.2	.1	14
--------	(.01)	(.004)	(0)	(.03)	(.009)	(.004)	(.60)
31.7	.2	.03	-------	.3	.1	-------	12
--------	(.01)	(.002)	-------	(.02)	(.006)	-------	(.75)
--------	0	0	0	0	0	0	4.5
--------	(0)	(0)	(0)	(0)	(0)	(0)	(.47)
4.1	.8	.4	-------	1.0	.5	-------	4.5
--------	(.04)	(.02)	-------	(.05)	(.02)	-------	(.21)
7.2	1.4	.5	.4	2.0	.8	.7	15
--------	(.04)	(.01)	(.01)	(.05)	(.02)	(.02)	(.41)
5.5	1.9	.9	-------	2.3	1.1	-------	13
--------	(.12)	(.06)	-------	(.15)	(.07)	-------	(.84)
7.9	.6	.3	-------	.8	.4	-------	6.7
--------	(.06)	(.03)	-------	(.08)	(.04)	-------	(.65)
6.1	6.2	1.7	1.1	7.3	3.2	2.5	51
--------	(.07)	(.02)	(.01)	(.08)	(.04)	(.03)	(.58)
6.9	.6	.3	.2	.8	.4	.3	7.0
--------	(.06)	(.03)	(.02)	(.08)	(.04)	(.03)	(.74)
83.3	.04	0	-------	.5	.01	-------	7.0
--------	(.004)	0	-------	(.005)	(.001)	-------	(.76)
6.2	1.4	.8	.6	1.6	.8	.7	11
--------	(.08)	(.05)	(.03)	(.09)	(.05)	(.04)	(.63)
10.0	.8	.3	-------	1.2	.4	-------	13
--------	(.04)	(.01)	-------	(.05)	(.02)	-------	(.59)
11.2	.3	.1	-------	.5	.2	-------	4.8
--------	(.02)	(.01)	-------	(.04)	(.01)	-------	(.34)
--------	-------	-------	-------	-------	-------	-------	--------
--------	-------	-------	-------	-------	-------	-------	--------
4.4	.7	.2	-------	.9	.2	-------	3.3
--------	(.23)	(.06)	-------	(.29)	(.06)	-------	(1.06)
2.8	3.3	1.6	-------	3.9	2.0	-------	9.5
--------	(.44)	(.21)	-------	(.52)	(.26)	-------	(1.26)
3.9	8.6	4.4	3.4	9.5	5.0	3.9	33
--------	(.17)	(.09)	(.07)	(.19)	(.10)	(.08)	(.67)
3.7	14	6.5	-------	15	7.7	6.0	50
--------	(.18)	(.09)	-------	(.20)	(.10)	(.08)	(.66)
2.7	5.6	3.5	-------	6.2	3.8	-------	16
--------	(.31)	(.20)	-------	(.35)	(.21)	-------	(.89)

TABLE 5.—*Summary of flow-duration data for continuous*

[Discharge in cubic feet per second; discharge in

	Station	Drainage area (sq mi)	Discharge which was equaled or exceeded for indicated percentage of time			
			30	50	70	90
1699.5.	Pettibone Creek at Milford	18.0	12 (.67)	7.5 (.42)	5.5 (.31)	4.0 (.22)
1700.	Huron River at Milford	125	92 (.74)	62 (.50)	45 (.36)	30 (.24)
1705.	Huron River near New Hudson [1]	143	115 (.80)	80 (.56)	56 (.39)	35 (.24)
1708.	Davis Creek near South Lyon.	24.4	12 (.49)	3.0 (.12)	1.0 (.04)	.3 (.01)

[1] Affected by regulation.
[2] Drainage area indefinite.
[3] Includes about 3 cfs from industrial and municipal effluent.

of ground water to streams. Where comparison of flow variability is desired for other locations, the lower part of the flow duration curves may be drawn from data listed in table 5.

Streams having well-sustained base flows (Clinton and Huron Rivers) due to a gradual release of water, principally ground water, have relatively high flows per unit area even at the low end of the duration curve. Geologic factors which influence the ground-water flow to streams include: (1) permeability of the soil through which the water must percolate, (2) storage space available to ground water, and (3) ability of the ground-water body to transmit water to the stream. An evaluation of duration data with these factors in mind permits a reconnaissance evaluation of basin geology.

A rapid guide to the variability of streamflow may be obtained from the variability index listed in table 5. This index is obtained by dividing the 90 percent duration discharge into the 30 percent duration value. Streams having large index values have highly variable flow, for instance they may have higher runoff per unit area after a storm but a low base flow. Those streams having lower index values maintain more uniform flow. A generalized picture of flow variability based on the variability index is shown in figure 38.

Streams at low flow

Low-flow frequency analyses provide a statistical estimate, based on past experience, of how often the flow of a stream will recede below certain amounts; whereas, flow-duration curves ex-

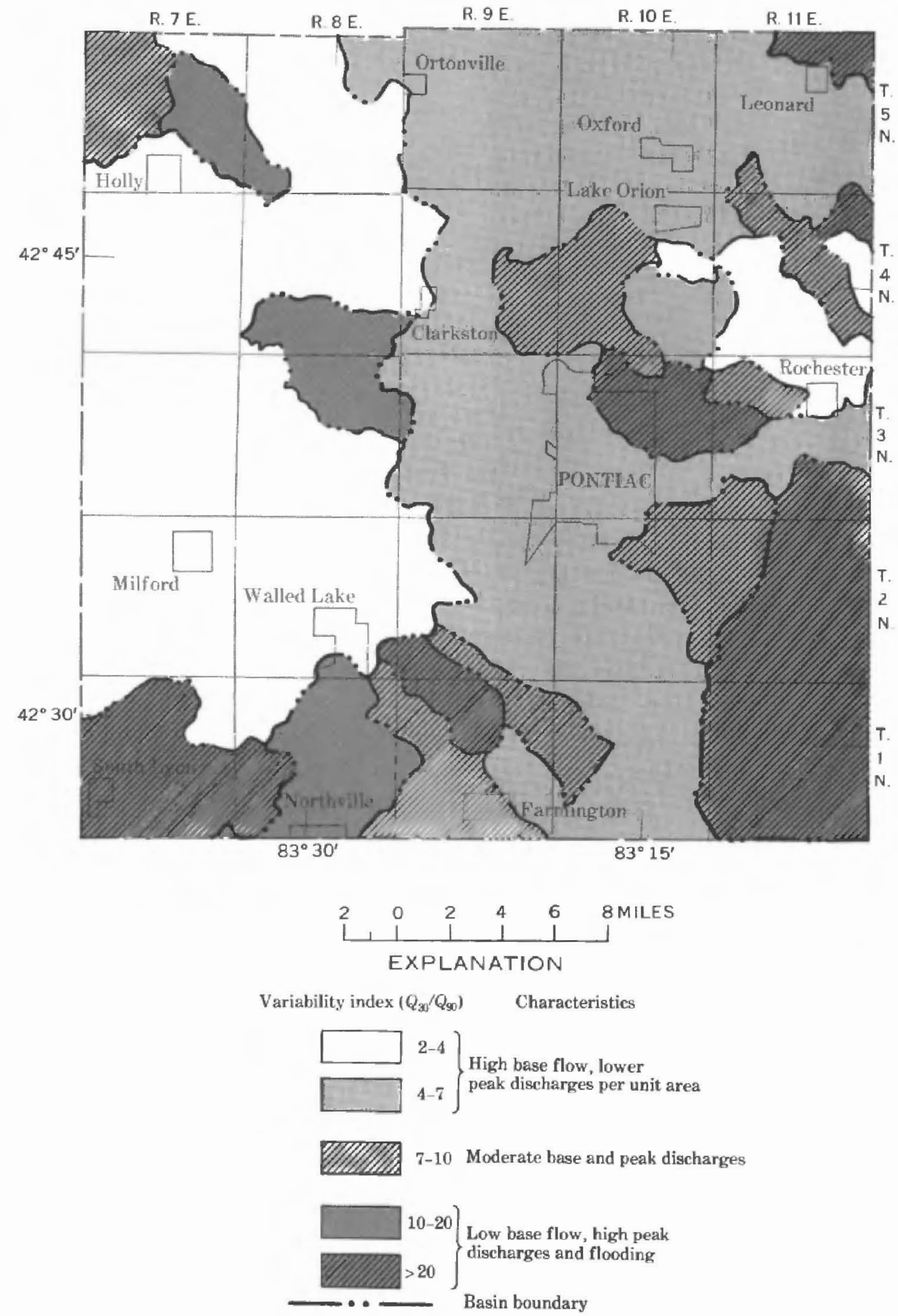
and partial-record stations in Oakland County—Continued
cubic feet per square mile shown in parentheses]

Variability index (Q_{30}/Q_{90})	Lowest average discharge for indicated period of consecutive days and for recurrence interval shown						Average discharge
	7 days			30 days			
	2 yr	10 yr	20 yr	2 yr	10 yr	20 yr	
3.0	3.4	2.0	-------	4.0	2.1	-------	12
--------	(.19)	(.11)	-------	(.22)	(.12)	-------	(.67)
3.1	28	13	9.3	33	17	13	85
--------	(.22)	(.10)	(.07)	(.26)	(.14)	(.10)	(.68)
3.3	27	14	11	35	21	18	105
--------	(.19)	(.10)	(.08)	(.24)	(.15)	(.13)	(.73)
40.0	.2	.1	-------	.4	.1	-------	12
--------	(.008)	(.004)	-------	(.02)	(.004)	-------	(.49)

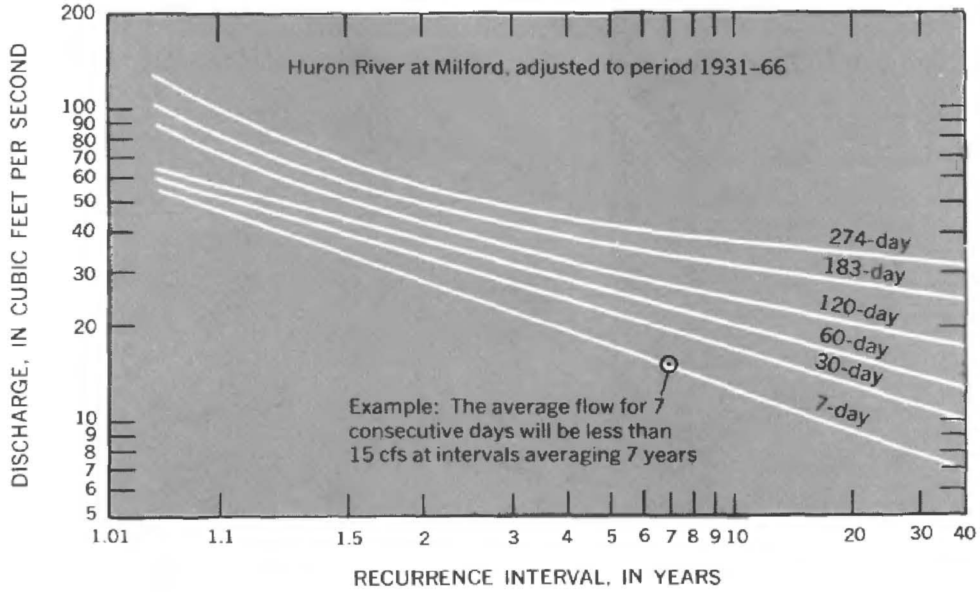
press the full regimen of streamflow without regard to the sequence of occurrence of particular flows. Flow-duration curves, for example, do not indicate whether flows less than a certain amount were uniformly distributed throughout the period of record or if they occurred principally in 1 or a few years. Low-flow frequency data therefore can be of great value in appraising a stream for water supplies, assessing storage requirements, and delineating the hydrologic characteristics of a basin. It is the quantity, duration, and probability of occurrence of low flows that dictate the suitability of a stream for an intended use. Without storage to augment flow during dry periods, the magnitude of low flow determines the dependable supplies.

A family of low-flow frequency curves is shown in figure 39. Similar families of curves were drawn for all the long-term gaging stations in the county and in adjacent areas. These sets of curves were correlated with records at short-term gaging stations and partial-record stations. Results of the analyses are given in table 5. As was done for flow duration, estimates of low flow are adjusted to the 1931–66 period in predicting probable frequency of future low flows. Provided in the table are the magnitude of average discharge for periods of 7 and 30 days and for recurrence intervals of 2, 10, and 20 years. The discharge at the 2-year recurrence interval represents the median annual or normal low-flow of a stream. Average low-flows for return intervals averaging 10 and 20 years are important considerations when a user must be concerned about the more critical drought conditions.

Many investigators use the median 7-day flow (7-day Q_2) as an index of the low-flow characteristics of a stream. The 7-day Q_2 for streams in Oakland County is shown graphically in figure 40.



Runoff characteristics vary greatly throughout the county as is shown by the wide range in variability indexes. FIG. 38



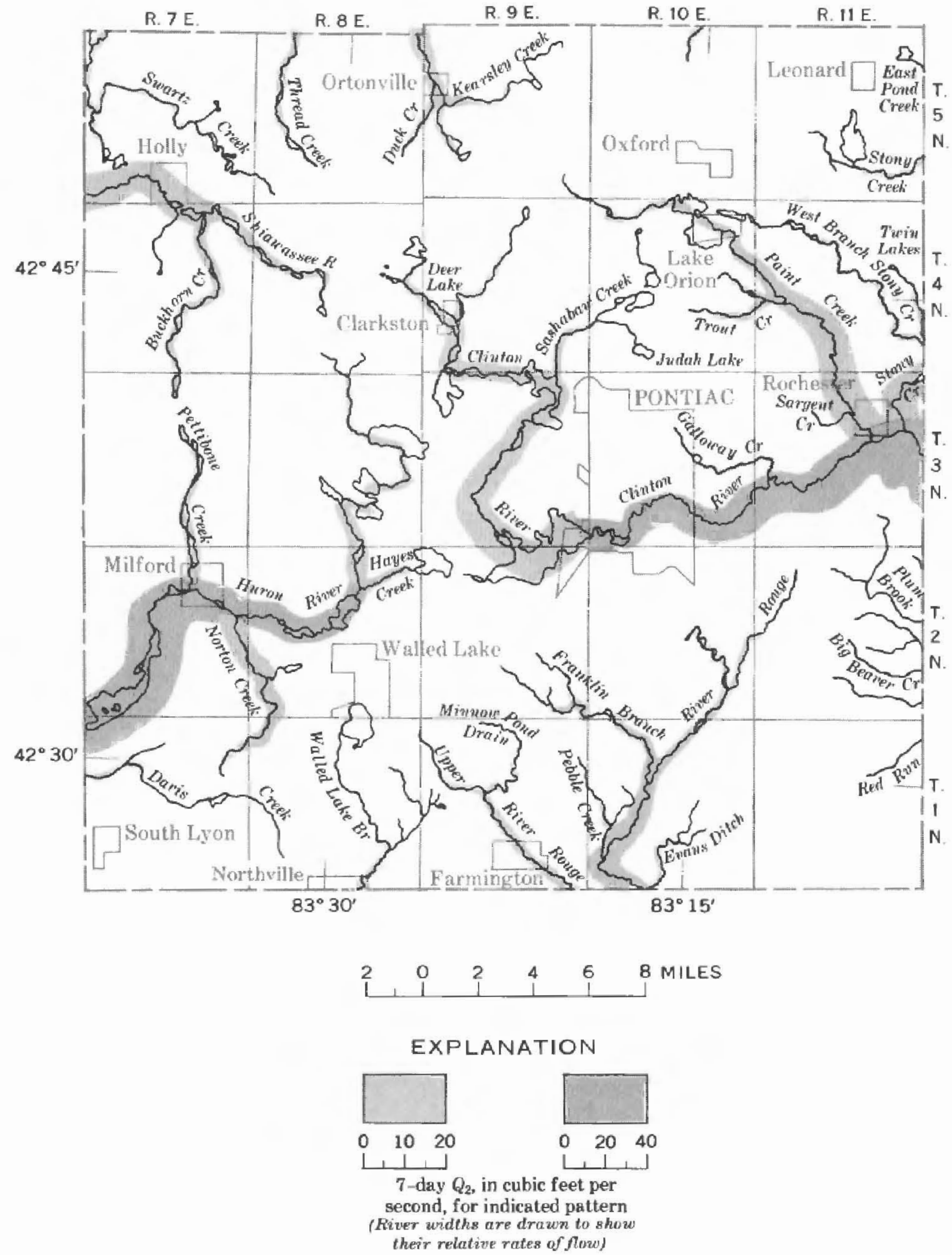
The magnitude and frequency of low flow of a stream is often the controlling factor in determining the suitability of a stream for a water supply. FIG. 39

In a later section, the 7-day Q_2 is used as a low-flow index in a regional analysis of storage requirements for augmenting low flow.

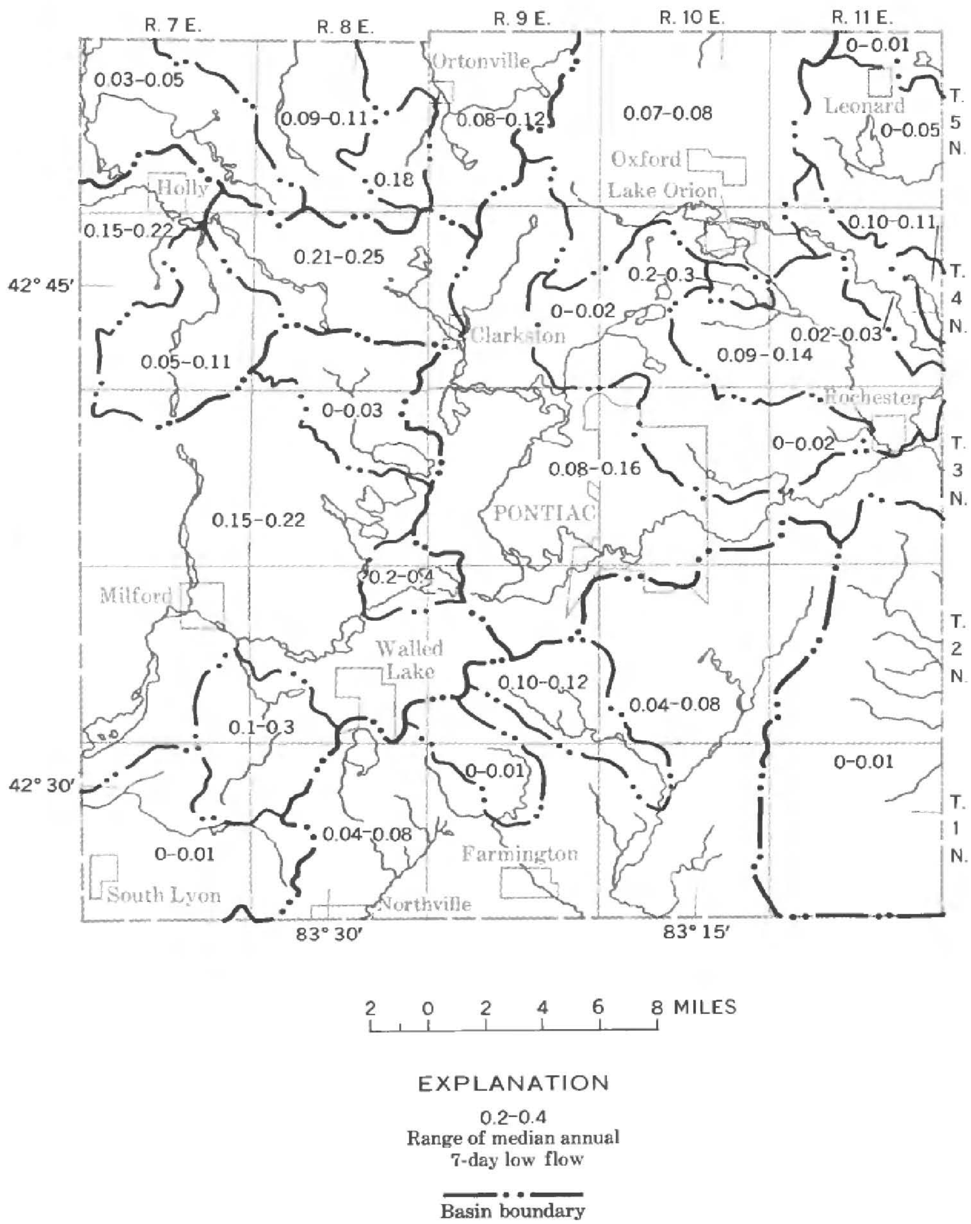
Basin geology governs to a large extent the magnitude of low flows. Basins in which the predominant glacial materials are highly permeable (glacial outwash and sandy lake beds) maintain higher base flows per unit area than those having compact glacial materials (morainal deposits and clayey lake beds). Surface deposits in Oakland County (fig. 63) vary markedly and cause a wide range in low flows even in adjacent river basins; this variance is depicted in figure 41.

High flow—another aspect of streams

Peak flows in Oakland County occur as a result of snow melt, extended or intense rains, or combinations of these events. Such flows may occur any time during the year but most occur during the spring (fig. 42). It is also during the spring months that more severe flooding is apt to occur. At this time, water from rainfall, augmented by water from melting snow, flows over frozen or partly frozen and often saturated ground and readily reaches the stream to produce high discharges. Such a combination of events occurred on April 6, 1947, when about 3 inches of rain fell on snow-covered ground. The resultant flood discharges were the highest since at least 1902 and caused extensive damage along stream valleys.

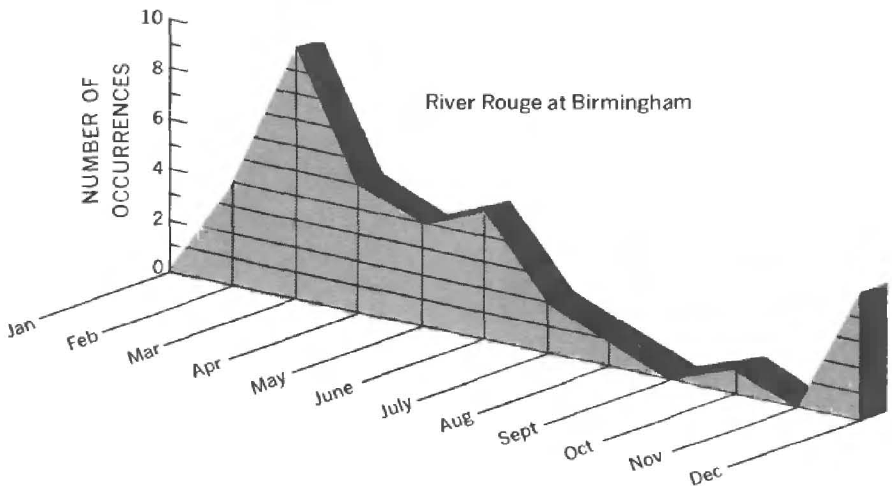


An index of low-flow characteristics for Oakland County streams is provided by median annual 7-day low flows (7-day Q_2). FIG. 40



Median annual 7-day low flows range from 0 to 0.4 cubic feet per second per square mile. FIG. 41

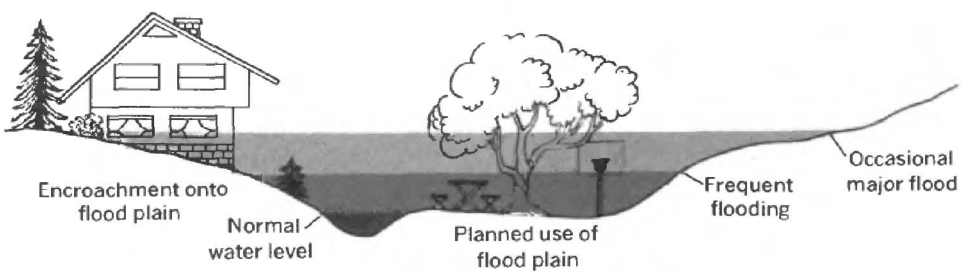
Heavy, intense summer storms, while not common and usually of limited areal extent, can cause severe flooding. This type of storm occurred on June 24–25, 1968. The resulting flood caused a considerable amount of damage in the southeastern part of the county.



Most peak flows occur during the spring months (distribution shown is for peak flows greater than 180 cubic feet per second occurring between 1950 and 1966). FIG. 42

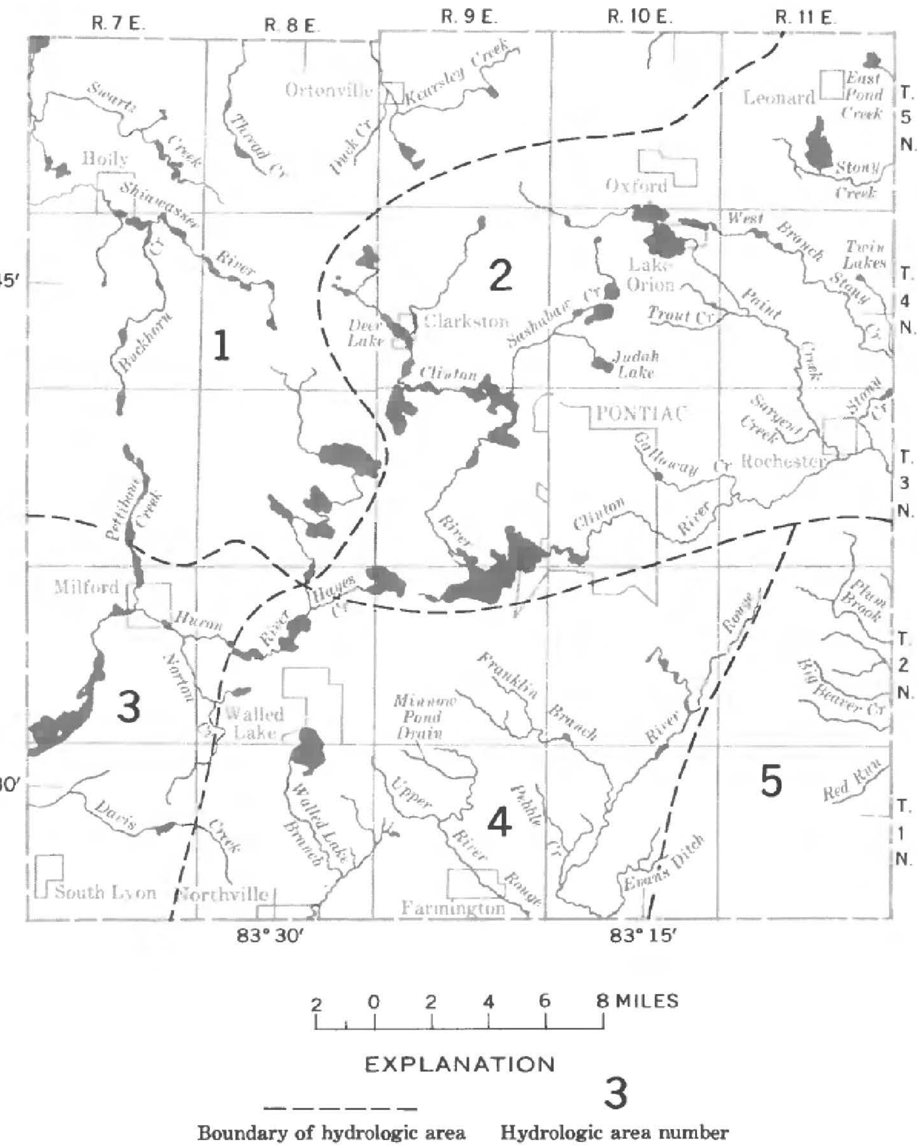
FLOODS—HOW OFTEN?

Measured in terms of geologic time, severe floods are a common occurrence. In terms of man's life, however, they are rare events and time soon reduces man's awareness of them. In man's lifetime, flooding of the bottom land in stream valley is observed with regularity. Floods of disastrous proportions are often only historical events and overlooked as improbable occurrences. Use of a stream and the land along it, however, is largely governed by the magnitude and frequency with which the stream is in flood (fig. 43). It is therefore necessary to evaluate flood events when considering the construction of dams, bridges, culverts, highways, sewage-treatment plants, or other structures within reach of a stream's floodwaters. The feasibility of construction, economics in design, and engineering problems of design require analysis of flood data.

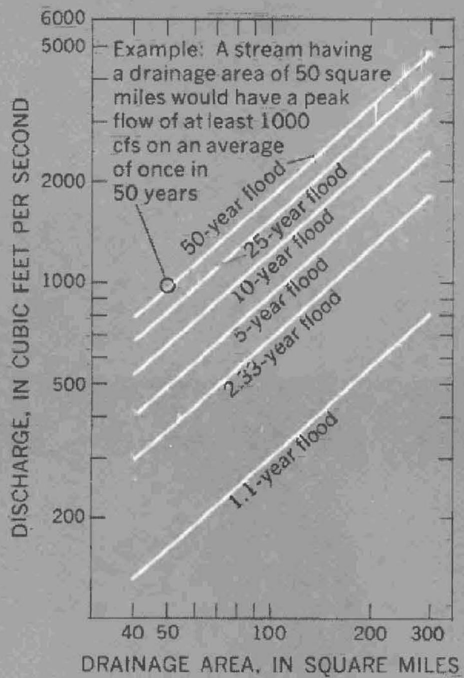


Planned use of river flood plains should take into account the magnitude and frequency of flood events. FIG. 43

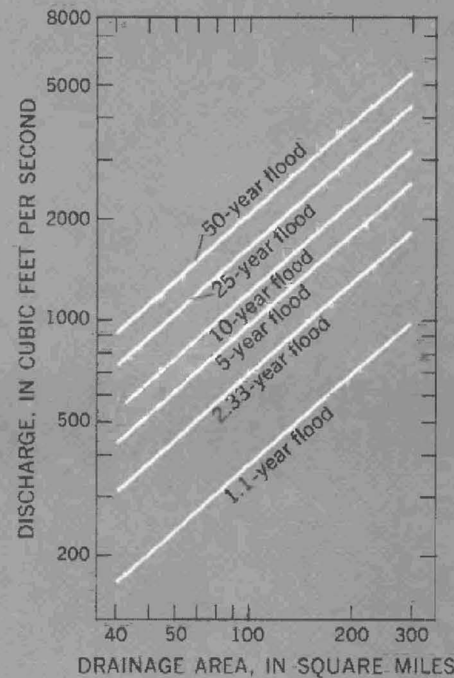
The time of occurrence of a flood cannot be predicted. It is possible, however, through evaluation of past records to state with some assurance the chance of a flood of a certain magnitude occurring in any year. Where records are short, regional analyses of flood data provide a basis for estimating floodflows. Such an analysis is contained in a comprehensive report on floods by Wiitala (1965). In that report, Oakland County, because of its variations in flood-flow characteristics, is divided into five hydrologic areas, which are shown in figure 44. Flood-frequency relationships applicable to each area with an example of the application of the curves are shown in figure 45.



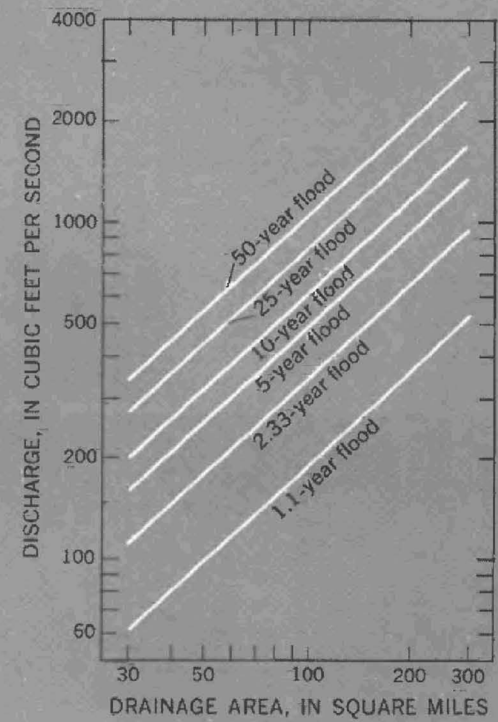
Five hydrologic areas are used to define flood-flow characteristics. FIG. 44



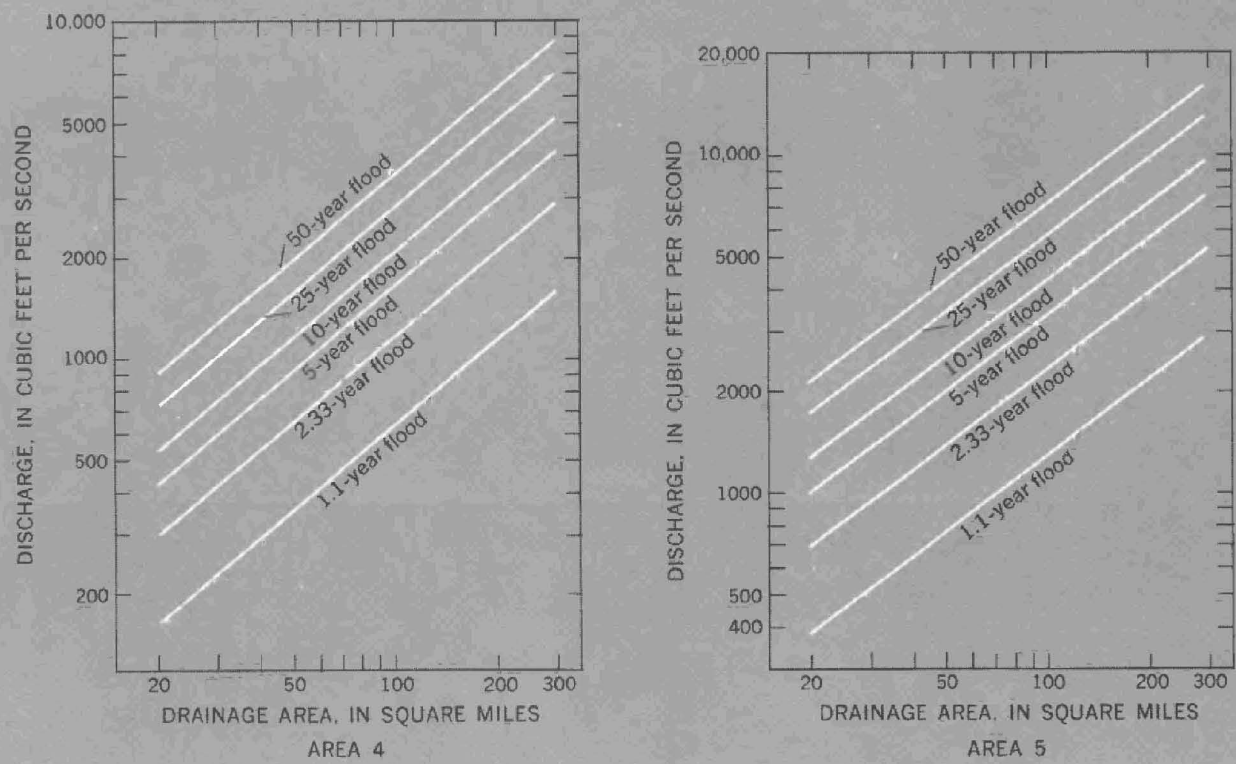
AREA 1



AREA 2

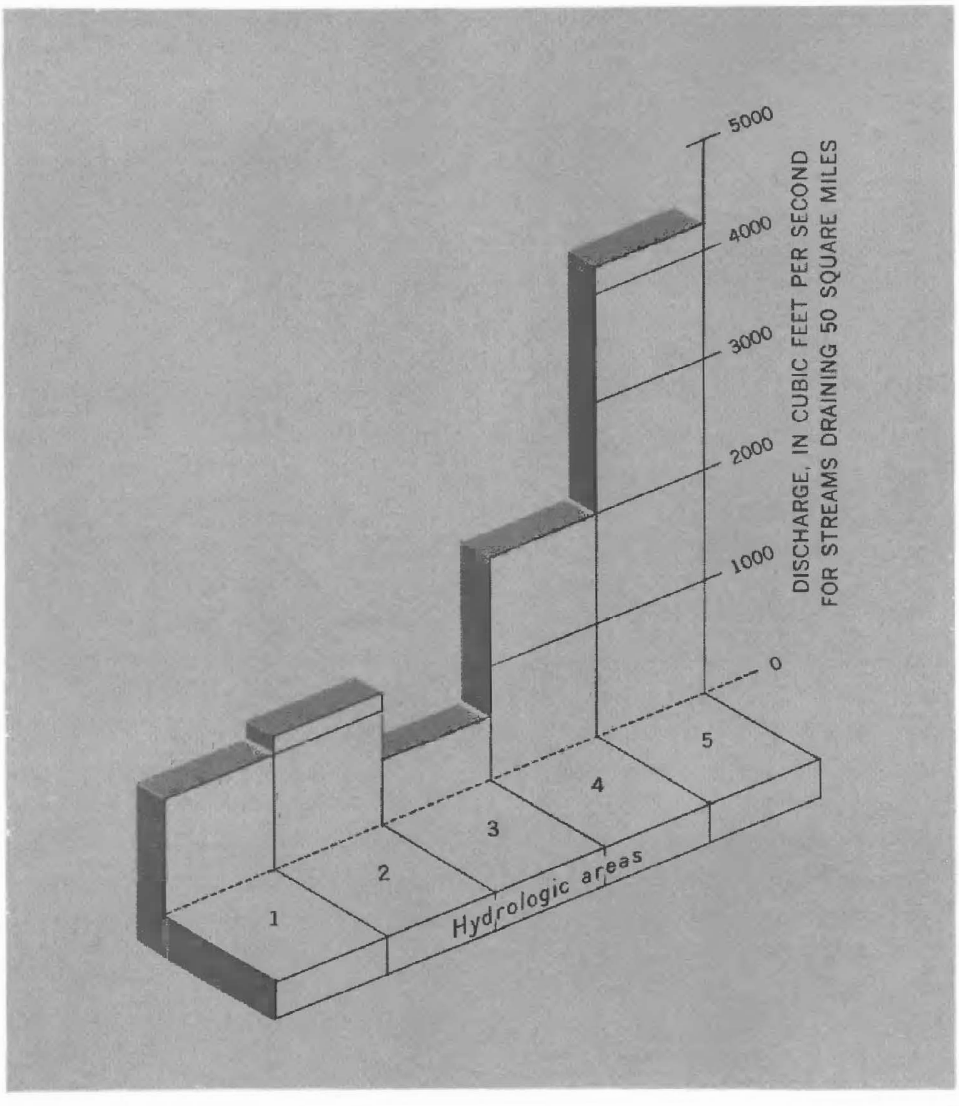


AREA 3



Variations in flood flow between hydrologic areas is shown by flood-frequency curves. FIG. 45

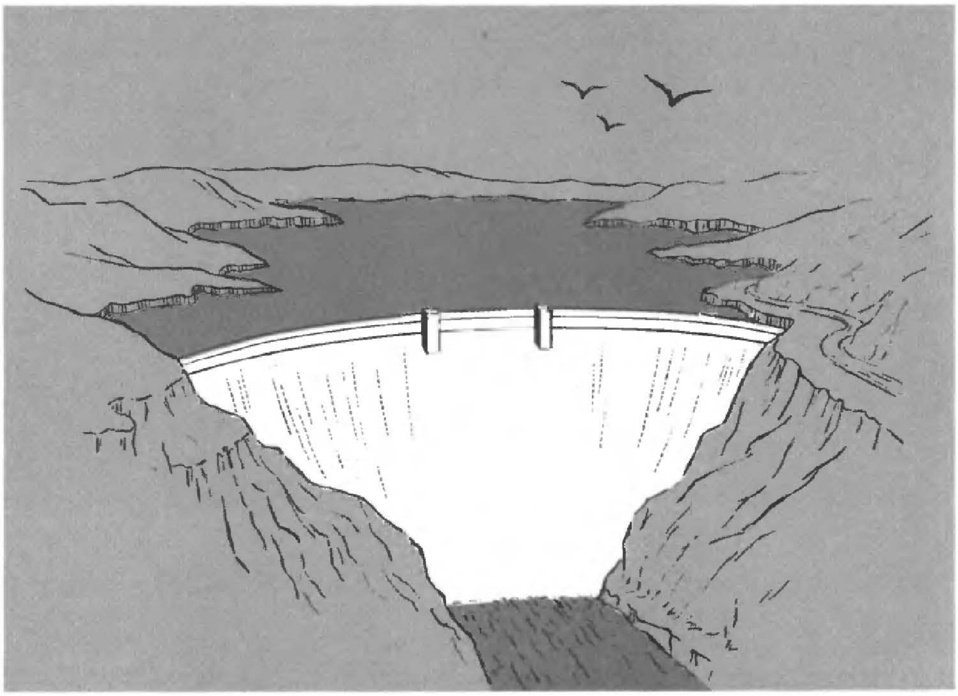
Although much of Oakland County is relatively free from destructive flooding, floods are a serious problem in the southeastern part of the county. To illustrate this, the magnitude of a flood having a 50-year recurrence interval for streams draining an area of 50 square miles was determined for each hydrologic area (fig. 46). As shown, hydrologic areas to the southeast (areas 4 and 5) have substantially higher flows than those for other areas. Also, hydrologic area 5 has peak discharges more than eight times greater than those of area 3. High flows in areas 4 and 5 are primarily the result of compact, impermeable soils; however, urbanization has also contributed to the flood problem.



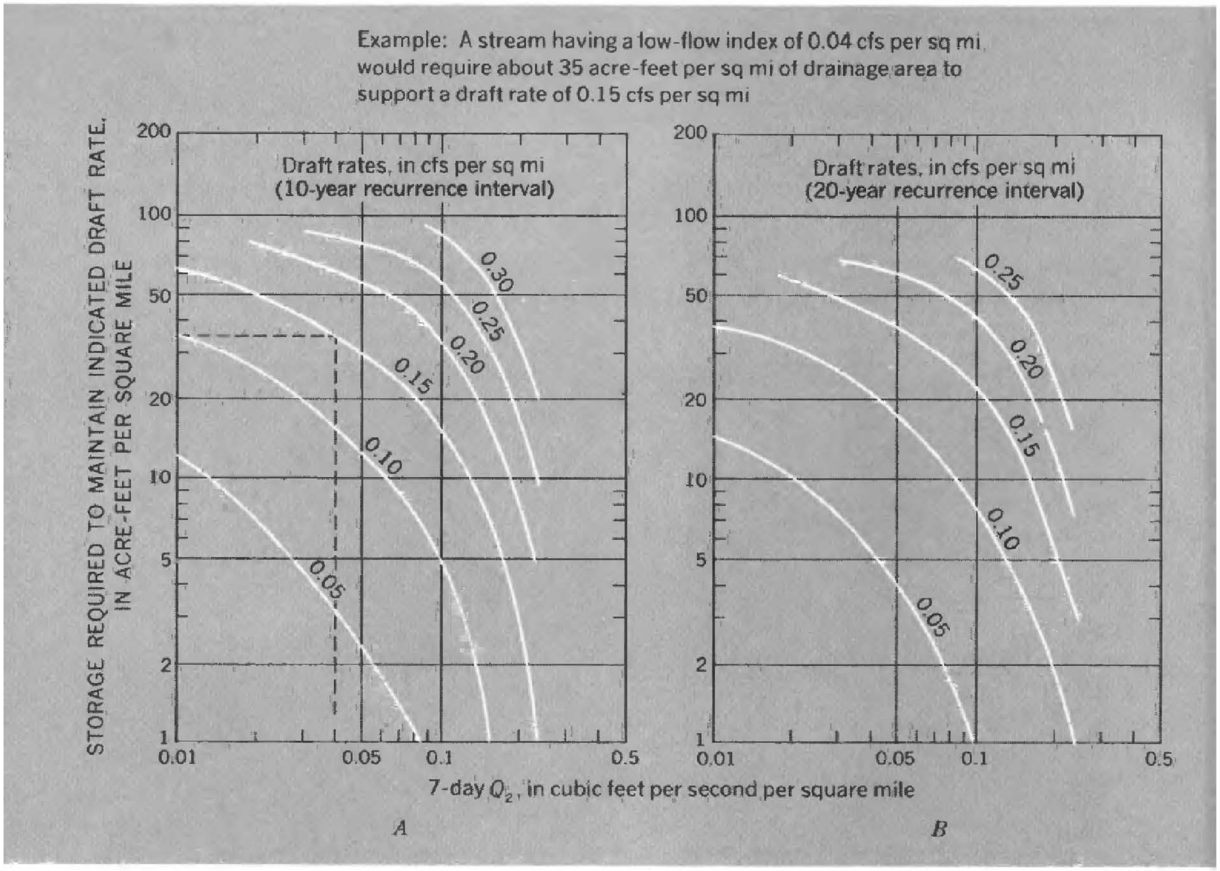
The magnitudes of floods having a 50-year recurrence interval are greatest in hydrologic areas 4 and 5. FIG. 46

WATER STORAGE

The total amount of water flowing out of Oakland County averages about 575 cfs. This is more than six times the normal low flow of the streams. With this tremendous difference it is obvious that potential supplies are great, whereas dependable supplies, based on low flows, may be inadequate for most uses. To increase dependable supplies, storage must be provided.



Estimates of storage requirements may be accomplished by several methods if streamflow records of sufficient length are available. However, where limited data are available, a regional analysis of low-flow records in relation to anticipated demands provides a basis for estimating storage needs (H. C. Riggs, written commun.; Martin and Hulme, 1957). This method involves relating draft-storage relations, computed from low-flow frequency curves, to an index of low flow. Regional curves relating draft, storage, and frequency were defined from draft-storage relationships developed for long-term stations in Oakland County and adjacent areas. Curves for recurrence intervals of 10 and 20 years are shown in figure 47. 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.



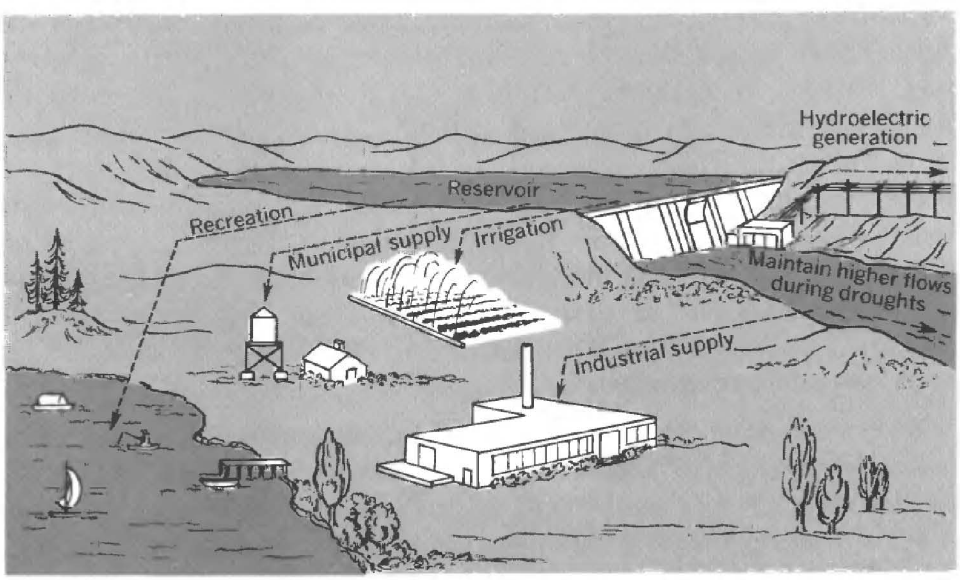
Regional draft-storage curves can be used to make storage estimates.
FIG. 47

1. Determine drainage area upstream from point of use.
2. Estimate the low-flow index (7-day Q_2). Values of 7-day Q_2 are given for 54 locations in table 5. Estimates of 7-day Q_2 may be made from figure 40 or by obtaining a few base-flow measurements, preferably on different recessions and in different years and correlating these data with concurrent data for locations having a known low-flow index.
3. Examine figure 47*A* or 47*B*, depending upon how often an inadequate amount of storage can be tolerated, with the 7-day Q_2 in cubic feet per second per square mile. Intersect selected draft-rate curve and read storage from the ordinate scale.

Storage estimates obtained from the regional curves are useful primarily in making a preliminary evaluation of development potential and for comparing the possibilities between different streams. Development 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.

The gross water supply available from water stored in a reservoir generally is lessened by evaporation. According to Kohler, Nordenson, and Baker (1959), annual evaporation from an open body of water in the county would be slightly more than 30 inches per year—an amount approximately equal to the annual precipitation. Most losses due to evaporation are during the summer months when, coincidentally, streamflow is generally lowest. About 80 percent of the total evaporation occurs during the May-October period. Evaporation losses, therefore, are important considerations in reservoir design and must be accounted for when determining storage requirements. Other factors to be considered are seepage and conveyance losses and losses in storage capacity through sedimentation; also, changes in hydrologic conditions caused by impoundment must be considered. Where impoundments inundate large areas of swamp land, reduction in evapotranspiration may result in a net gain in runoff. In other areas higher ground-water levels caused by impoundment may induce subsurface diversions or interbasin flow of water.

Major reservoirs will be required to provide sufficient storage capacities to withstand droughts of 2 or more years. Often such reservoirs are not economically feasible unless several uses or benefits (fig. 48) may be realized from the impoundment. Reten-



Major reservoirs may be designed to have many uses. FIG. 48

tion of flood waters, recreation benefits, improved property values, higher drought flows, and water supply for irrigation, municipal, and industrial needs are among the benefits which may be realized from a multiple-purpose reservoir.

Streams for storage

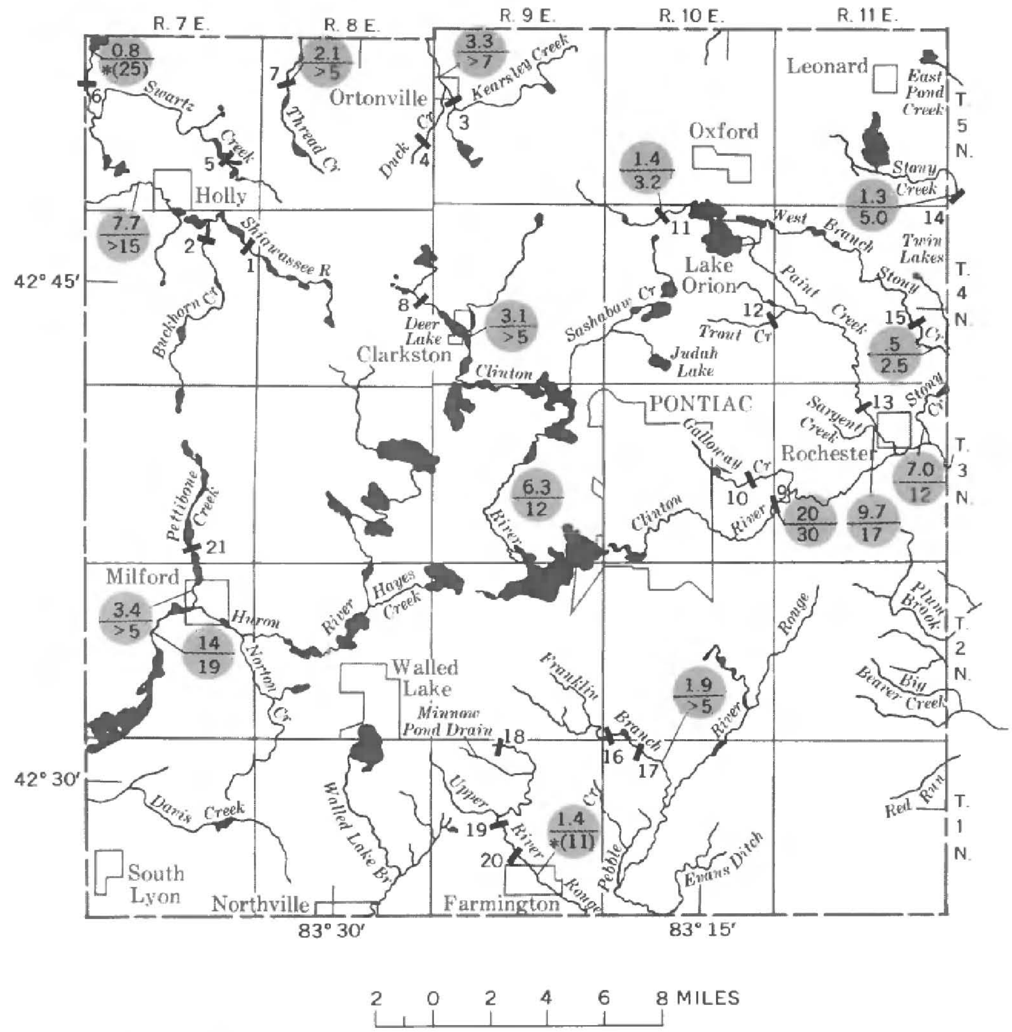
Dams can be built and reservoirs can be created at many locations in Oakland County, but it is not always economical to utilize every location. Lakes, for example, that invite construction of dams at their outlets are generally limited to esthetic and recreational use; this results in residential development and high property values which do not justify construction of a dam. Barring economic limitation, however, topography in the county is favorable for reservoir development at a number of locations. From a map study, 21 sites have been identified and are shown in figure 49. Specific data on each site are listed in table 6.

Increases of several times the present flow are possible by reservoir development, and at some sites potentially available flows approaching the average annual flow may be achieved. By way of illustration, the presently and potentially available supplies are shown for several sites in figure 49. Potentially available supplies are based on the storage volumes listed in table 6 and the application of draft-storage relationships shown in figure 47.

The reservoirs considered to be available could store an estimated 60,000 acre-ft of water. Some of the reservoirs would require the entire flow of the stream for periods in excess of 1 year before they would be filled. Smaller dams might be desirable in these cases unless the larger impoundment could serve several uses. Where recreation, esthetics, flood control, and improved property values are important considerations, larger dams may be warranted. Other locations suitable for reservoir development are undoubtedly available, especially where economic and engineering considerations can be overcome, or where small supplies are needed and impoundments with somewhat less than 1,000 acre-ft of storage capacity would be adequate.

Additional storage in lakes

Economic and conflict of interest considerations largely influence decisions regarding the use of lakes for water supply. Also, some uses alter the quality of water and may have a deleterious effect on the lakes. Use of lakes as storage reservoirs, however, has little influence on quality and, barring other limitations, may serve as a water-supply source or to augment low flow.



EXPLANATION

(14 / 19) Present supply (7-day Q_2), in cubic feet per second
Potential supply (20-year recurrence interval), in cubic feet per second

Potential supply is that which could be developed in reservoirs listed in table 6

* Approaching average annual discharge, shown in parentheses

> More than

6 Dam location; number corresponds to site listed in table 6

The assured flow of streams may be increased severalfold through reservoir development. FIG. 49

Most lakes in Oakland County fluctuate about 2 feet each year under natural conditions but may have a long-term range in stage of several feet. If the volume represented by this range in stage could be utilized as storage space, the lakes and ponds represent a

TABLE 6.—*Suitable sites for reservoir*

	Site	Location	Drainage area (sq mi)
1.	Shiawassee River	NW¼ sec. 12, T. 4 N., R. 7 E.	11.6
2.	Buckhorn Creek	NE¼ sec. 10, T. 4 N., R. 7 E.	23.8
3.	Kearsley Creek	SE¼ sec. 18, T. 5 N., R. 9 E.	19.7
4.	Duck Creek	SW¼ sec. 24, T. 5 N., R. 8 E.	4.63
5.	Swartz Creek	NE¼ sec. 26, T. 5 N., R. 7 E.	4.92
6.	Do	SE¼ sec. 1, T. 5 N., R. 6 E.	27.7
7.	Thread Creek	NW¼ sec. 5, T. 5 N., R. 8 E.	18.5
8.	Deer Lake Inlet	NW¼ sec. 19, T. 4 N., R. 9 E.	13.2
9.	Clinton River	SW¼ sec. 19, T. 3 N., R. 11 E.	126
10.	Galloway Creek	NW¼ sec. 24, T. 3 N., R. 10 E.	16.4
11.	Paint Creek Drain	NW¼ sec. 4, T. 4 N., R. 10 E.	16.7
12.	Trout Creek	SE¼ sec. 24, T. 4 N., R. 10 E.	6.11
13.	Paint Creek	SW¼ sec. 3, T. 3 N., R. 11 E.	65.5
14.	Stony Creek	NW¼ sec. 31, T. 5 N., R. 12 E.	24.8
15.	West Branch Stony Creek	NW¼ sec. 25, T. 4 N., R. 11 E.	20.8
16.	Franklin Branch	SW¼ sec. 31, T. 2 N., R. 10 E.	13.3
17.	Do	SE¼ sec. 5, T. 1 N., R. 10 E.	15.0
18.	Minnow Pond Drain	NW¼ sec. 5, T. 1 N., R. 9 E.	3.26
19.	Upper River Rouge	SW¼ sec. 16, T. 1 N., R. 9 E.	15.8
20.	Do	NW¼ sec. 27, T. 1 N., R. 9 E.	17.0
21.	Pettibone Creek	NE¼ sec. 34, T. 3 N., R. 7 E.	16.1

significant storage reservoir. There are 1,468 lakes and ponds in the county (Humphrys and Green, 1962) having a total surface area of 15,313 acres. Practical limitations, however, would restrict development to those lakes having adequate drainage into them and active inlets and outlets.

Fifteen lakes, or combinations of lakes, were selected from a map study to illustrate the potential of lakes as reservoirs (table 7). Together, these lakes have more than 6,700 acres of surface area. If they could be regulated within a 2-foot range in stage, a storage volume of more than 13,000 acre-ft would be realized. It is expected, however, that lakes will continue to serve primarily for their recreational and esthetic value.

LAKES

The numerous lakes in Oakland County are of immense value. They provide esthetic and recreational uses that no other features can provide. Thus, great efforts should be made to maintain these lakes in usable existence for as long as possible. To accomplish this, we must have a better understanding of those factors

Storage (acre-ft)	Pond altitude (feet)	Pond area (acres)	Dam height (feet)	Remarks
3,400	950	335	18	Would inundate Long and Kirby Lakes.
2,700	950	245	22	
1,900	960	275	17	
900	980	80	15	
3,500	950	275	31	
18,200	870	1,340	24	On Oakland-Genessee County line.
1,930	910	315	20	
2,200	1,000	325	28	
2,280	850	215	31	Some residential areas in Auburn Heights would be inundated.
2,200	900	135	50	
670	1,010	130	11	
1,220	940	115	27	
1,250	800	135	22	Requires railroad relocation.
1,540	920	140	24	Located in Macomb County.
860	900	75	41	
1,960	830	130	42	Multipurpose use, water supply and flood-water retention.
3,570	840	190	52	
900	750	60	40	
1,700	900	110	26	Small area drained, suitable for flood-water retention.
3,000	910	150	36	
1,900	800	110	52	
4,030	760	210	52	
2,500	970	300	26	

that are important in determining the usability of a lake. Of all factors, three are of major importance—lake levels, water quality, and depth. If these can be maintained within desirable standards the useful life of the lakes will be greatly prolonged.

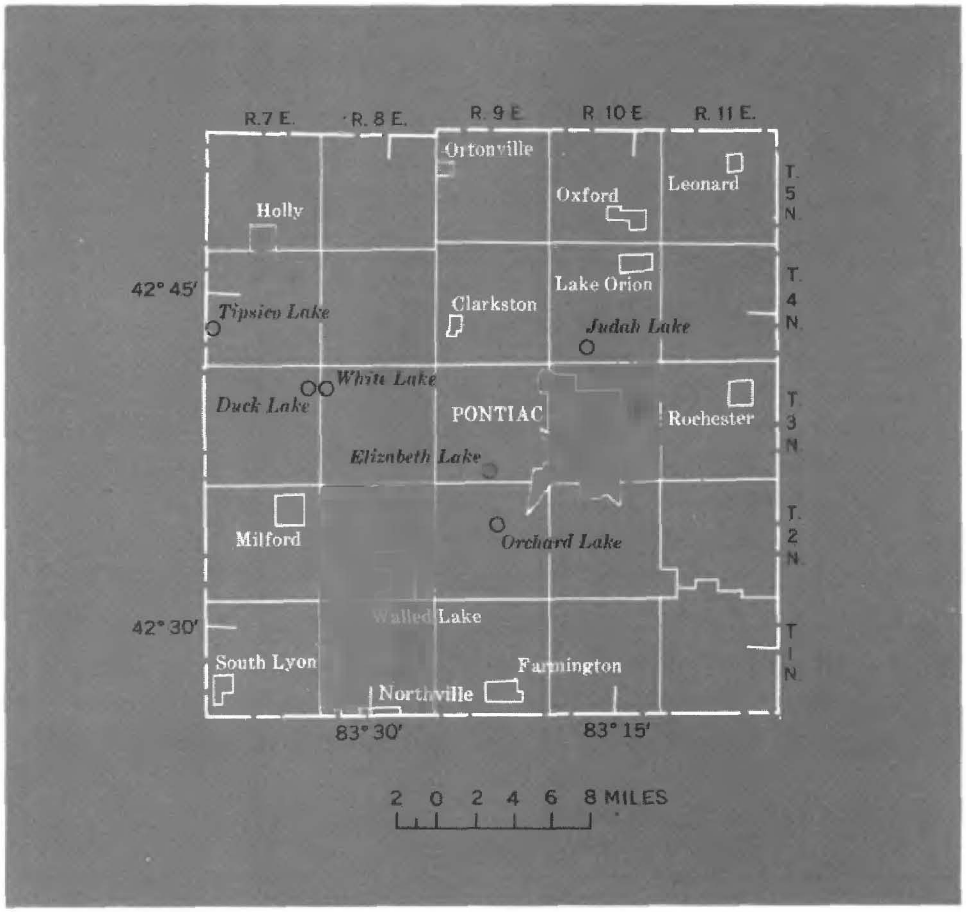
TABLE 7.—*Fifteen selected lakesites with storage potential in Oakland County*
[Data on surface area from Humphrys and Green (1962)]

Lakesite	Drainage basin	Surface area (acres)
1. Hemstead	Kearsley Creek	103
2. Deer	Clinton River	137
3. Greens-Lotus-Maceday-Lester-Mill Pond.	do	[1] 612
4. Woodhull-Oakwood	do	[1] 470
5. Angelus-Mohawk-Wormer-Schoolhouse-Upper Silver-Silver-Loon.	do	[1] 880
6. Orchard-Cass	do	[1] 2,068
7. Sylvan-Otter	do	[1] 539
8. Indianwood	Paint River	122
9. Pontiac	Huron River	640
10. Oxbow	do	290
11. Cedar Island	do	134
12. Wolverine-Twin Sun	do	[1] 288
13. Commerce	do	262
14. Lower Pettibone	Pettibone Creek	89
15. Moore	do	92

[1] Combined area of lakes.

A study of six lakes

To maintain Oakland County lakes in usable condition, a better understanding of their hydrology is necessary. Thus, a study was made of six lakes (fig. 50, table 8) selected because they occur in



Six lakes that reflect different environmental settings. FIG. 50

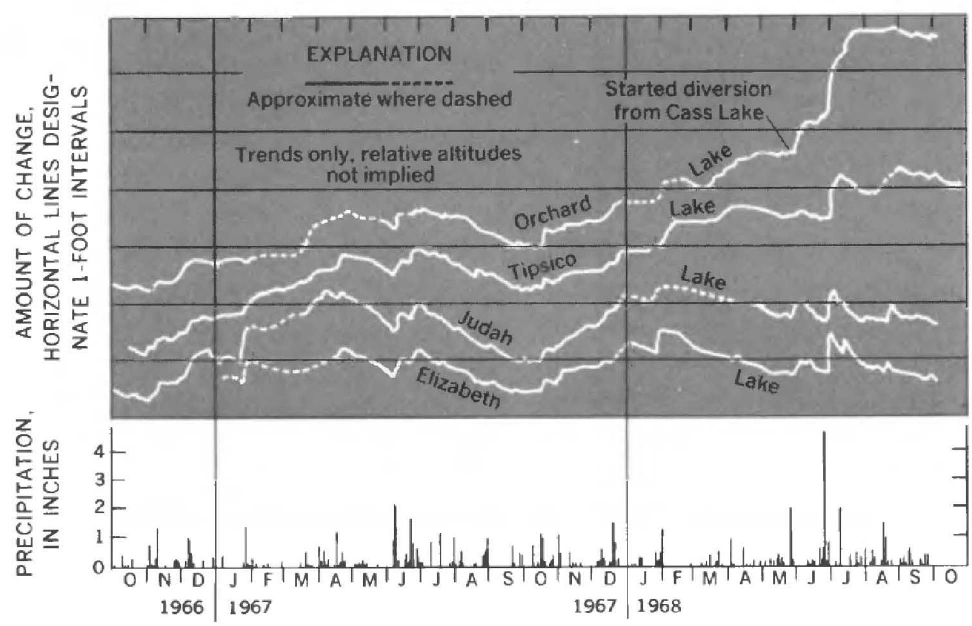
varied environmental settings, yet have features that are characteristic of many other lakes in the county. The hydrologic regimen at two of the lakes, Duck and White, were altered by lake-level restoration projects in the summer of 1966. The effects of the restoration projects on these two lakes is discussed at the end of this section of the report.

A desirable lake level is one that remains relatively high and has a minimum of fluctuation. Under natural conditions this situation seldom exists. Lake levels continually rise and fall; at times unusually high levels cause destruction to shoreline property and

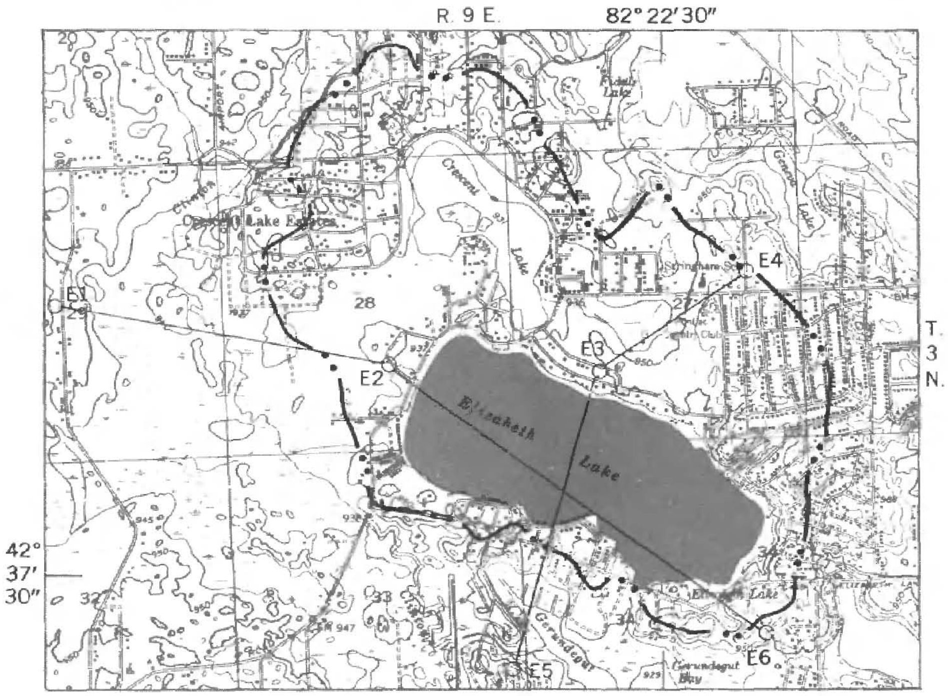
TABLE 8.—*Some environmental features of six selected lakes in Oakland County*

Lake	Size (acres)	Inlet and outlet characteristics	Geologic environment	Percentage of urbanized shoreline	Remarks
Tipsico	301	No inlet, intermittent outlet.	Moraine and till.	40	No flow from outlet during period of study.
Orchard	788	Landlocked	Moraine	90	Water from Cass Lake pumped into lake occasionally since May 1968.
Elizabeth	363	No inlet, intermittent outlet.	Moraine	100	
Judah	115	Intermittent inlet and outlet.	Moraine	30	Flow from outlet during much of the year. Several observation wells drilled around this lake were dry.
Duck	253	Landlocked	Outwash	80	Water pumped from deep wells into lake occasionally since November 1966.
White	540	Landlocked	Outwash	100	Water pumped from deep wells into lake occasionally since July 1968.

at other times they are undersirably low. An obvious factor influencing lake-level fluctuation is precipitation. Hydrographs of four of the six lakes studied (fig. 51) illustrate the relation between precipitation and lake levels. In reality, however, precipitation only produces a rise in lake levels, not a decline. Lake-level decline can be attributed principally to evaporation. Through evaporation, as much as 6 inches of water can be removed from a lake in a month's time. Because evaporation is greatest during the summer months, these are the months during which lake levels often show the greatest decline.



Lake-level trends for four lakes. FIG. 51



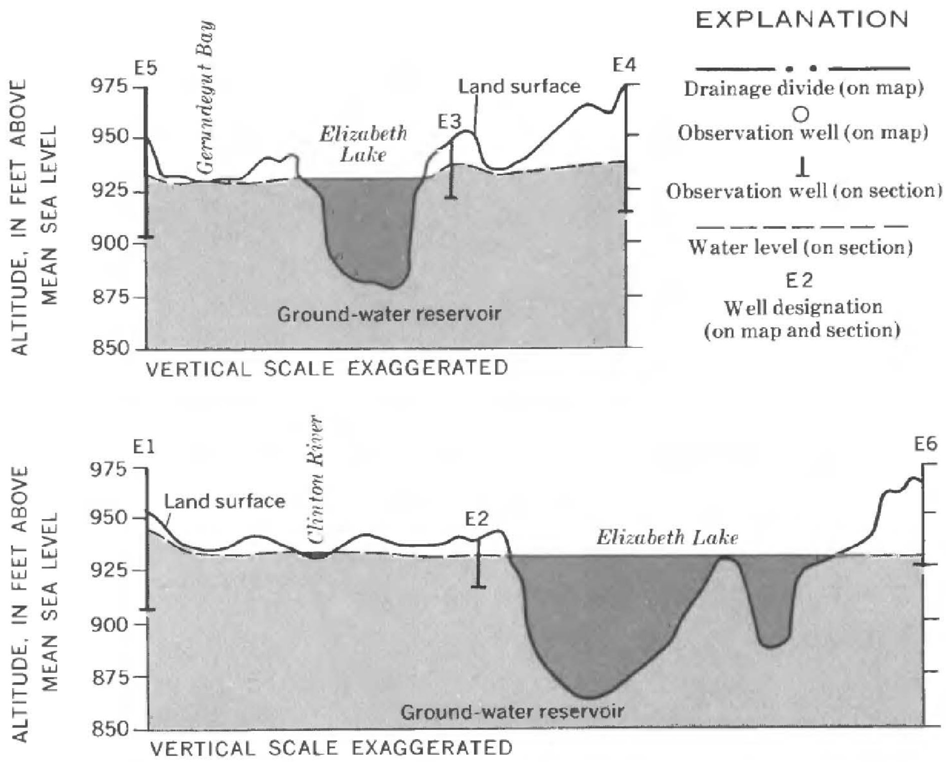
Base from U.S. Geological Survey; 1:24,000; Clarkston, Pontiac North, Pontiac South, and Walled Lake, 1952

0 ½ 1 MILE

CONTOUR INTERVAL, 10 FEET
DATUM IS MEAN SEA LEVEL

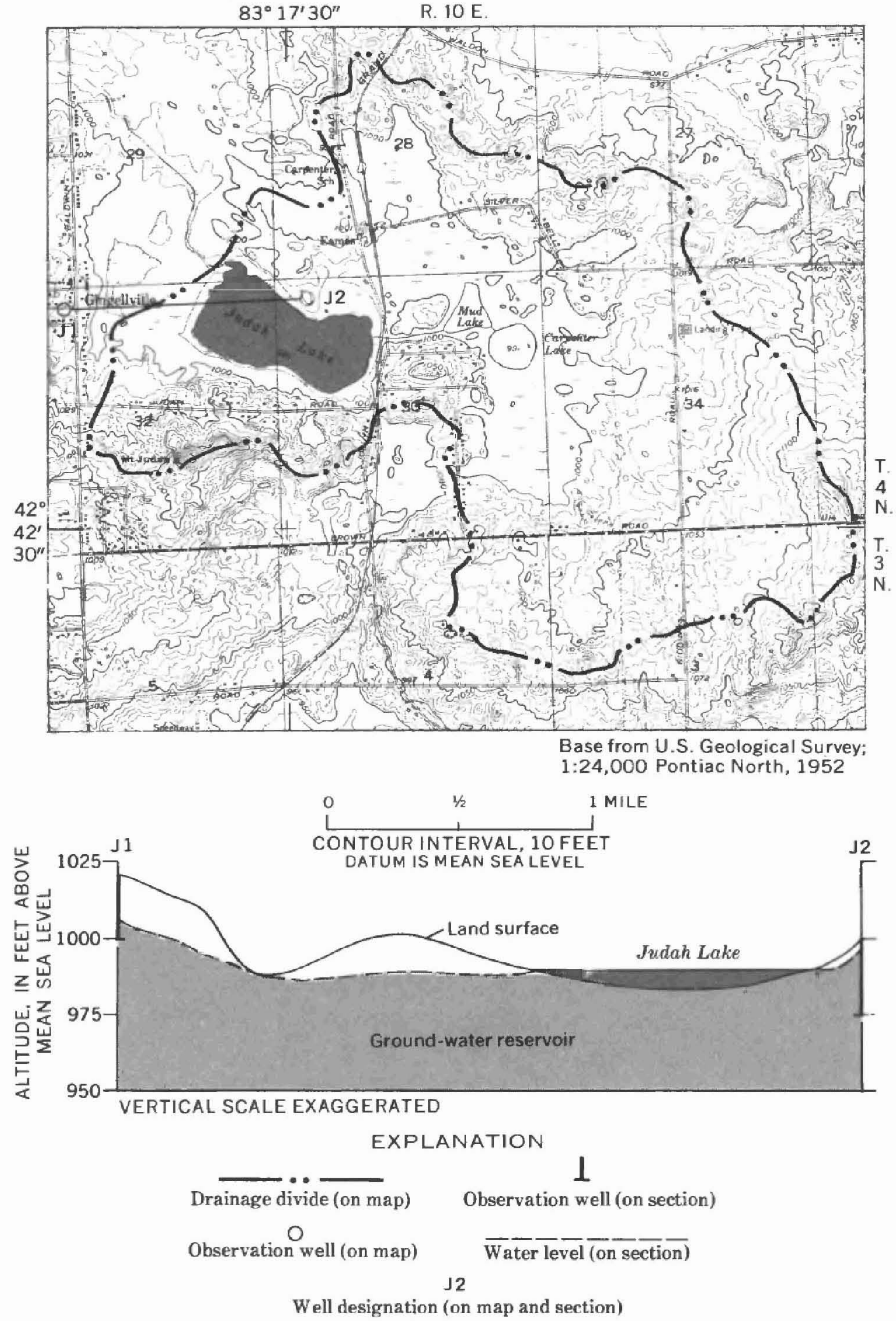
Another factor affecting lake levels is their inlet-outlet characteristics. Lakes without an inlet have only the precipitation which falls within their usually small drainage basins and, in some cases, ground-water inflow as replenishment sources for maintaining their levels. A lake with an inlet, however, receives replenishment not only from these sources, but also from the drainage area served by the inlet stream. Because of this added source of replenishment, the levels of such lakes generally rise faster than do levels in lakes of comparable size which do not have inlets. In addition, most lakes which have inlets also have outlet streams which, when equipped with a control facility provide a means for regulating the lake level. In the final analysis lakes with inlets, such as Judah, have the best chance for maintaining desirable levels.

The slope of the ground-water table adjacent to lakes also affects lake levels. Where the water table slopes toward the lake,



ABOVE AND LEFT: The water table around Elizabeth Lake slopes toward the lake except near the lake outlet. FIG. 52

ground water will flow into the lake; where it slopes away from the lake, lake water will flow into the ground. For most lakes that have outlets the water table in the vicinity of the outlet slopes away from the lake; elsewhere the slope is generally toward the lake. Of the six lakes studied Elizabeth and Judah Lakes best reflect this situation (figs. 52 and 53). Where the water table slopes away from a lake, the lake receives very little or no ground-water inflow and its levels, dependent primarily upon precipitation, often recede to undersirably low stages during extended dry periods. Such conditions commonly exist where earth materials in the vicinity of the lake are permeable and where parts of the nearby land surface are at a lower altitude than the lake. An example of this situation occurs at Tipsico Lake. Here, the earth material at depth is permeable sand and the land surface, although high in the area immediately adjoining the lake, is below lake level a short distance away (fig. 54). Thus, water flows away from Tipsico Lake into the ground.



Water levels in two observation wells indicate that some ground water is flowing into Judah Lake. FIG. 53

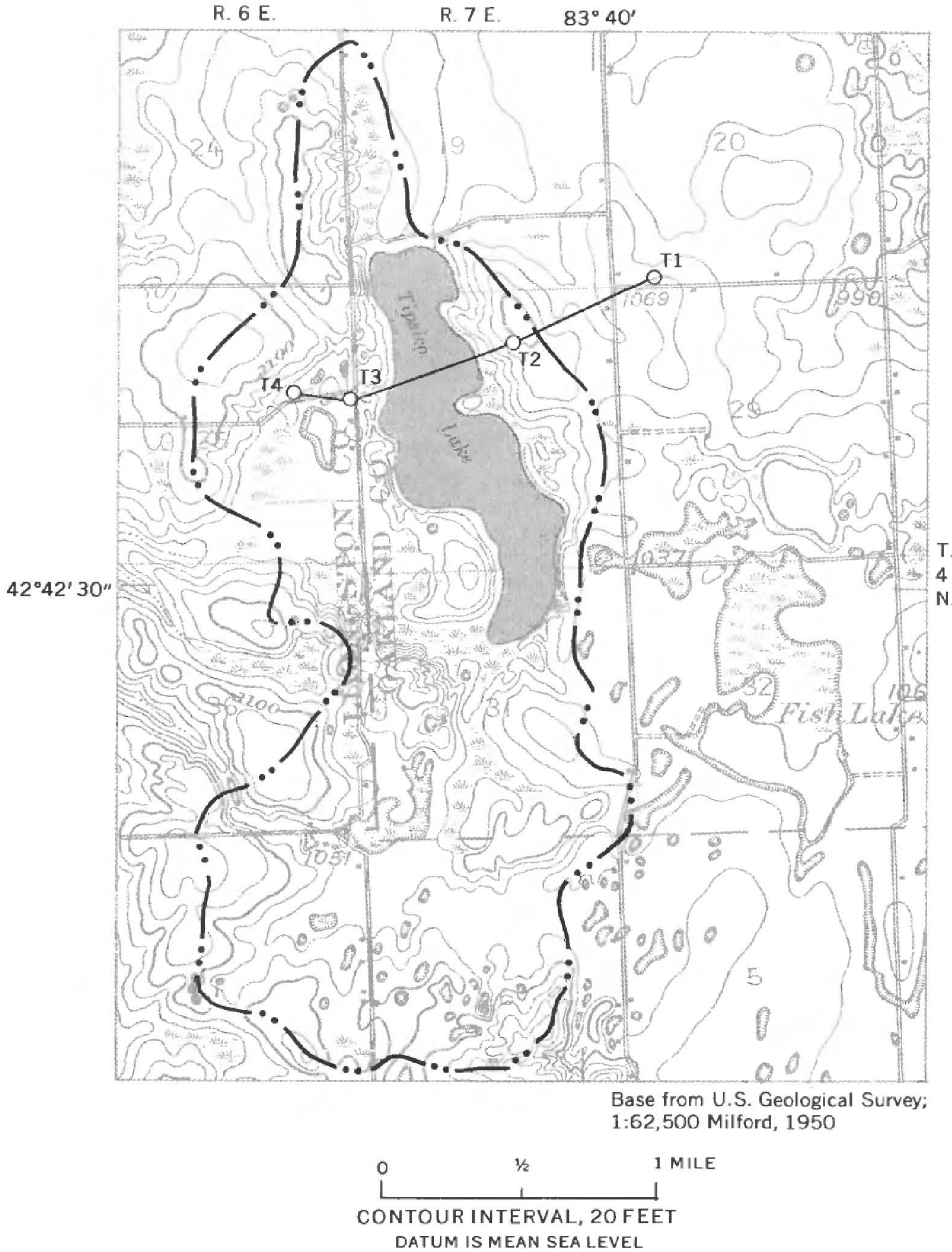
The influence of ground-water levels on lakes is dramatically illustrated in the record of water levels of Orchard Lake and adjacent Cass and Pine Lakes. During the past several years, Orchard Lake, although separated from Cass and Pine by only narrow strips of land, has been from 1½ to 2 feet lower in level. That it is lower suggests a tight seal in the earth materials separating the lakes and the possibility of underflow from Orchard Lake. Analysis of logs of wells verify the existence of materials of low permeability between the lakes, and water-level data show a steep slope in the water table from Orchard Lake to the south (fig. 55). Further analysis of the hydrologic situation here reveals that the base flows in Franklin Branch, southeast of Orchard Lake, are significantly higher than what might be expected for this area. It is apparent that water moves as underflow from Orchard Lake to the south and discharges to Franklin Branch. This results in Orchard Lake being lower in level than either Cass or Pine Lakes.

It might be supposed that Pine Lake also loses water by underground seepage to the south. However, ground-water levels immediately adjacent to the lake show less gradient away from the lake. Also, tighter soils restrict seepage to a greater extent than that from Orchard Lake. It is highly probable, however, that some water does seep to the south.

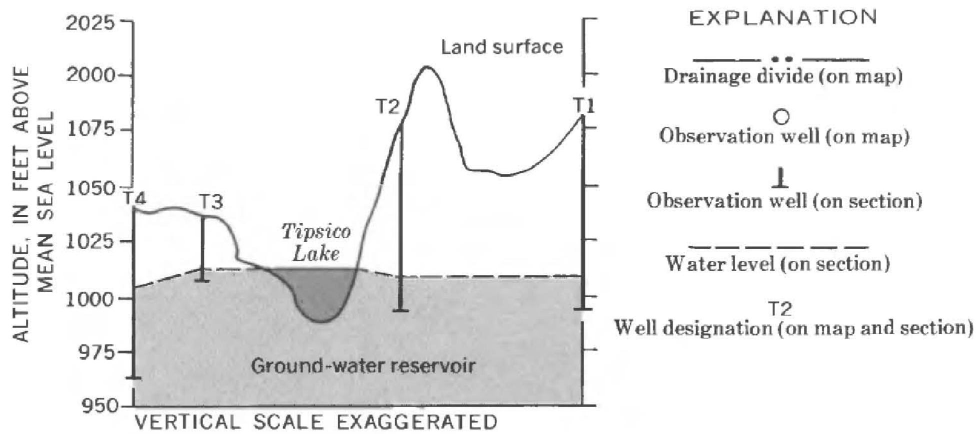
The problem of low levels in Orchard Lake has been relieved somewhat since the spring of 1968. Water is now diverted from Cass Lake via a pipeline and is pumped over a control facility into Orchard Lake. Since July 1968 the level of Orchard Lake has been about 1 foot higher than that of Cass.

Ground-water levels in the Duck and White Lakes area reflected a combination of conditions during periods when pumping water from the ground into the lakes was not in progress. Water levels for two such periods are shown in figure 56. As can be seen, some parts of the lakes were receiving ground-water inflow whereas other parts were losing water to the ground. In general, these conditions reflect the effect of the surrounding topography.

The chemical quality of lake water in Oakland County is often affected by the same factors that affect lake levels. Lakes which are replenished by ground-water inflow and surface-water runoff from inlet streams, for example, have higher total dissolved-solids content than lakes replenished primarily by precipitation. (See chapter 8 for details on water quality.) This reflects the difference



in total dissolved solids between these sources of supply. Table 9 gives the dissolved-solids content for water samples for each of the six lakes studied. As discussed earlier in this section, Tipsico was the only lake of the six studied that received most of its replenishment directly from precipitation, and as was expected, it had a very low dissolved-solids content.

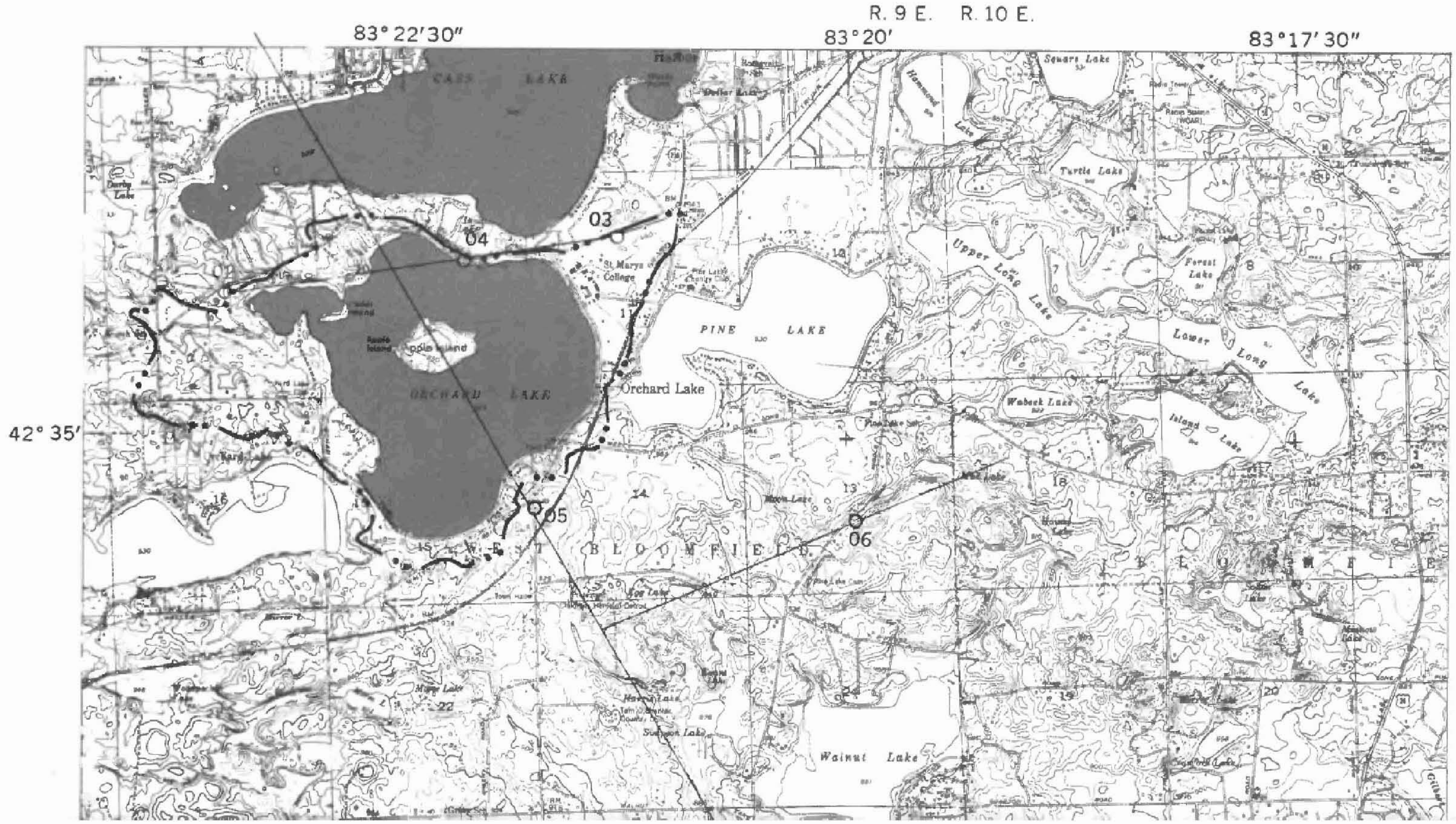


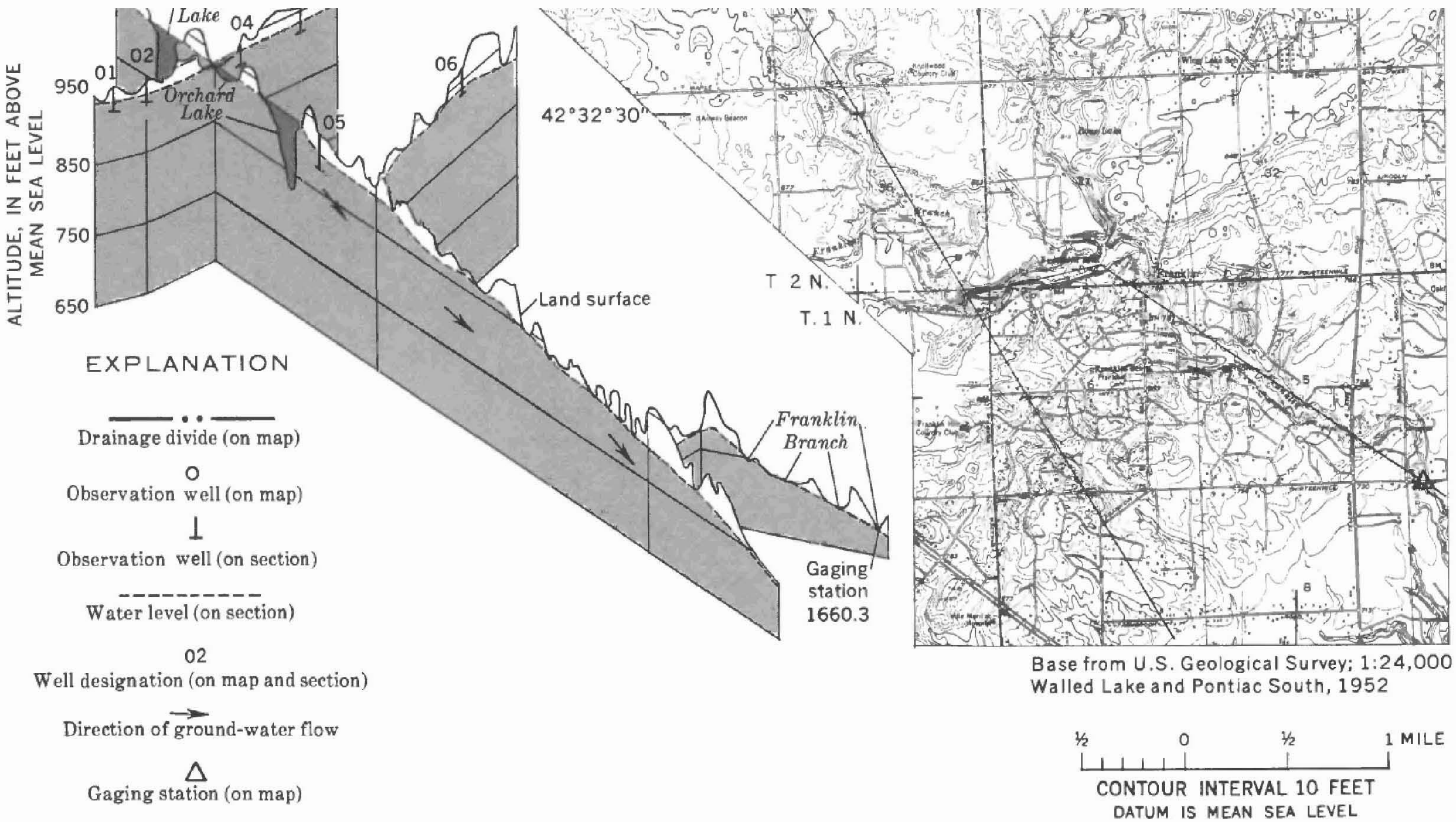
ABOVE AND LEFT: Water from Tipsico Lake recharges the ground-water reservoir. FIG. 54

The highest concentration of dissolved solids is in Elizabeth Lake. Although most environmental features of the lake are very similar to those of Tipsico Lake, it differs in two respects. It has a shoreline that is completely urbanized and it receives some of its replenishment from ground water. Either or both of these features could cause an increase in dissolved-solids content. Whether they do or not is not easily determined. Urbanization does not always produce great increases in the total dissolved solids of water even though it may produce high concentrations of certain individual chemical constituents. Evidence of this is shown by the much lower concentrations of dissolved solids in another completely urbanized lake, White Lake. Ground-water inflow does not necessarily raise the dissolved-solids content of lakes either. That

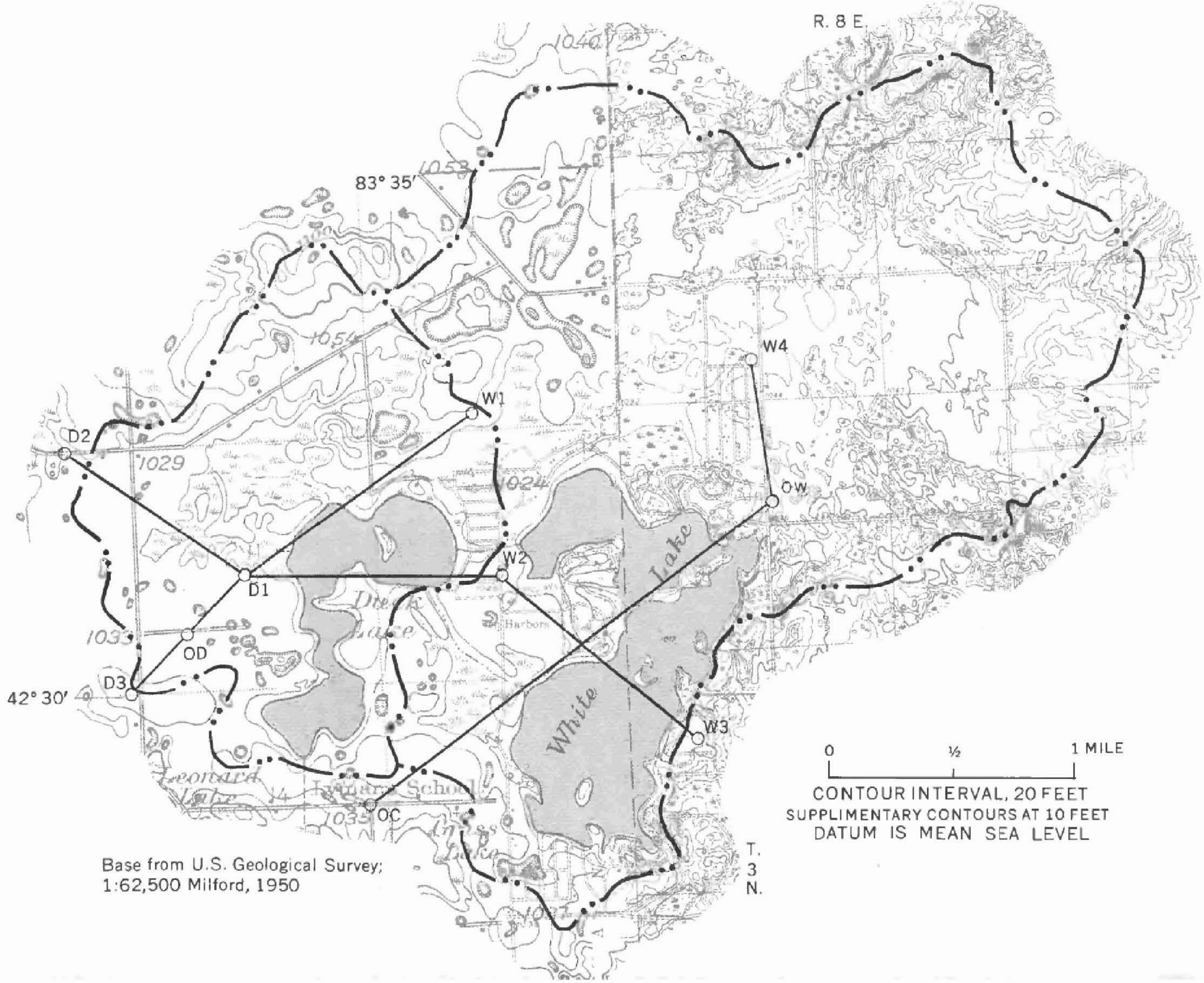
TABLE 9.—*Dissolved-solids content of six selected lakes varies with time and between lakes*

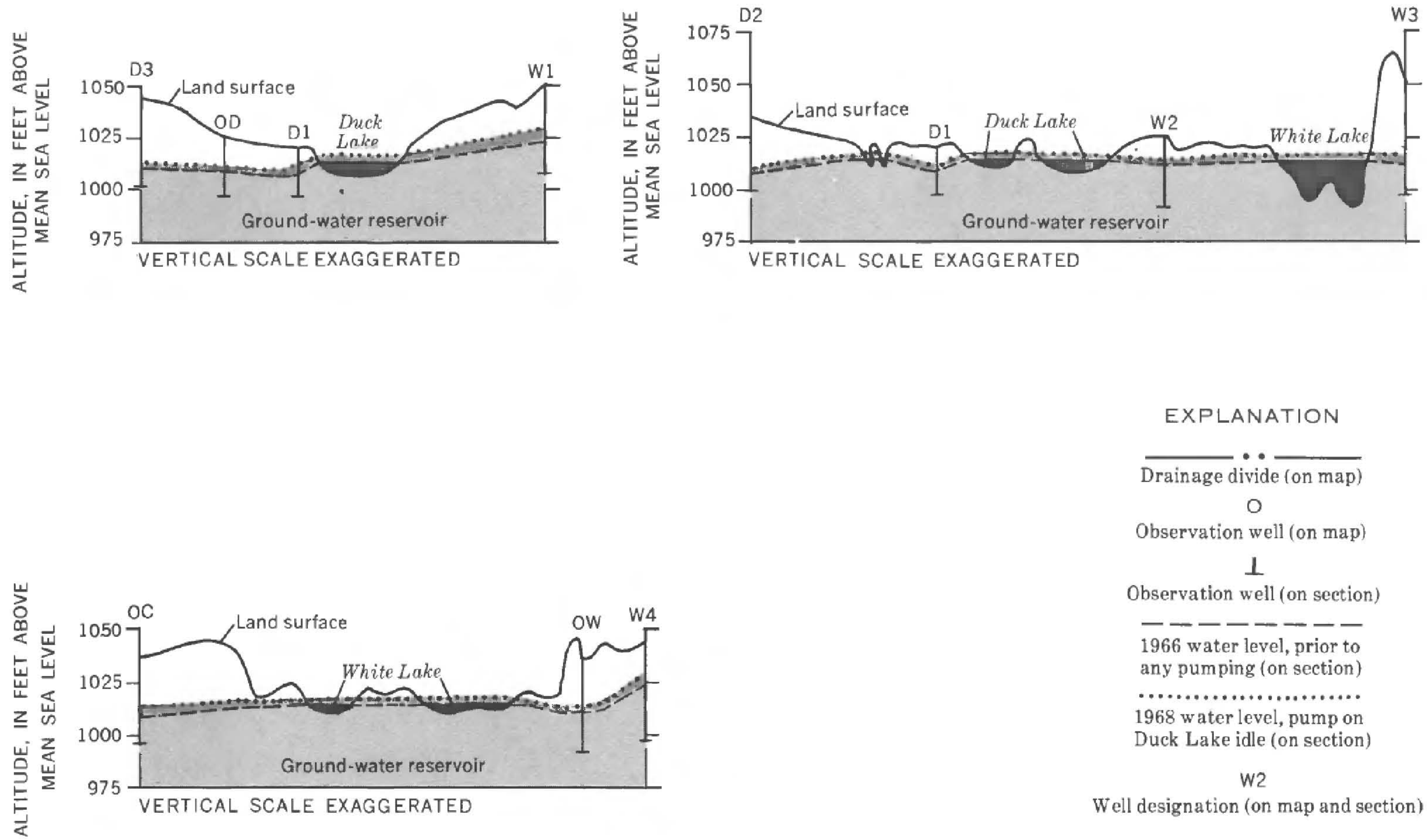
Lake	Date of collection	Dissolved solids (mg/1)	
		Individual sample	Average
Tipsico	Mar. 28, 1966	120	113
Do	Sept. 10, 1966	129	
Do	Apr. 17, 1967	90	
Orchard	Mar. 28, 1966	174	
Do	Apr. 18, 1967	194	187
Do	Nov. 15, 1967	194	
Elizabeth	Mar. 29, 1966	267	263
Do	Apr. 18, 1967	258	
Judah	Mar. 29, 1966	209	
Do	Apr. 17, 1967	256	233
Duck	July 23, 1966	222	210
Do	Apr. 17, 1967	198	
White	Mar. 28, 1966	155	
Do	July 23, 1966	186	168
Do	Apr. 17, 1967	164	


R. 9 E.
R. 10 E.
83° 22′ 30″
83° 20′
83° 17′ 30″
42° 35′
CASS LAKE
03
04
05
06
St. Marys College
PINE LAKE
ORCHARD LAKE
Orchard Lake
Upper Long Lake
Lower Long Lake
Square Lake
Turtle Lake
Forest Lake
Wabeek Lake
Island Lake
Walnut Lake
WEST BLOOMFIELD
BLOOMFIELD



Some water from Orchard Lake flows underground until it reaches Franklin Branch. FIG. 55


R. 8 E.
83° 35′
1040
1053
1054
1029
1024
1033
1035
W1
W2
W3
W4
OW
D1
D2
D3
OD
OC
42° 30′
White Lake
White
Lake
Harbor
School
Leonard
T.
3
N.
0
½
1 MILE
CONTOUR INTERVAL, 20 FEET
SUPPLIMENTARY CONTOURS AT 10 FEET
DATUM IS MEAN SEA LEVEL
Base from U.S. Geological Survey;
1:62,500 Milford, 1950



The water table around Duck and White Lakes slopes both toward and away from the lakes. FIG. 56

this is true, is shown by the concentration of dissolved solids in Duck Lake. In July 1966, prior to pumping ground water into the lake, the dissolved-solids content was 222 mg/l (milligrams per liter). In April 1967, after the lake level had been raised about 1 foot by the more than 180 million gallons of water pumped into the lake, the dissolved-solids content was 24 mg/l less than it was prior to pumping. Although two samples do not form a definite basis for evaluating the effects of ground-water pumpage into Duck Lake, it is significant to note that little change has been indicated. Thus, it may be that neither urbanization nor ground-water inflow produce the higher dissolved solids in Elizabeth Lake. There is still another aspect of urbanization that may produce a high dissolved-solids content in lake water. That aspect is the extensive use of salt to clear roads of ice during the winter months. In lakes that have effective inlets and outlets, the salt probably would be flushed away. However, lakes that are essentially landlocked would tend to collect the salt. After a period of time, the increased salt content would be reflected by higher con-

TABLE 10.—*Quality of water from*

[Dissolved constituents and hardness given in milligrams per liter; *,

Sample site	Lake	Date of collection	Sulfate (SO_4)	Chloride (Cl)
02N07E31BDDB	Kent	Apr. 18	39	26
02N08E01ABDD	Union	do	24	28
02N08E06DCCD	Sherwood	Nov. 15	110	12
02N08E11CDDA	Lower Straits	do	28	23
02N08E15AACB	Commerce	do	33	26
02N08E22DACC	Wolverine	do	22	62
02N08E34DBCB	Walled	Apr. 18	42	60
02N09E02ABAD	Cass	do	40	30
02N09E12BDCA	Pine	do	34	46
02N09E15ADDB	Orchard	do	26	24
02N09E16CABA	Upper Straits	Nov. 15	22	33
02N09E25ABAB	Walnut	Apr. 18	47	40
02N10E06DACA	Square	Nov. 15	17	38
02N10E17AADA	Lower Long	do	32	57
02N10E29BCCC	Wing	Apr. 18	40	74
03N07E12CBAC	Duck	Apr. 17	20	17
03N07E13ACBB	White	do	12	22
03N07E18CCBA	Dunham	Nov. 15	22	3.2
03N07E34ABCD	Lower Pettibone	do	22	15
03N08E13ABBB	Pontiac	Apr. 18	40	14
03N08E26BBBC	Oxbow	Nov. 15	28	19
03N08E33DBCB	Bogie	do	35	23
03N09E07ABBB	Maceday	Apr. 18	28	18
03N09E08CDDC	Williams	Nov. 15	26	23
03N09E10DADD	Loon	Apr. 18	41	29

centrations of chloride in the lake water. The chloride content of Elizabeth Lake is 56 mg/l or two to four times higher than that of lakes outside the more highly urbanized areas. Thus, although not known defintely, road salt may have an important influence on conditions of water in Elizabeth Lake.

Dissolved solids-content of Judah Lake reflects still another aspect of lake hydrology. This lake has the second highest concentration of dissolved solids and is the only one of the six lakes studied that has an inlet. Also, the lake is little influenced by urbanization. These features, when viewed collectively and in relation to those of the other five lakes, appeared to indicate a correlation between dissolved-solids content and lakes with inlets. However, the correlation based on Judah Lake alone was not conclusive. Therefore, an analysis was made of the concentration of dissolved solids in 55 of the 58 lakes for which water-quality data were collected (table 10). Three lakes were excluded from the analysis because of abnormally high concentrations of dissolved solids. The 55 lakes, were classified as "lakes with inlets"

58 lakes in Oakland County in 1967

dissolved solids computed by multiplying specific conductance by 0.59]

Bicarbonate (HCO_3)	Carbonate (CO_3)	Nitrate (NO_3)	Dissolved solids, evaporated at 180°C	Hardness as $CaCO_3$ Carbonate	Hardness as $CaCO_3$ Non-carbonate	Specific conductance (micromhos at 25°C)	pH
208	0	0.2	278	214	44	457	7.9
178	0	.0	208	181	35	397	7.9
201	0	-------	*301	256	91	510	8.1
154	0	-------	*198	184	58	335	8.1
245	0	-------	*266	250	49	450	8.1
177	0	-------	*286	196	51	485	7.3
152	0	.4	268	191	66	501	7.8
198	0	.6	280	218	56	455	8.0
138	0	.1	270	160	47	419	7.8
144	0	.1	194	154	36	342	8.0
94	3	-------	*206	173	3	350	8.3
156	0	.1	262	197	69	448	7.9
139	0	-------	*198	154	40	335	8.2
155	0	-------	*266	183	56	450	7.5
172	0	1.6	332	210	69	570	7.8
178	0	1.4	198	173	26	357	7.8
122	0	.6	164	123	23	281	8.1
185	0	-------	*171	176	24	290	8.0
223	0	-------	*218	206	23	370	8.3
190	0	.4	222	199	44	401	7.9
212	0	-------	*227	211	37	385	8.2
174	0	-------	*212	192	49	360	8.1
174	0	.1	212	177	34	364	8.0
183	0	-------	*198	183	33	335	8.2
206	0	.4	274	224	55	460	8.0

TABLE 10.—*Quality of water from*

[Dissolved constituents and hardness given in milligrams per liter; *,

Sample site	Lake	Date of collection	Sulfate (SO_4)	Chloride (Cl)
03N09E12AACB	Angelus	Apr. 18	21	20
03N09E22ABCA	Watkins	do	23	33
03N09E30BABB	Pleasant	Nov. 15	38	29
03N09E34BDDD	Elizabeth	Apr. 18	29	56
03N09E36DABA	Sylvan	Nov. 15	39	38
03N10E14CCCC	Galloway	Apr. 18	97	94
04N07E19CCAC	Tipsico	Apr. 17	12	2.5
04N07E22CABB	Buckhorn	Nov. 16	18	11
04N08E28ADBC	Big	do	18	10
04N09E04DDAD	Crooked	Apr. 17	30	2.0
04N09E12CDAB	Walters	Nov. 16	33	12
04N09E17ACDD	Cranberry	do	15	54
04N09E29BBCA	Deer	Apr. 18	39	22
04N09E34DCAC	Oakland	Nov. 16	39	28
04N10E01BDAD	Long	do	23	11
04N10E10BCDA	Square	Nov. 16	26	22
04N10E11ACDB	Orion	Apr. 17	62	16
04N10E16DBCC	Sixteen	Nov. 16	53	23
04N10E20DABB	Voorhies	Apr. 17	53	16
04N10E33BBBC	Judah	do	51	26
04N11E02BCCB	Cranberry	Nov. 16	38	14
05N07E10ABAA	Fagan	Apr. 17	171	14
05N07E23BDDB	Crotched	do	22	11
05N07E27DCDB	Bush	Nov. 16	35	19
05N07E34CCCA	Stiffs Mill	do	37	15
05N08E33BAAA	Valley	Nov. 16	19	7.2
05N09E30AABD	Louise	Apr. 17	38	20
05N10E23DCDD	Parker	Nov. 16	52	16
05N10E28BBDA	Tan	Apr. 17	50	14
05N10E28CBBD	Clear	Nov. 16	50	8.2
05N11E01CDAA	Secord	Apr. 17	46	4.5
05N11E27ACDA	Lakeville	do	36	12
05N11E31CDAD	Indian	Nov. 16	23	6.8

and "lakes without inlets." Two of the lakes in the group without inlets were known to receive most of their replenishment from precipitation and were identified as a special group. Although two lakes do not provide a significant sampling number they were grouped separately for purposes of comparison. These three groups, along with their average dissolved-solids contents, are shown in table 11.

A statistical analysis was used to determine the validity of the range in dissolved-solids content between the two major groups in table 11. The analysis indicated that the two groupings were significantly different, although the range in dissolved solids overlapped somewhat. The tests pointed out one additional aspect in

58 lakes in Oakland County in 1967—Continued
dissolved solids computed by multiplying specific conductance by 0.59]

Bicarbonate (HCO_3)	Carbonate (CO_3)	Nitrate (NO_3)	Dissolved solids, evaporated at 180°C	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH
				Carbonate	Non-carbonate		
183	0	.0	198	178	28	338	7.9
166	0	1.0	214	169	33	389	7.9
163	0	-------	*227	195	61	385	7.9
160	0	.6	258	187	56	473	7.8
224	0	-------	292	242	58	495	8.1
226	4	1.6	498	340	148	785	8.3
84	0	.1	90	81	12	166	7.6
234	0	-------	*218	212	20	370	7.9
168	0	-------	*168	157	19	285	7.7
187	0	2.0	196	185	32	343	7.8
156	0	-------	*183	176	48	310	8.0
150	0	-------	*239	166	43	405	8.2
246	0	.5	278	250	48	483	8.1
246	0	-------	*283	252	50	480	7.8
202	0	-------	*209	180	14	355	8.2
159	0	-------	*192	174	44	325	8.3
194	0	1.6	284	233	74	456	7.9
223	0	-------	*206	258	75	450	8.2
174	0	1.8	226	205	62	411	7.8
156	0	.3	256	194	66	400	7.8
152	0	-------	*186	177	52	315	8.2
238	0	21	496	398	203	716	7.9
189	0	.2	188	179	24	353	7.9
227	0	-------	*233	212	26	395	8.3
326	0	-------	*304	307	40	515	7.7
183	0	-------	*174	172	22	295	7.5
204	0	.3	258	218	51	415	8.0
193	0	-------	*233	224	66	395	7.7
202	0	1.8	288	224	58	439	8.0
215	0	-------	*236	232	56	400	7.6
188	0	.1	224	203	49	382	7.9
200	0	.6	252	203	39	402	7.9
194	0	-------	*130	190	31	220	7.5

that lakes with inlets varied more about the average than lakes without inlets. This would normally be expected because of the greater differences in drainage areas and the nature of the areas drained.

TABLE 11.—*Dissolved-solids content of lakes is influenced by inlet characteristics*

Lake classification	Number of samples	Dissolved solids (mg/l)	
		Range	Average
Lakes with inlets	[1] 25	206–304	252
Lakes without inlets	[2] 28	164–268	208
Lakes without inlets; primary source of replenishment is precipitation	2	90–130	110

[1] Galloway Lake was not included in this calculation because its dissolved-solids content was abnormally high.
[2] Wing and Fagan Lakes were not included in this calculation because their dissolved-solids content was abnormally high.

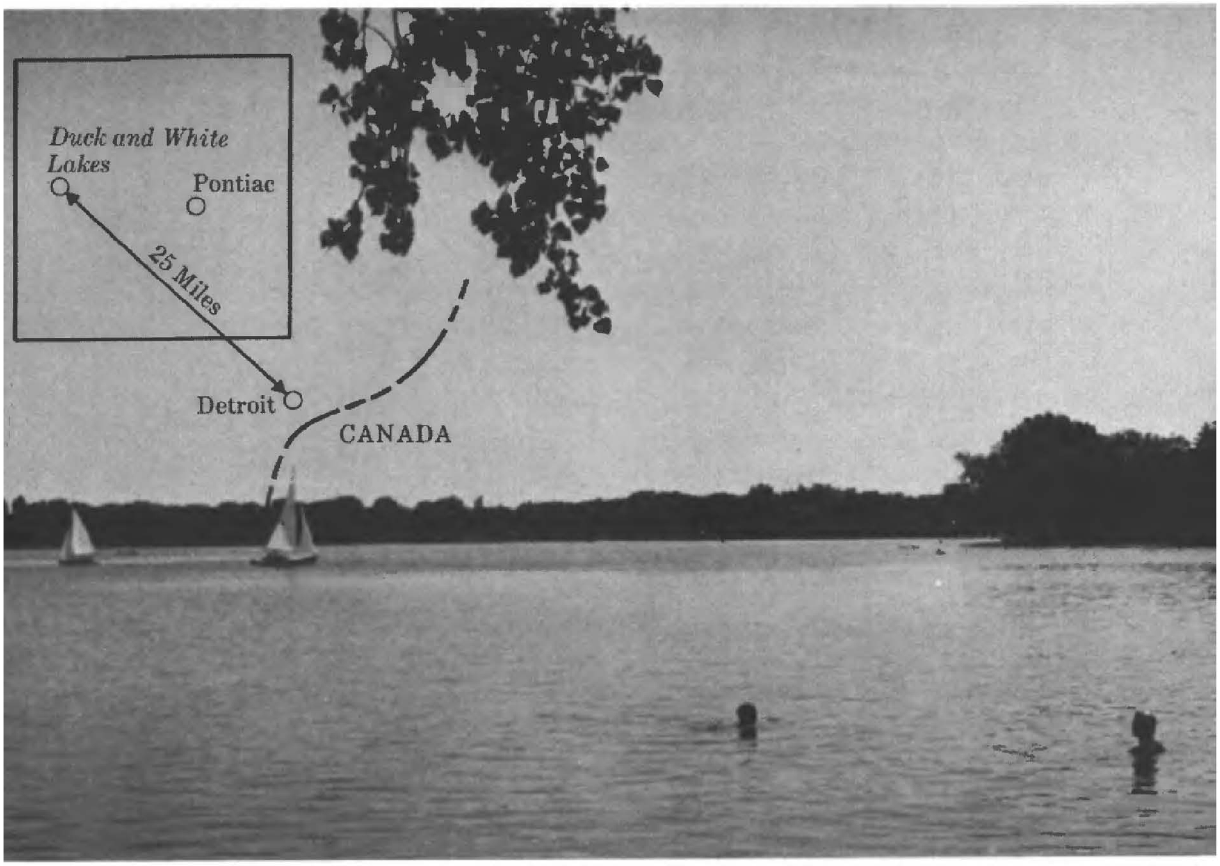
In general, the information and deductions shown in this section can be applied to most lakes in Oakland County; however, as illustrated by Elizabeth Lake, there are always exceptions. As urbanization around the lakes increases, the exceptions will increase also. This may be either good or bad. Man's entrance on the scene often causes deterioration in the quality of lake water. This deterioration is reflected by an increase of materials in solution and suspension and by an increase in bacteriological content. Eventually this increase promotes growth of aquatic vegetation. When the vegetation dies, large volumes of organic materials accumulate on the lake bottom. The final result is a reduction in lake depth until the lake becomes a marsh or swamp. As a lake, it is dead. One might say that under natural conditions this happens anyhow. This, of course is true. It should be added, however, that the life span often is much longer for lakes that are not urbanized. No single statement can be made as to the expected life of the lakes in Oakland County. Each lake is an entity that is affected by unique conditions, and to predict its life would require a concentrated study over a period of several years.

Man's entrance on the scene does not always have a degrading effect on the lakes. In fact, some lakes are being made more useful through man's efforts. The usefulness and life span of lakes increases when man dredges lake bottoms and increases lake depths. Other cases in point are the recent lake-level restoration projects. The effects of such projects on Duck and White Lakes are discussed below.

Ground water for lake-level improvement

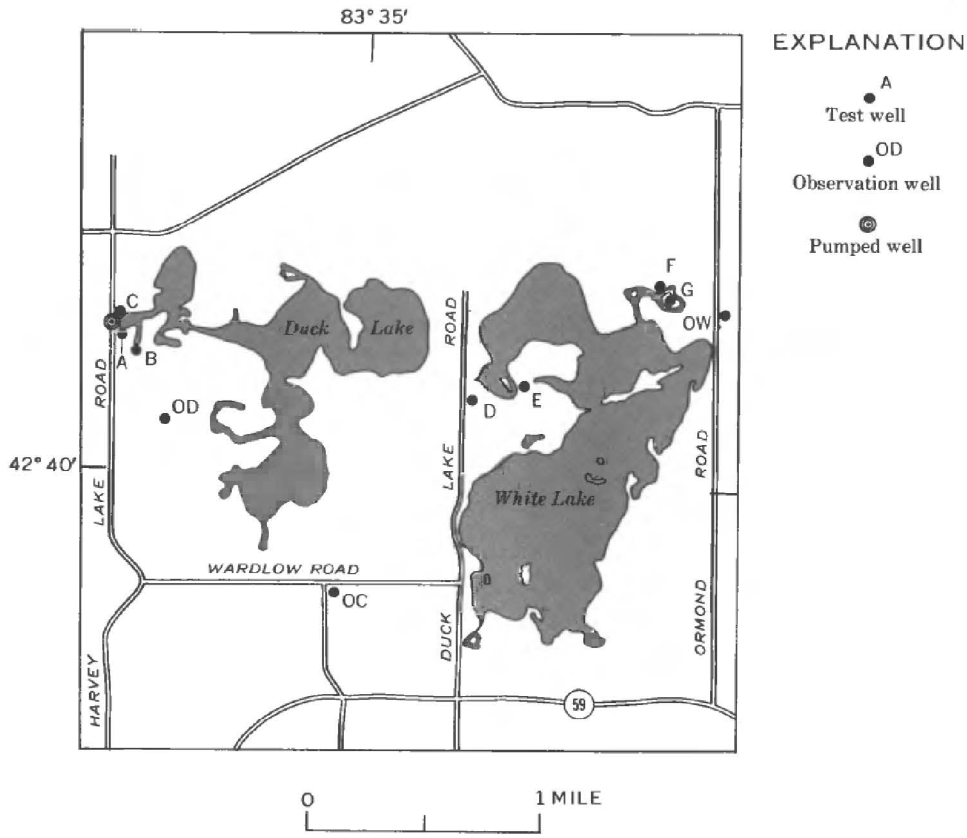
For many years the numerous isolated lakes in Oakland County were viewed only as places of recreation and relaxation—little thought was given to the level of the lake water. Recently, however, a new wave of interest has arisen. Suburban Detroit has been, and still is, spreading northwest into the county (fig. 57). Along with the spread have come people searching for lake-front property on which to build homes; homes that are often unusual and expensive. As the property was being developed, the homeowners soon realized that the level of the lake waters fluctuate and that shorelines sometimes become mudflats. To the homeowner this was an unsatisfactory situation; the lakes needed to be raised to a satisfactory level and maintained at this level!

To raise the water levels, water had to be added to the lakes. Water levels in several lakes have been raised with water from



Recreational use of lakes located in the path of urban expansion is becoming an important consideration in the Detroit Metropolitan area. FIG. 57

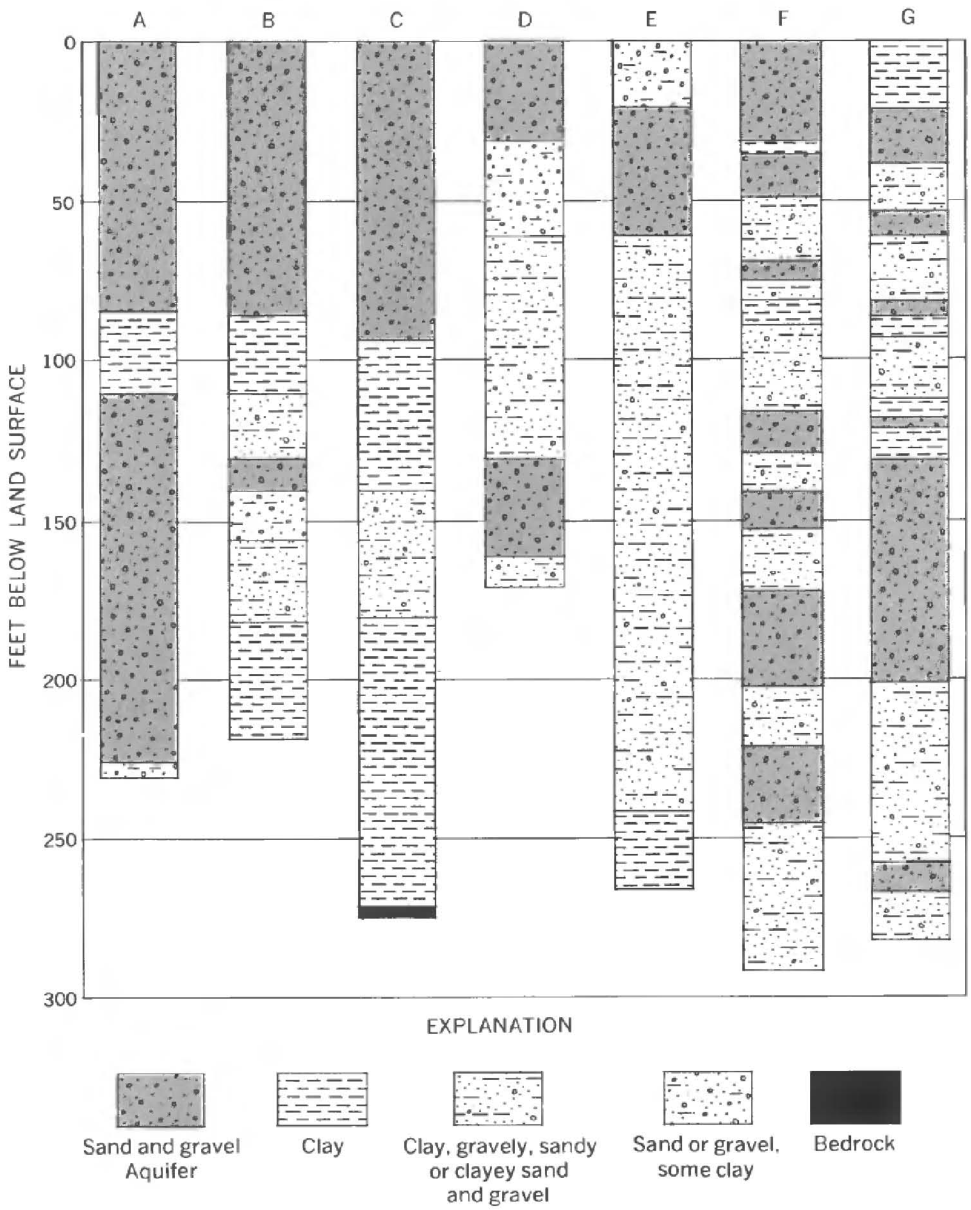
nearby large perennial streams. However, streams are not easily accessible to some lakes, and at Duck Lake an effort was begun in 1966 to raise its level by using ground water from deep wells. Exploratory drilling on the west side of Duck Lake (fig. 58, wells A and B) indicated the existence of two aquifers; an upper and a lower aquifer separated by at least 25 feet of clay (fig. 59). In a third well (fig. 59, well C) about 700 feet away, there was no lower aquifer. Therefore, a large-diameter well was installed between test wells A and B to utilize the lower aquifer as the chief source of water supply and lessen drawdown in nearby shallow wells. Pumping began in November 1966 at the rate of about 1,050 gpm (gallons per minute). At this time climatological factors were causing lake levels to rise—this was indicated by the natural rise of White and Tipsico Lakes (fig. 60). However, with pumped water being added, the level of Duck Lake rose at a faster rate. Thus, after 6 months of pumping, Duck Lake had



Lake levels of Duck and White Lakes are being raised by water being pumped into them from the ground. FIG. 58

risen over 1 foot more than its counterparts. By the winter of 1967–68, Duck Lake was at its established legal level. Homeowners around Duck Lake were relieved of the mudflat problems, and use of ground water to restore the level of Duck Lake proved to be a feasible venture. During 1968 natural recharge was sufficient to keep the lake at its legal level—no pumping was needed.

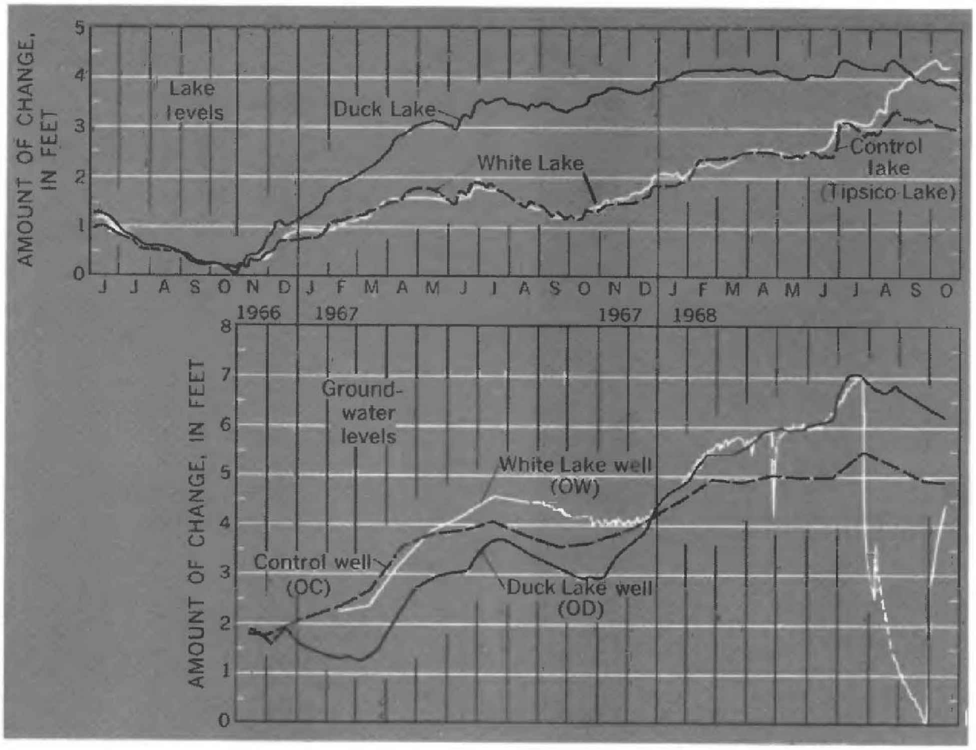
During the time that the level of Duck Lake was being raised, work was also being done to restore White Lake. Late in 1966 exploratory drilling began on the west side of the lake (fig. 58). Test holes revealed a lack of adequate aquifer materials (fig. 59, wells D and E). A pumping test yielded only about 200 gpm, an insufficient quantity of water for lake-level control. Additional exploratory holes were drilled on the north side of the lake. The materials penetrated were completely different from those of the other exploratory wells. Aquifer materials existed throughout the section (fig. 59, wells F and G) and in sufficient abundance to yield nearly 3,000 gpm to a single well. A production well was in-



The lithology of glacial deposits in the Duck and White Lake area differs greatly from well to well. FIG. 59

stalled (at same location as test well G on fig. 58) and pumping, at the rate of 2,700 gpm, was started in July 1968. The level of White Lake began to rise (fig. 60) and by November 1968 was nearing its legal level.

Evaporation loss is an important factor that must be considered whenever attempts are made to raise lake levels. Actual losses from Duck and White Lakes were not measured; however,



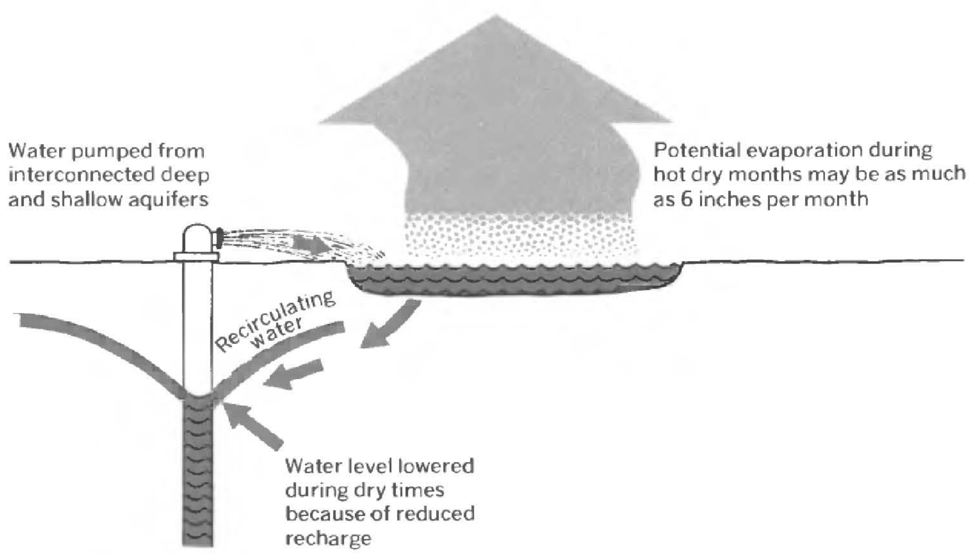
Pumping ground water into lakes raises lake levels but may lower ground-water levels. FIG. 60

evaporation from class A evaporation pans in southern Michigan indicate potential evaporation losses to be about 30 inches a year. During some summer months, potential evaporation is as much as 6 inches. Also, studies in the Swartz Creek basin previously described reveal that 23 inches of water was lost to evapotranspiration in that basin during a 1-year period in 1967–68. Another indication of evaporation losses can be obtained by analyzing the actual lowering of levels in Tipsico and White Lakes. In 1967, during the 90-day period between July 1 and September 27, the level of these two lakes dropped about 6 inches (fig. 60). During this same period, recharge from rain amounted to more than 6 inches. Thus, the total loss from each of the lakes for this time was about 12 inches or about 4 inches per month. Included in this figure are the losses or gains from ground-water outflow or inflow—parameters which are not easily evaluated. However, as these parameters were effective throughout the year and as there was no deficiency in precipitation during the 90-day period, it was assumed that the drop in the lake levels was due primarily to evaporation. Thus, during long periods of hot weather, evaporation losses cannot be overlooked. It is during such times that evaporation will extract large quantities of water directly from the lakes. The effect that different evaporation rates might have on water loss from Duck and White Lakes is illustrated in the following table:

Evaporation rate, in inches per month	Loss, in gallons per minute	
	Duck Lake	White Lake
1	180	340
2	360	680
3	540	1,020
4	720	1,360
5	900	1,700
6	1,080	2,040

During periods of normal or above normal precipitation, water generally can be pumped from streams or wells to improve lake levels. During such times, water from precipitation may be more than adequate to recharge the aquifers. Also, by pumping from streams, water may be captured which otherwise would run off as excess flow.

When precipitation is below normal, pumping water to raise lake levels may or may not be desirable. If water is being pumped from a stream which has a high base flow, or from a deep aquifer that is sealed from shallower aquifers, pumping even during drought conditions probably will not be undesirable. On the other hand, pumping from streams which have low base flow may deplete streamflow during dry times to a level that would be undesirable to property owners along the stream. Similarly, pumping from interconnected deep and shallow aquifers, may lower



ground-water levels. For example, levels in the observation well on White Lake (fig. 60) were lowered as much as 7 feet after pumpage into White Lake began. Another factor to be considered is that pumpage may induce recirculation of ground and lake water.

Records showing the effects of pumping water into White and Duck Lakes are of such short duration that a reliable analysis of total environmental changes is inconclusive. However, some changes have occurred that are interesting to note as they may have some bearing on future situations.

From the winter of 1966 through the fall of 1968, natural conditions favored artificial recharging of lakes. Throughout Oakland County, precipitation was about normal and evapotranspiration losses were not overly excessive. Also, lake and ground-water levels were showing a gradual and almost continuous rise; the typical trends under natural conditions are shown by records from Tipsico Lake and from well OC (fig. 60). In 1966, levels of Duck and White Lakes (fig. 60) followed the typical trend from June into November. Pumping into Duck Lake began in November and the level of the lake started to rise at an accelerated rate. During the early stages of pumping, ground-water levels in the vicinity of the Duck Lake production well showed a definite response to pumping, as is shown by records from well OD (fig. 60). However, after February 1967, natural recharge was sufficient to raise water levels in wells in the lake area and to mask most of the effects of pumping. Pumping into White Lake began in July 1968, a time when ground-water levels throughout the area were relatively high and lake levels had been on the uptrend for the previous 9 months. The response was immediate—the lake level began to rise and the water level in well OW began to fall. This trend continued until pumping was stopped near the end of September 1968.

Although present evidence is inconclusive, it appears that pumping ground water into Duck and White Lakes during long periods of droughtlike conditions will have a noticeable effect of ground-water levels in the area. The only way a reliable determination of this effect can be obtained is by careful observation of trends in both ground-water and lake levels over a period of years. The results obtained from such observation will be of great importance in evaluating not only the Duck and White Lake situation but for an evaluation of future projects of this type.

7. Water in the Ground

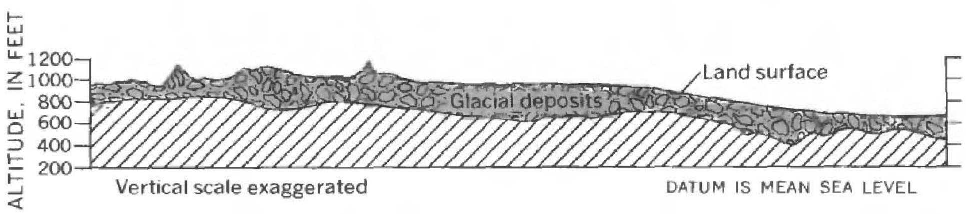
CHARACTERISTICS OF THE CONTAINER

The availability of water in the ground, or ground water, can be defined for much of Oakland County on the basis of three factors —the container in which the water occurs, the land surface covering the container, and the quantity of water available for addition to the container. Also, in some areas, water withdrawn from the container will be a significant factor.

The land surface is discussed, in part, in chapter 5. It has been shown how the configuration of the land influences the occurrence of water. However, the composition of materials at land surface is important also in that this is the factor that controls the rate of percolation of precipitation. If materials at the surface are primarily clay, little water will percolate into the ground and runoff will be high. If the materials are sand and gravel, the percolation rate will be high and runoff will be low. Thus, the composition of the container cover, combined with its configuration, are important for determining the amount of water from precipitation that will recharge ground water.

The quantity of water that is potentially available for addition to the container is dependent primarily upon precipitation. As discussed earlier, precipitation in Oakland County is about 30 inches per year. However, water used by plants and evaporation losses reduce this supply by about 70 percent. Also, because the land surface is not in all places completely flat and because its composition is such that it cannot absorb all precipitated water, large quantities of water run off the land and are carried away by streams. Thus, out of the water potentially available for recharge, only about 15 percent percolates to the ground-water container.

Because present technology precludes great alterations in either land surface or precipitation, it is the container that becomes the focal point in the ground-water availability picture. For it is here that water will be collected and stored. Because the container is composed of rocks, it is the variance in rocks that causes variance in ground-water availability. In fact, the type of rock underlying an area may completely define the area's water-producing potential, as some rocks yield large quantities of water; others yield little or none. The rocks that have immediate bearing on the problem of ground-water availability can be divided into two major groups—glacial deposits and bedrock (fig. 61).



Glacial deposits and bedrock are the two major groups of rocks. (Line of section is shown in fig. 22.) FIG. 61

WATER IN GLACIAL DEPOSITS

In Oakland County, glacial deposits, their occurrence, mode of deposition, and water-yielding properties are a unique and complex subject. Glaciers that moved over the county many years ago left a conglomeration of deposits that appear to be without any definite sequence or orderly pattern. A deposit in one area may differ completely from a deposit several hundred yards away. What appears at land surface may be no indication of what occurs at depth. Thus, it is only with great difficulty that the pieces of the puzzle can be fitted together and the following broad generalizations made.

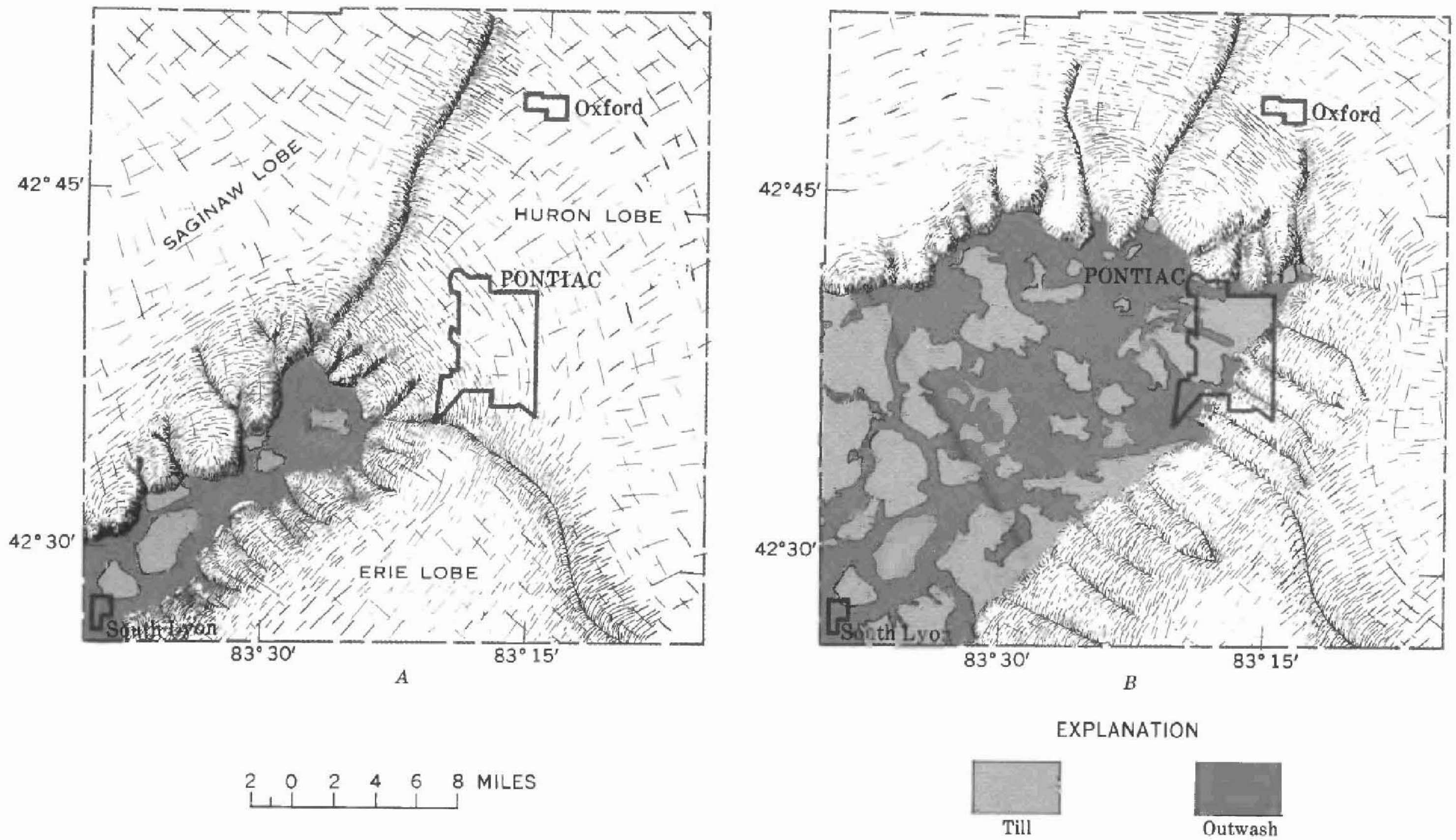
Four times within the last million years, Michigan was glaciated and the land covered with new deposits of glacial materials. It was during the last of these glacial periods, the Wisconsin, that the materials so prominent throughout Oakland County today were deposited. The majority of existing landforms were formed during the retreat of the last glaciers some 15,000 years ago. Only minor changes have taken place since that time.

By nature, glaciers follow the course of least resistance, and because of this they often divide into smaller lobes. During Wisconsin time, Oakland County was overridden by three such ice lobes. The Saginaw Lobe entered the county from the northwest, the Huron Lobe from the northeast, and the Erie Lobe from the southeast (fig. 62). These three lobes merged along a northeast-southwest line roughly from Oxford to South Lyon. With the advent of warmer climates, melting at the leading edge of the ice was more rapid than ice advancement, and the glacial lobes began to recede. The most likely positions of the ice lobes at various times during ice retreat are shown in figure 62. When recession of the ice lobes was uniform, rock debris was scattered more or less uniformly over the land producing gently undulating till plains. Occasionally large ice blocks broke from the glacier to become buried in the debris; at a later date the blocks melted and depressions called kettles or pit lakes were formed. Today, these depressions are the basins for most of the lakes in the county. During some periods, melting and ice supply were equal, causing the ice front to remain stationary. At these times, rock debris carried by the glacier was dumped along the ice front to form morainal hills and ridges. During most of the periods of ice recession, meltwater from the glacier carried sand, gravel, and clay and deposited them in outwash plains or channels. The location of these materials as expressed at land surface is shown on the surficial geologic map (fig. 63).

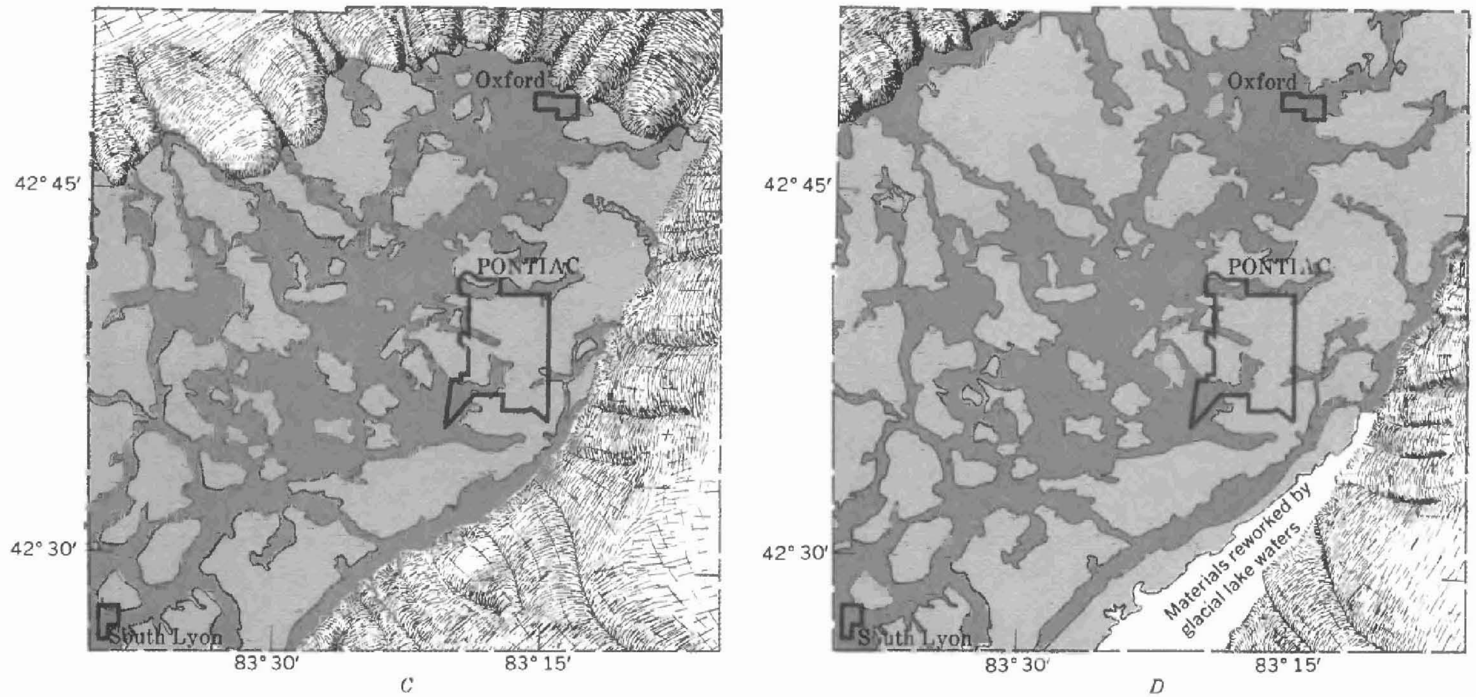
Relative to its capacity to yield water, outwash is the most important glacial deposit in Oakland County. This material commonly contains many beds or lenses of well-sorted sand and gravel that may provide storage for large quantities of water (fig. 64). Most of these deposits were produced by glacial meltwater that flowed southwestward away from the glacial lobes. It should be kept in mind, however, that the outwash areas as expressed at land surface may not be continuous to bedrock. In some areas the water-borne debris was deposited over previously-formed glacial deposits. In these areas, the outwash may be very thin and of little value as an aquifer. In other areas, however, there were more definite and distinct channels for the meltwaters to flow in throughout extensive periods of time. Here, the sorted materials are thick and water is often plentiful. Several of the better defined channels are identified on the surficial geologic map.

Two other features produced by deposition of debris from meltwater are eskers and kames. These features are formed within, or in contact with, the melting ice mass. Usually they are composed of water-sorted material (sand and gravel) and have a pronounced relief.

Numerous kames can be found within the county. The most outstanding single example is Grampian Hills (fig. 2) which rises 230 feet above the surrounding moraine. The most interesting group of kames is found in townships T. 5 N., R. 7 E., and T. 5 N., R. 8 E. (Holly and Groveland Townships). Landforms associated with these kames may be traced as far southeastward as Pon-

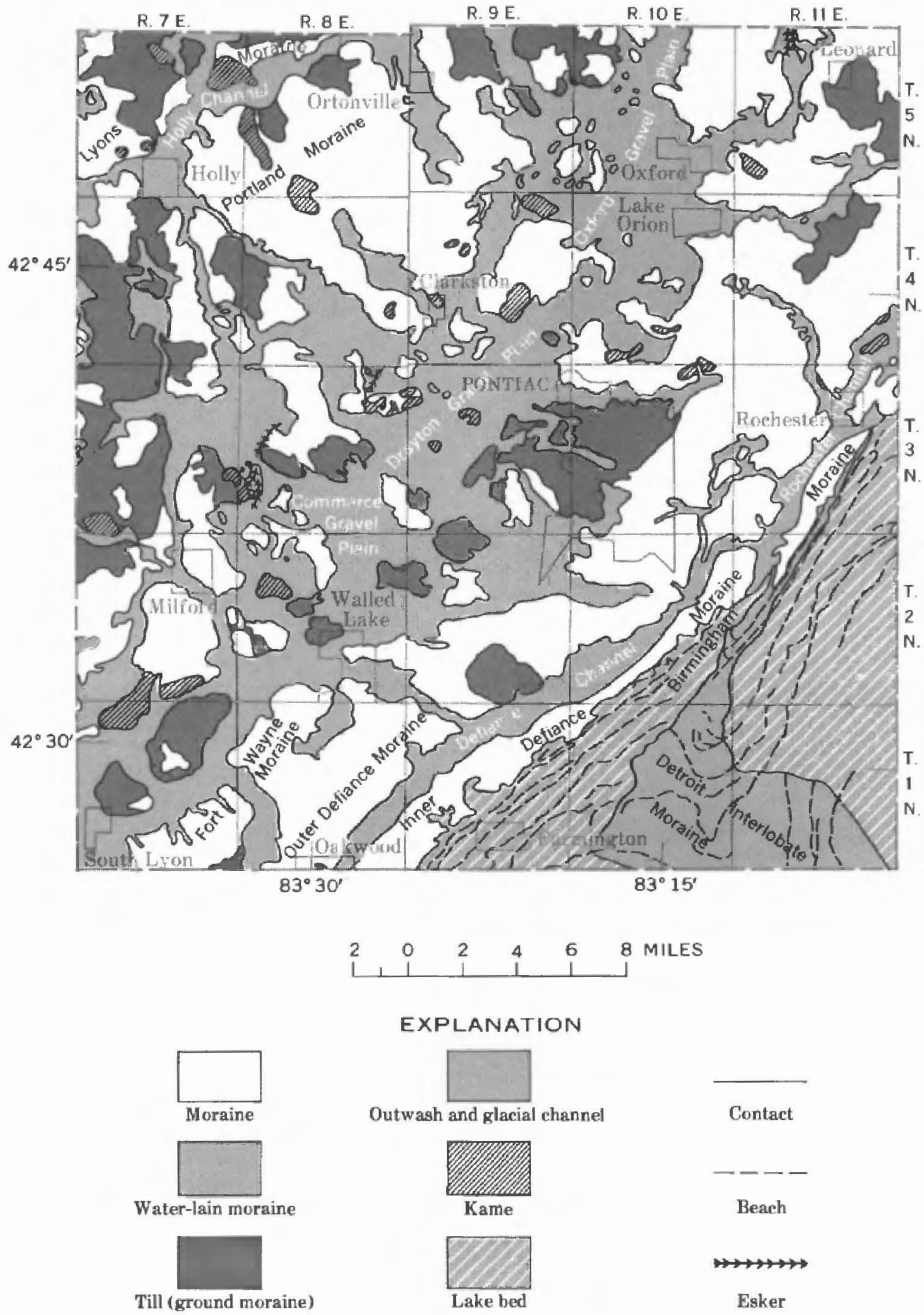


Oxford
42° 45′
SAGINAW LOBE
HURON LOBE
PONTIAC
42° 30′
ERIE LOBE
South Lyon
83° 30′
83° 15′
A
2 0 2 4 6 8 MILES
Oxford
42°45′
PONTIAC
42°30′
South Lyon
83° 30′
83° 15′
B
EXPLANATION
Till
Outwash



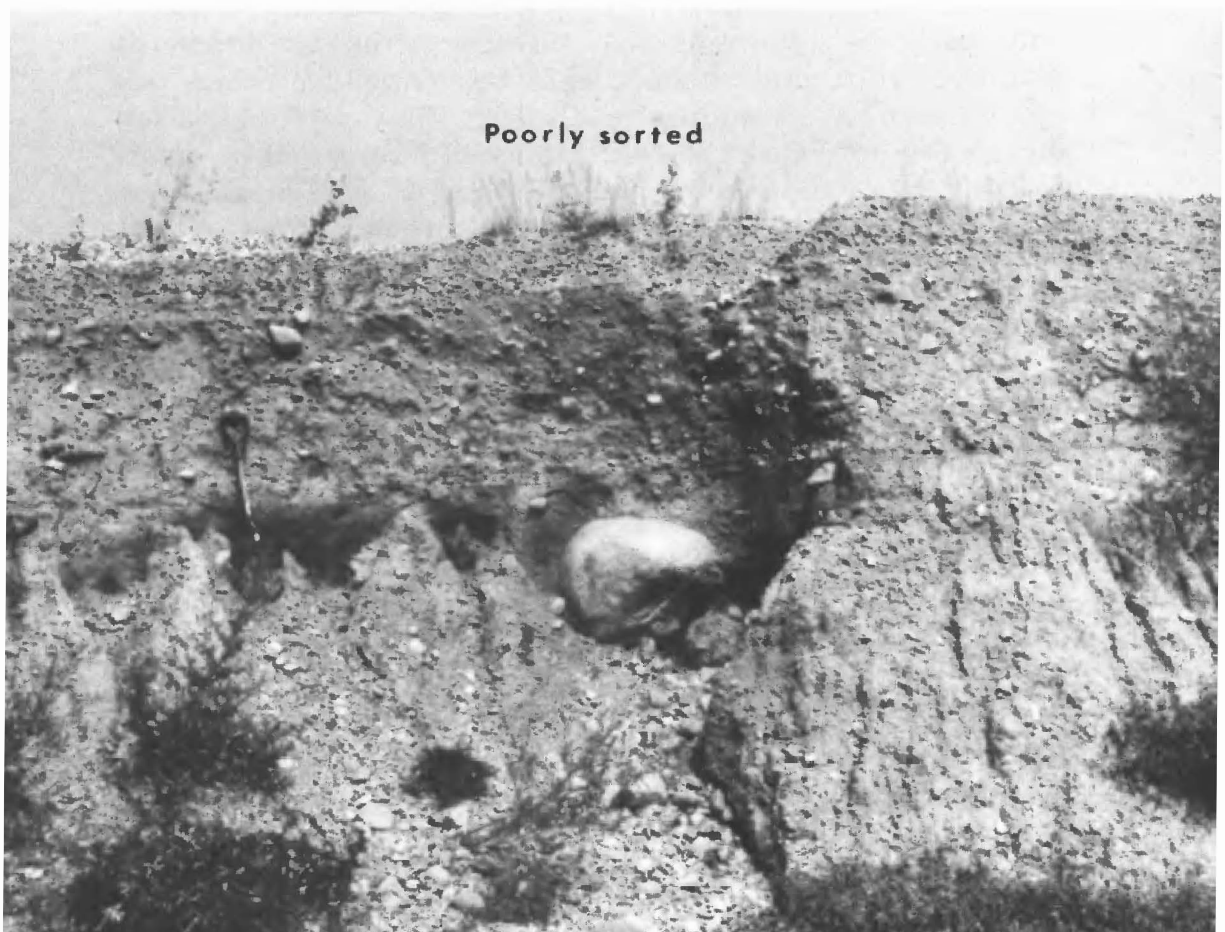
Glacial deposits were left behind as the glaciers retreated farther and farther from Oakland County. *A*, *B*, *C*, and *D* denote most likely positions of the lobes at various stages of ice retreat. FIG. 62

tiac Lake. Many kames contain well-sorted sands and gravel that are of economic importance. Glacial deposits in some kames, however, were a result of rapid deposition and are poorly sorted.



A surficial geologic map shows how the county was covered by materials deposited during the glacial period. FIG. 63

Glacial materials range from well sorted (top photograph) to poorly sorted (bottom photograph). FIG. 64



Several eskers can be seen in the county but all are poorly developed. None of the ridges have the sinuous characteristics associated with eskers, possibly because of their short length. The longest esker occurs just east of White Lake and extends intermittently southward for several miles (fig. 63). The northern part of this esker has a remarkably flat top which, in places, is deeply pitted. Several small gravel pits expose the well-sorted material of which the esker is composed.

Till has the greatest areal extent of any of the glacial deposits. It is the material that forms the till plains and moraines shown on the surficial geologic map. However, its importance as an aquifer is far less significant than that of outwash. Till is made up of gravel, sand, and clay, is poorly sorted, and has little stratification. These characteristics are a deterrent to transmission of large quantities of water. Thus, as an aquifer, till is far less important than outwash.

Again, as with outwash, there is no certainty that till is continuous with depth. During periods when the glacier was in retreat, meltwater flowing across till areas would deposit outwash. When the glacier readvanced, this outwash would be covered with till. Thus, in some areas, till and outwash may appear in a complex, bedded sequence.

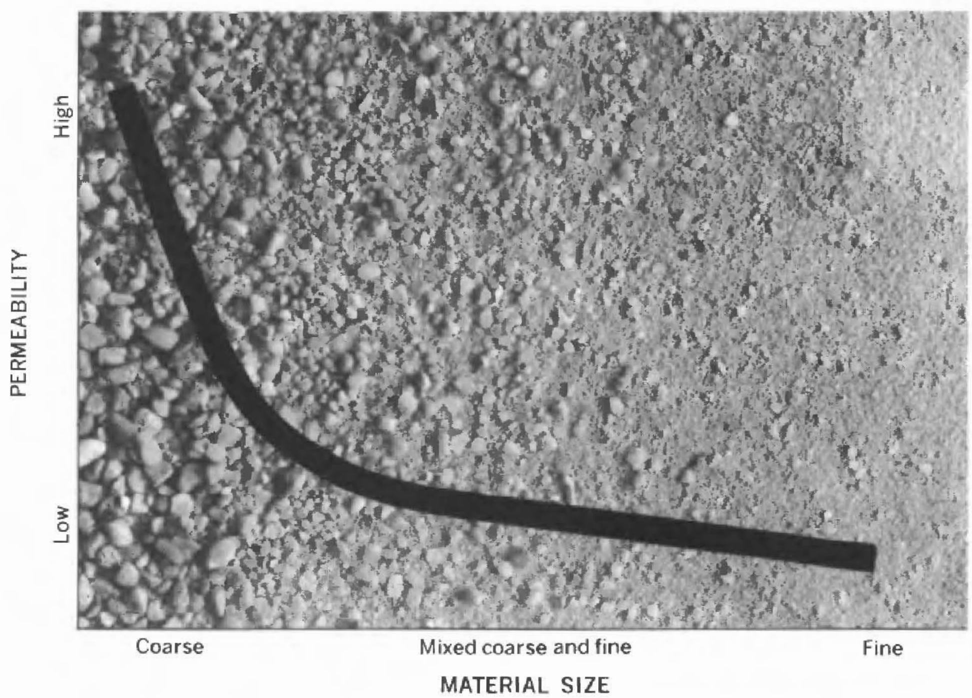
During the final stages of glacier retreat the southeastern part of Oakland County was inundated by water from a large glacial lake. The level of this lake was controlled to a large degree by the activities of the glaciers as they retreated to the east and north. Beaches were formed at times when the glacier movement, and thus the lake level, remained relatively stationary. If the glaciers advanced or retreated, the resulting beach level would be higher or lower than the preceding beach. Several of these beach deposits are relatively thick and thus are important sources of well-sorted sand (fig. 65). Except for the beach deposits, sediments in the area shown as lake beds on the surficial geologic map are dominated by clay and thus, generally are a poor source of water. In several localities, however, such as along the Inner Defiance Moraine, there is an abundance of sand and gravel, in some cases to a considerable depth. Also, sand and gravel deposits are found at depth in other parts of the lake bed areas; however, additional data are needed before the areas underlain by sand and gravel can be delineated.

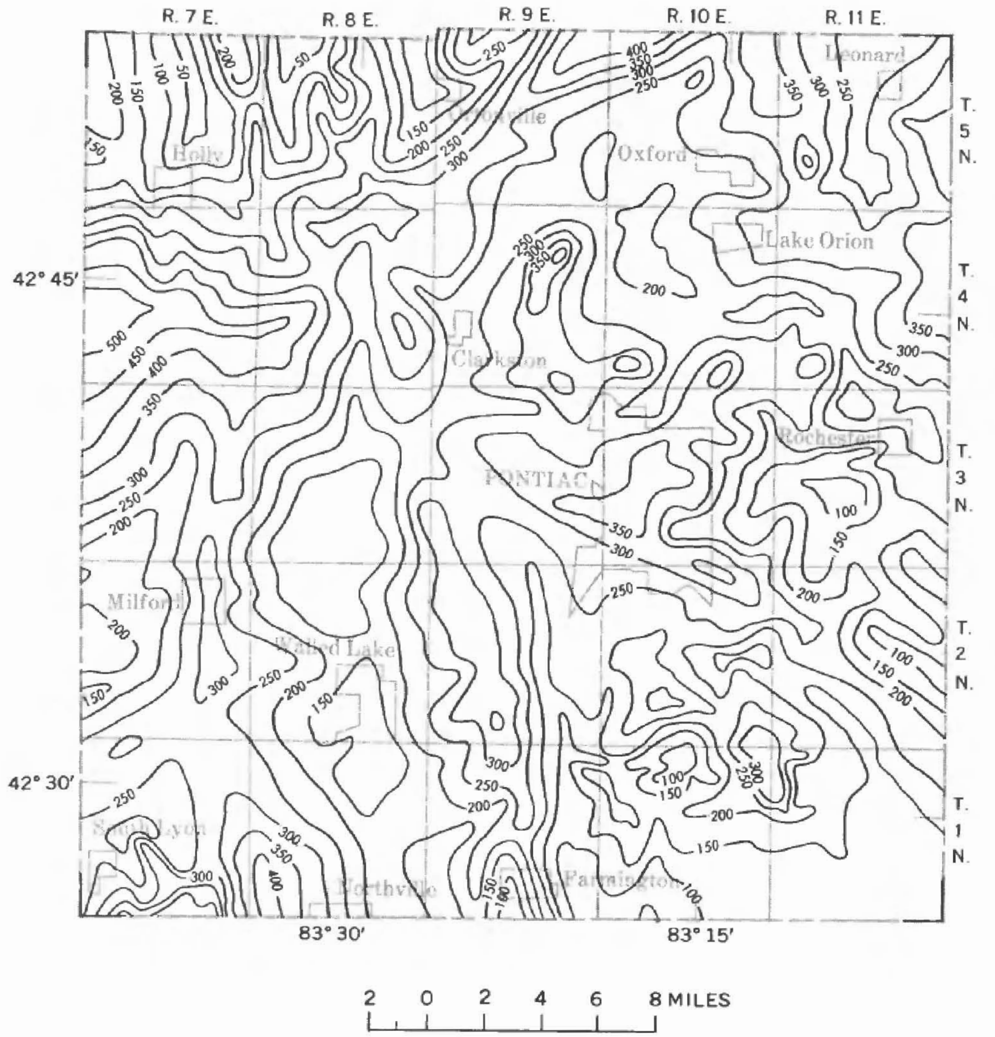
The thickness of the glacial materials varies throughout the county. As is shown in figure 66, glacial materials are as much as 400 feet thick in several areas and in one area, along the western

A beach deposit in the southeastern part of the county. FIG. 65

boundary, are more than 500 feet thick. In the southeastern part of the county, there are several areas where the thickness is less than 100 feet. Only in small areas in the northwestern and southeastern corners of the county is the thickness less than 50 feet.

The ability of the different rock types to yield water varies considerably. Unless undisturbed samples of the rocks are available, there is no way of knowing exactly what percentage of a





EXPLANATION

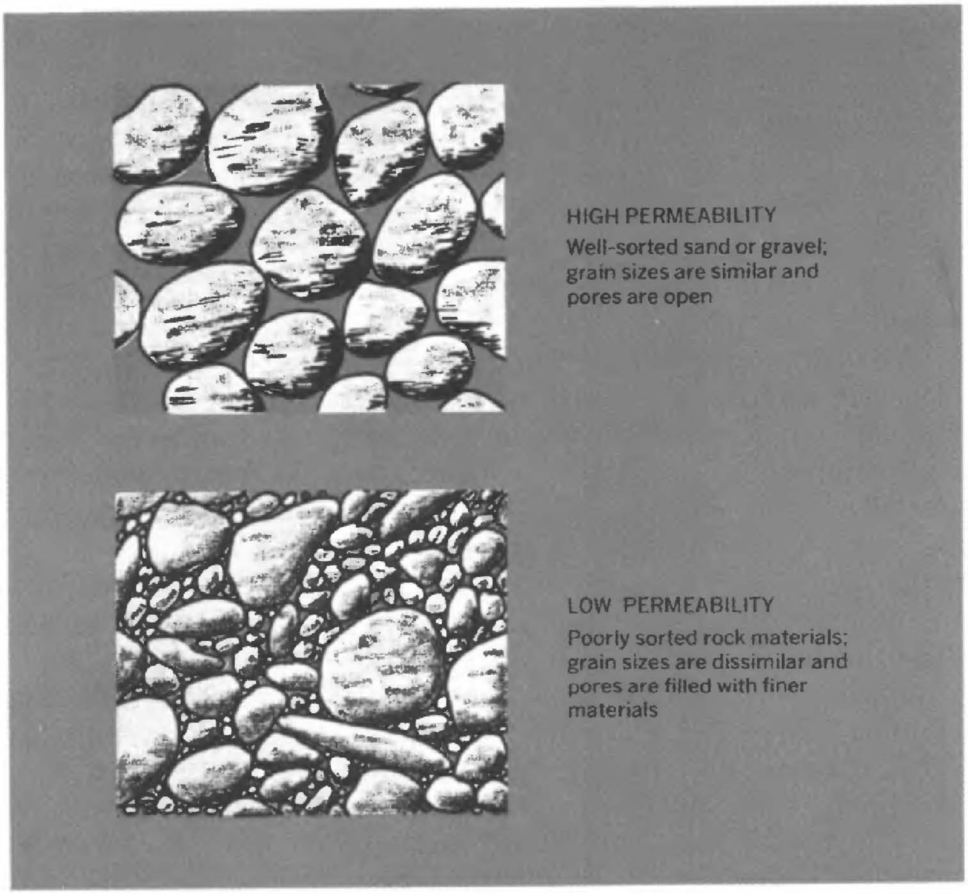
——— 200 ———

Line of equal thickness of glacial deposits

Interval is 50 feet

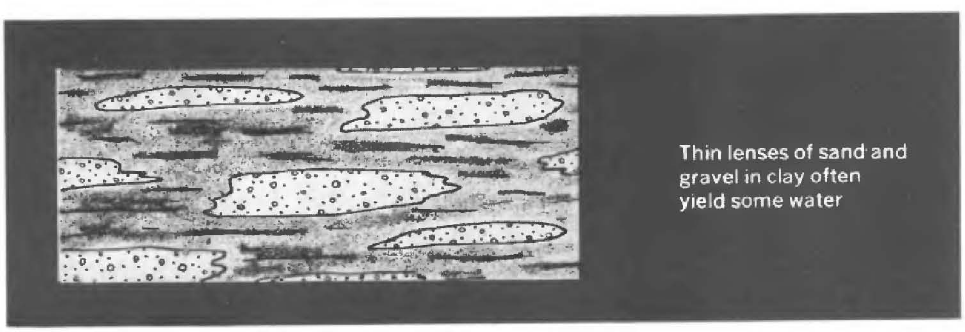
Materials deposited during glacial time range in thickness from less than 50 to more than 400 feet. FIG. 66

given unit might yield water. Some coarse-grained sands and gravels yield hundreds or thousands of gallons of water per minute to wells, whereas fine-grained materials, such as clay, yield little or no water. However, one factor must be kept in mind—sands and gravels that yield large quantities of water usually are well sorted (fig. 67). Any variance from this condition reduces the permeability. In mixtures of materials, such as sand and clay



Well-sorted sands and gravels yield significantly more water than poorly sorted rock materials. FIG. 67

reported in drillers' lithologic logs, clay particles may fill the pore space between sand grains and the permeability will be reduced to practically zero. However, the sand and clay may occur as thin lenses within the units and the actual mixing of the materials may occur during drilling (fig. 68). In this case the unit reported



Thin lenses of sand and gravel in clay often yield some water. FIG. 68

as sand and clay, although appearing to have a relatively low permeability, can be considered to be a minor aquifer.

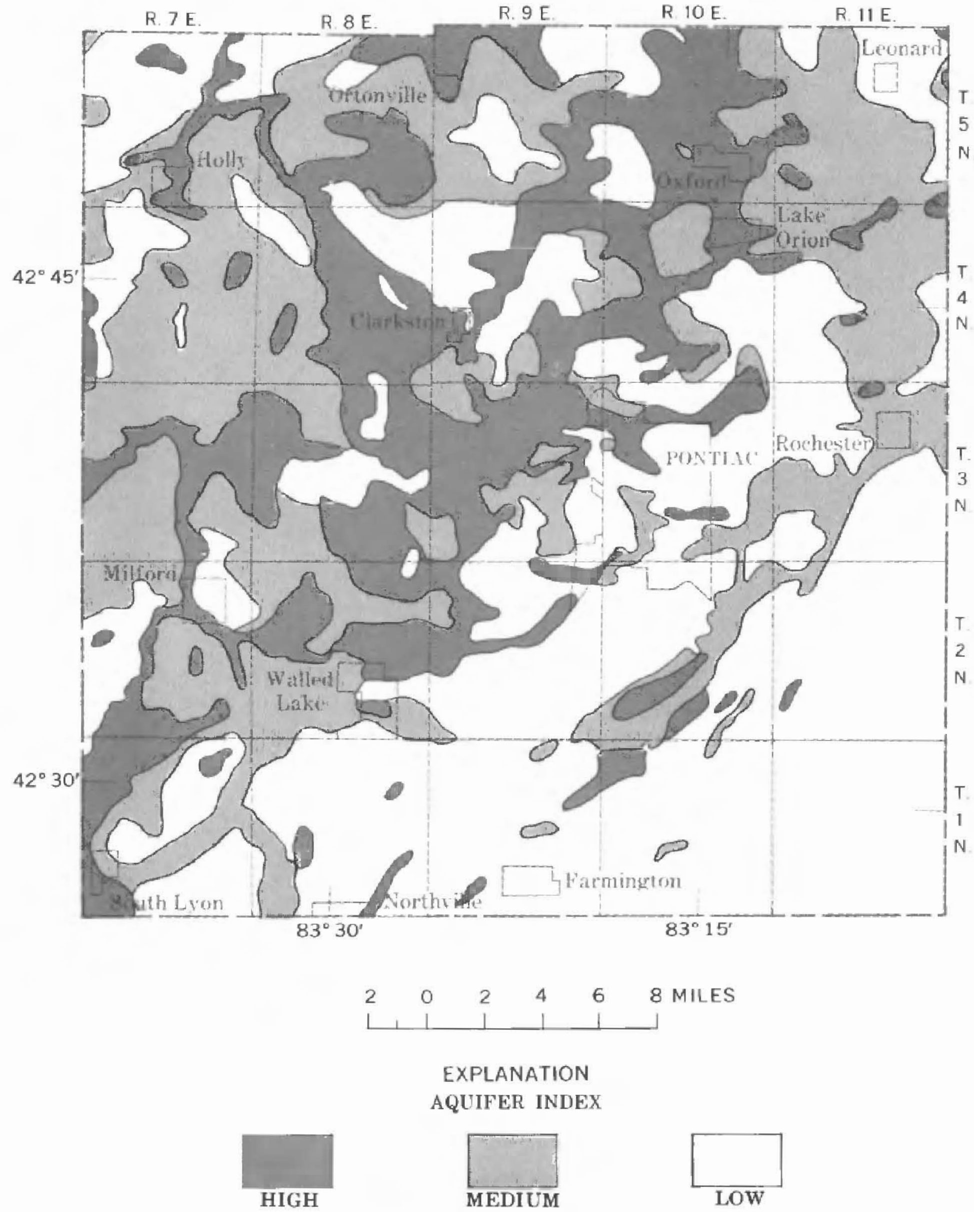
Because of the jumbled nature of the glacial deposits the ground-water reservoirs cannot be delineated by common procedures. Instead, delineation is made by using maps that show the aquifer characteristics of glacial deposits for 50-foot vertical intervals. To do this, glacial deposits were separated into a variety of common rock types and common modifiers. As an example, on a log reading "sand, gravelly, coarse-grained" the first term is the rock type and the two succeeding terms are modifiers. Each rock type and modifier was assigned a number. For a rock type, this number was a reflection of the percentage of aquiferlike materials comprising a rock unit and the unit's ability to yield water. For a modifier, the number reflected the modification made on the water-yielding ability of the rock. Thus, for every 50-foot interval penetrated by each well, a numerical value of water-yielding ability of the materials was determined. This value is termed "the aquifer index."

A computerized evaluation of the geologic data provided plots of the aquifer index for 50-foot depth intervals in each well. Wells within a designated range of values were grouped in areas identified as low, medium, or high as shown in figures 69 through 72. The terms "low," "medium," and "high" reflect the probable permeability of the material. On the basis of present data, it appears that an applicable range in yields for the terms defining the aquifer indices is as follows:

Probable permeability	*Gallons per minute*
Low	0 to 50
Medium	50 to 400
High	>400

Maps showing the areal extent of the three groupings were prepared only for depths to 200 feet. Below this depth, available data are so scanty that area delineation is very inaccurate. Even the map for depths between 150 and 200 feet contain some indefinite areas because of poor control.

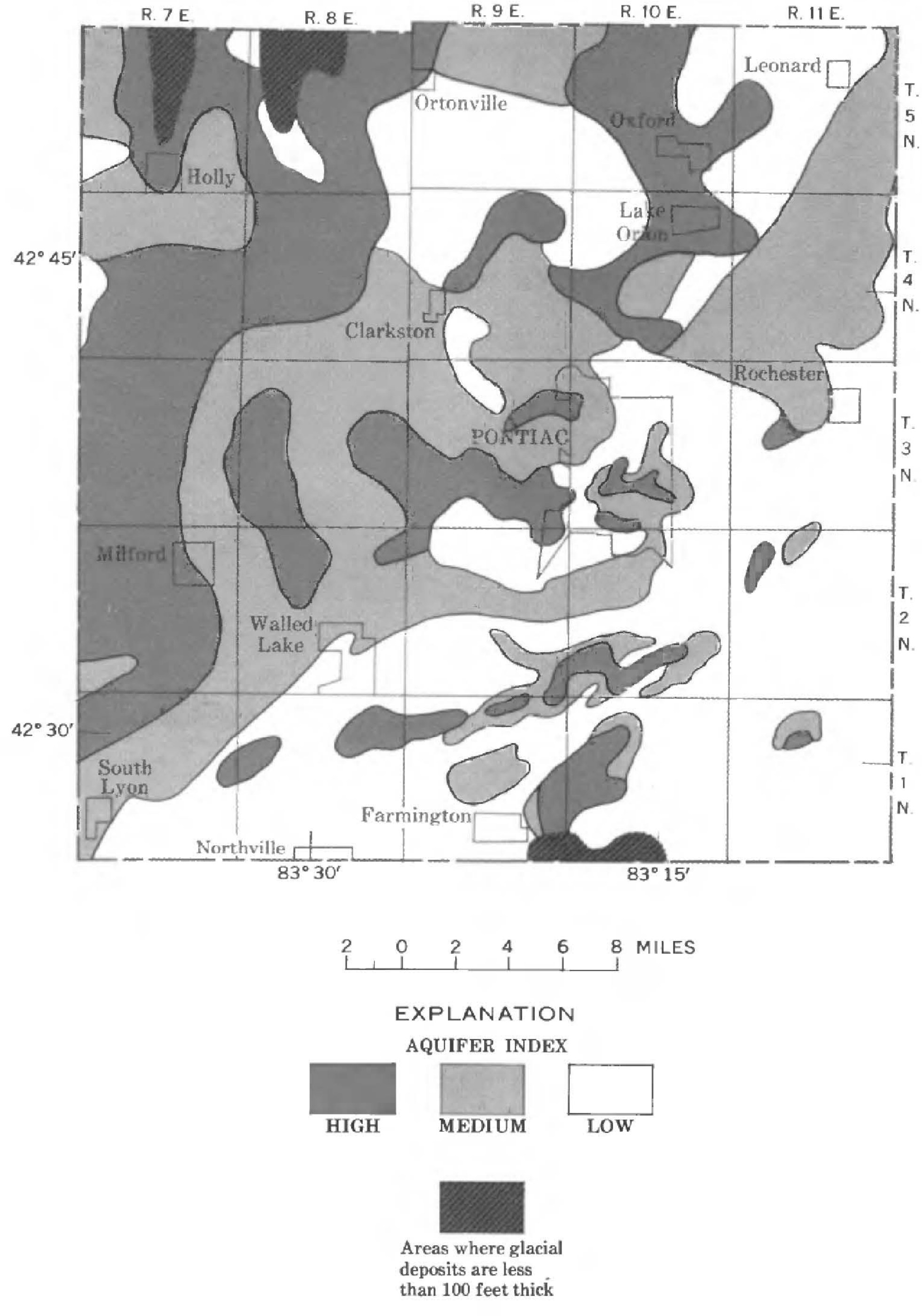
The possibility of encountering aquiferlike materials in glacial deposits varies greatly from area to area and with depth. In general, however, the northwestern part of Oakland County is underlain by glacial deposits that have a medium to high aquifer index from land surface to a depth of 150 feet. The only large area having a definite low aquifer index is in the southeast.



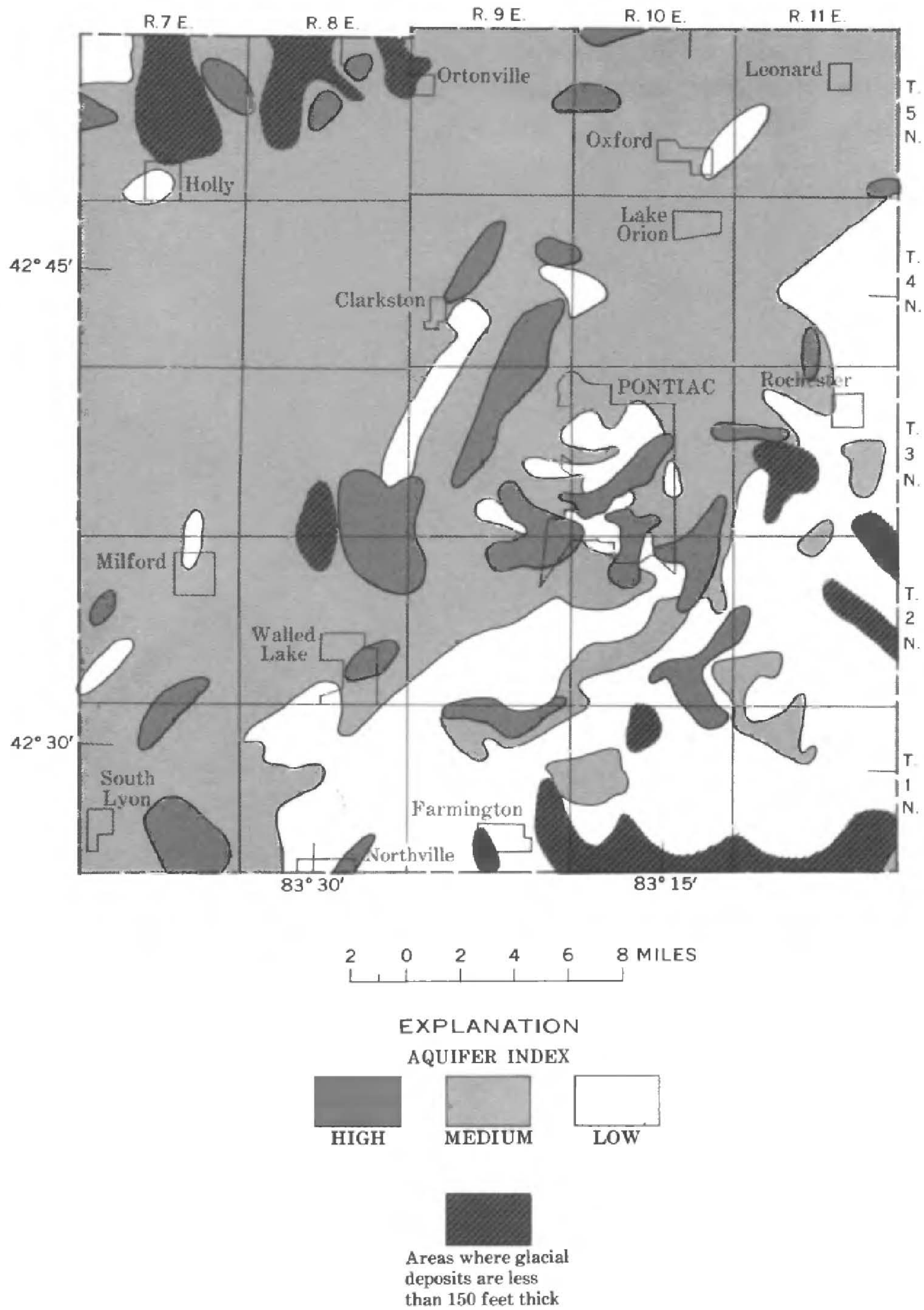
Glacial deposits from land surface to a depth of 50 feet have a medium to high aquifer index throughout much of the northwestern part of the county. FIG. 69

INFLUENCE OF THE BEDROCK SURFACE

Beneath the glacial drift is a surface that was carved on bedrock, primarily before glacial time. This surface is referred to as the bedrock surface. It consists of hills and valleys similar to those at land surface, although their actual orientations and locations are not always coincident. Altitude of the bedrock surface ranges from just less than 400 feet in the southeast corner of the county to slightly more than 850 feet in the northwest (fig. 73).

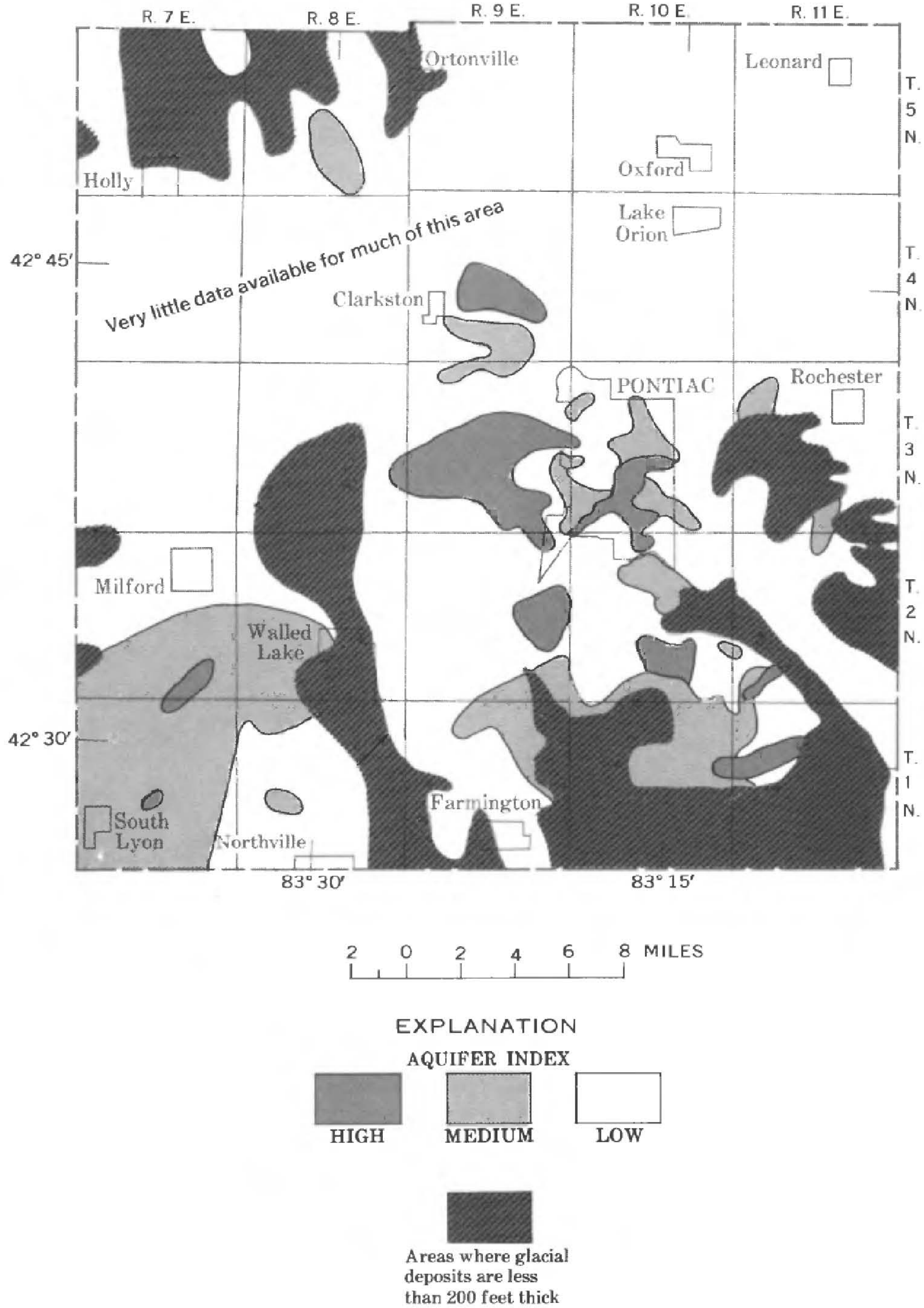


From 50 to 100 feet below land surface there are several areas that have a high aquifer index. FIG. 70

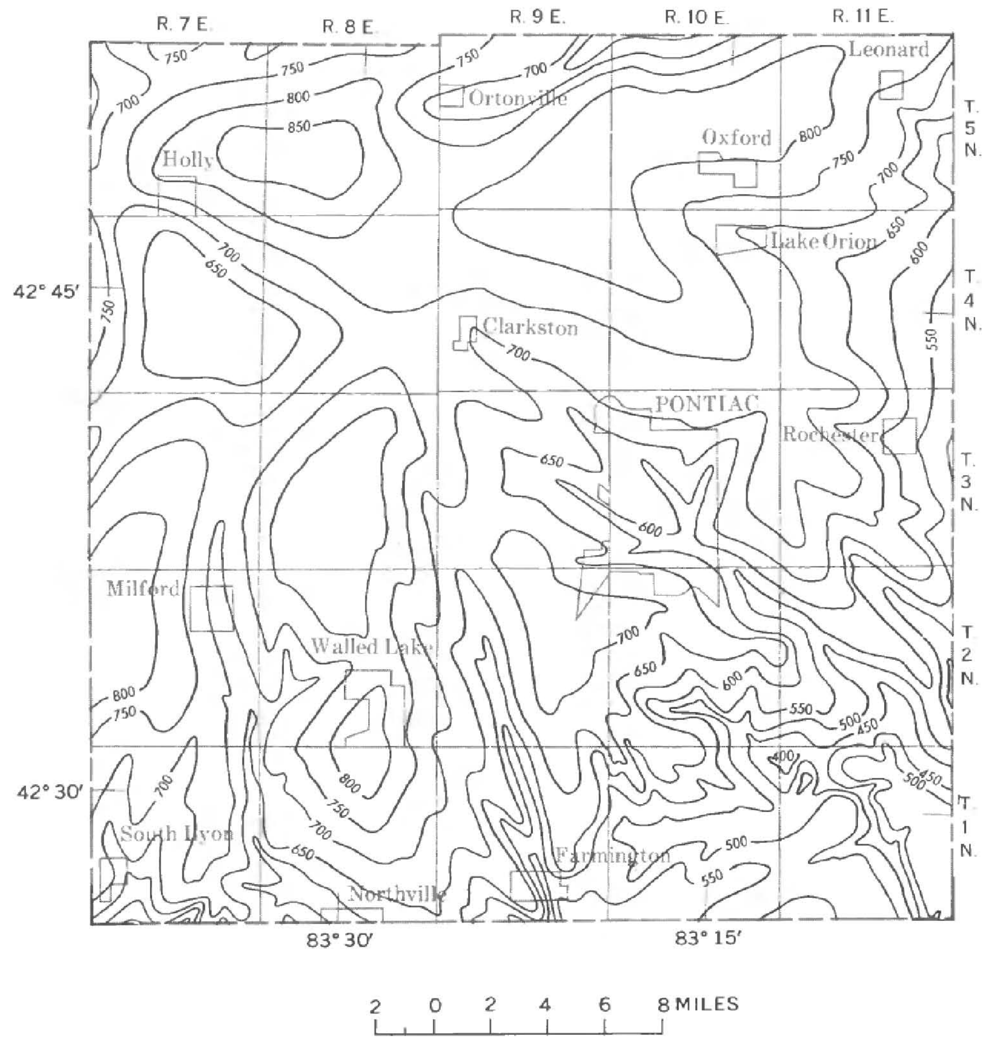


A medium to high aquifer index is predominant in glacial materials from 100 to 150 feet below land surface. FIG. 71

The original drainage on the bedrock surface was somewhat as it is at present; that is, outward from the higher areas in the northwest part of the county. Although the preglacial valleys and hills



From 150 to 200 feet below land surface, glacial deposits throughout much of the county appear to have a low aquifer index. However, accurate evaluation of deposits in the northwest is impossible because data are lacking. FIG. 72



EXPLANATION

600

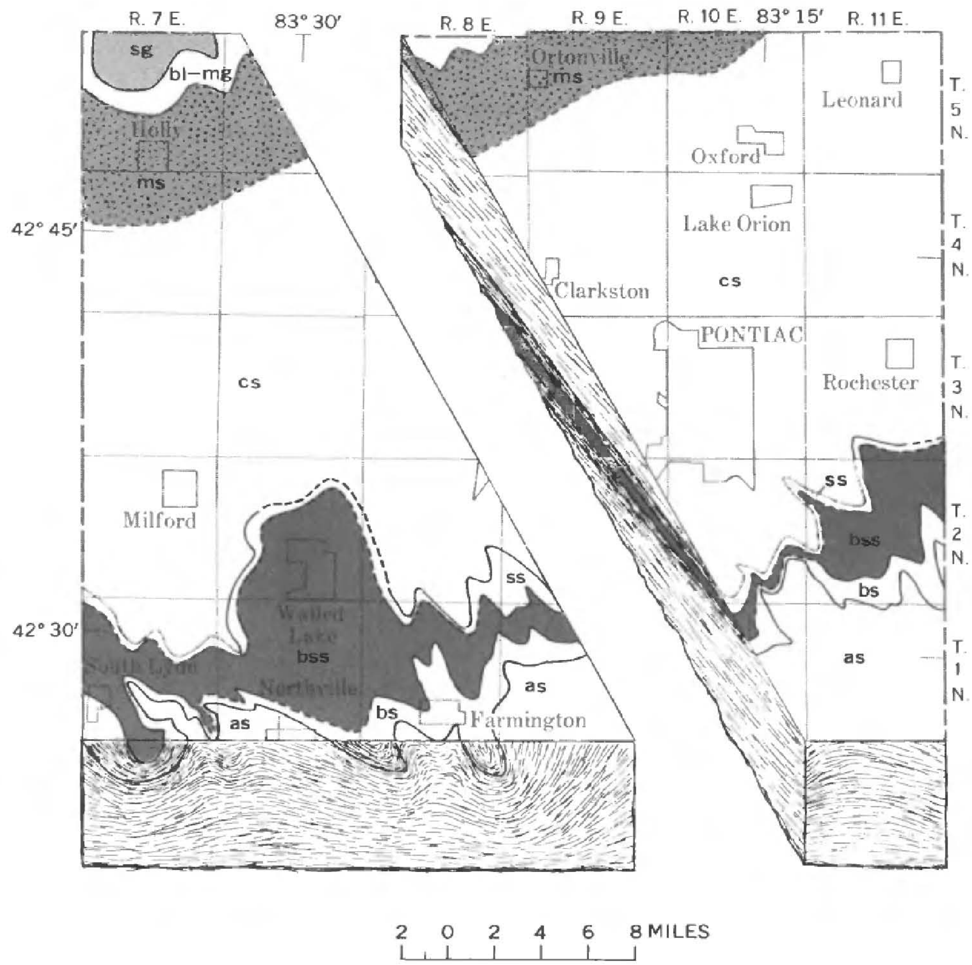
Contour line of the bedrock surface showing altitude above mean sea level; contour interval is 50 feet. Contours were constructed from well data; geophysical studies by Peebles (1969) supplemented well data in five northwestern townships

The topography of the bedrock surface is similar to that of the present land surface. FIG. 73

are covered today and have little direct effect on surface drainage, they are an important factor in the occurrence and movement of ground water, especially where the bedrock surface was carved from relatively impervious material. If the overlying drift is permeable, water will flow from the higher bedrock areas to the buried valleys. Some of these valleys, such as those in the Pontiac-Clarkston area, may contain and yield large quantities of water. However, if the drift in the buried valleys is mostly clay or other impermeable material, it will yield little if any water.

BEDROCK FORMATIONS THAT YIELD WATER

Other sources of water are the bedrock formations underlying the glacial drift. Three northeast-trending bands in figure 74 delineate the subcrop areas for the bedrock formations which will yield water of potable quality. Of the three formations, only the Marshall Formation appears to offer a consistently reliable source



ABOVE AND RIGHT: Subcrops of the three bedrock aquifers—the Saginaw, Marshall, and Berea Formations—are of limited areal extent. FIG. 74

of water. In areas underlain by the Saginaw and Berea Formations some wells yield sufficient water for domestic supplies; however, other wells are dry.

The Marshall Formation has not been tapped extensively by

EXPLANATION

Bedrock units		Average thickness in Oakland County (ft)	Description
Bedrock aquifers	Other Subcrops		
sg Saginaw Formation		50?	Sandstone, sandy shale, gray and blue shale, underclay, coal, and limestone in cyclic sequence. The name "Parma" often is applied to the sandstone or conglomerate present below the lowest shale. Local variations in lithology and thickness exist due to erosion
	bl Bayport Limestone	40-100?	Limestone and dolomite, white to gray or bluish-gray; lenses of sandstone and sandy nodular chert beds are sometimes present. Sand content increases toward the base and forms a white coarse-grained sandstone. The Bayport is extensively eroded in many places in its subcrop area
	mg Michigan Formation	50-100?	Shale, gray, some green and blue; some thick dolomite and thin selenite gypsum. A thick brown dolomite commonly is found at the base. Below the dolomite in places is the "Michigan Stray Sandstone." The contact between the Michigan and the underlying Marshall is believed to be gradational
ms Marshall Formation		115	Sandstone, white, gray, and red, very fine grained to coarse-grained; some beds of conglomerate, shale, and dolomite. Two members present: at the top is an extensive fine- to coarse-grained white to light-gray sandstone called Napoleon Sandstone; underneath is a fine to very fine grained sandstone called Lower Marshall which is often cemented with dolomite. The base of the Marshall generally is shaly and dolomitic grading into the underlying formation
	cs Coldwater Shale	625	Shale, blue to light-gray; some iron carbonate concretions and thin beds of limestone or dolomite. Occasionally, lenticular beds of sandstone and sandy shale are found near the bottom and top
	ss Sunbury Shale	40	Shale, black to dark-gray, hard; some dolomite and some gray sandstone or light-gray micaceous, sandy shales
bss Berea Formation		140	Sandstone; lower part is light gray, dolomitic, silty, shaly, contains some pyrite, and is well cemented with silica or dolomite. Middle part is friable, fine to medium grained, angular to subangular, with some scattered beds of shale. Upper part is similar to the lower member but is less shaly and more pyritic. The middle member is more dominant in Oakland County. The Berea grades into the underlying formation
	bs Bedford Shale	135	Shale, gray; upper part is silty and sandy
	as Antrim Shale	145	Shale, black to brown; some dark-gray to greenish-gray shales; carbonaceous, finely laminated, fissile, hard. Has concretions of pyrite 1-3 inches in diameter. Also contains concretions of anthraconite and bituminous limestone ranging in diameter from 1 inch to 6 feet

wells; however, the few wells that have penetrated this sandstone indicate that it is a good source of supply. Several wells in the northeast corner of T. 5 N., R. 7 E., yield sufficient water to supply a small subdivision. Analysis of water shows that the water is of fair quality although hard. The Marshall also underlies the city of Holly, where it supplies water to one industrial and one city well. Pumping tests on both these wells indicate that the Marshall in this area will readily yield 500–1000 gpm, and that yields of several thousand gallons per minute, with a drawdown of less than 15 feet, may not be unrealistic. Thus, it appears that the Marshall will yield large quantities of relatively good water to wells nearly anywhere in its subcrop area. Depending on site location, wells penetrating this aquifer would have to be 200 to 350 feet deep to obtain maximum yield. North of the subcrop area, the Marshall Formation underlies younger formations, but here also it may yield large quantities of water. However, present data indicate that the water may be of increasingly poorer quality with increasing depth.

The Saginaw Formation is an alternating succession of thin beds of sandstone, shale, limestone, and coal, most of which are difficult to trace over any large area. Because of this, there may be a wide variation in yields between wells. In general, the yield from any one well depends on the percentage of sandstone. In the Flint area, just north of Holly, it was found that where the Saginaw was more than 75 percent sand, the formation would yield as much as 500 gpm; in areas where it was less than 25 percent sand, production was only a few gallons per minute (Wiitala and others, 1963). The Saginaw subcrop in Oakland County is limited to about 10 square miles in the extreme northwestern corner. Wells are sparse in this area; thus, little information is available concerning the nature and extent of the Saginaw as an aquifer. On the basis of data from the Flint area, it is expected that wells pentrating sandstones in the formation would yield sufficient good quality water for domestic supplies. However, it may be necessary to put down several test wells to depths ranging between 125 and 200 feet to locate any water-bearing sands.

The Berea Formation contains several types of material, among which are beds and lenses of fine to medium-grained sandstone. Wells that penetrate this sandstone commonly have low yields and sometimes are dry. This indicates that the sandstone has a low permeability, either because of poor sorting or because cementing material fills the cavities between grains. In general, the Berea is not a good source for large water supplies; however, in many places it will yield sufficient water for small domestic supplies. Depth is an important factor in the consideration of the Berea as an aquifer—in most of its subcrop area the formation is overlain by at least 200 feet of glacial material. North of this subcrop area the overburden is even thicker. Thus, the cost of drilling to these depths will be high.

All available data indicate that the bedrock formation of most importance as a source of water in Oakland County is the Marshall Formation. Aquifers of limited thickness and areal extent exist in other bedrock formations; however, their value as a source of water can only be determined by intensive local investigations.

The foregoing discussion illustrates the importance of the container in determining the availability of water in Oakland County. A container composed of permeable material, such as well-sorted sand and gravel in the glacial deposits or sandstone in the Marshall Formation, can store and yield large quantities of water. On the other hand, impermeable materials, such as the clay in both glacial deposits and bedrock, may store water but will yield only small quantities of it to wells.

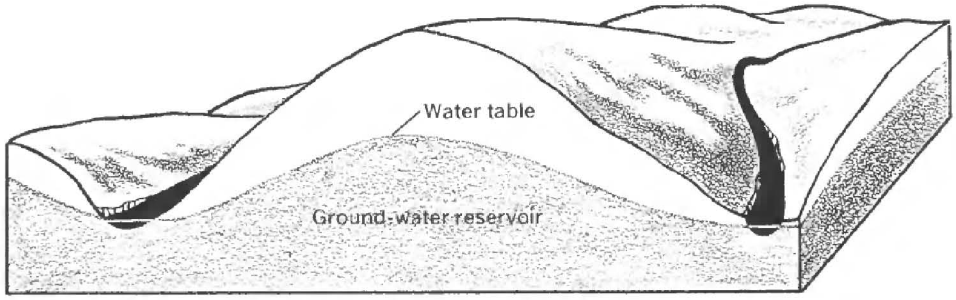
By studying the lithologic data on drillers' logs, we can obtain a fair understanding of the container and be able to delineate areas that appear favorable as sources of ground water. However, before selecting the most favorable areas information will be needed concerning the depth to water and the actual amount of water that can be obtained from the container. This type of information can be obtained only by making pumping tests and water-level measurements. Thus, wells become a prerequisite to the information. However, wells are not everywhere available from which data has been or can be collected.

DEPTH TO WATER

The depth to water is determined by measuring water levels in existing wells. Not many years ago, water-level measurements could be made for most wells, and several maps showing water levels were published (Ferris and others, 1954; Mozola, 1954). Today, however, check valves in wells and buried submersible pumps make such measurements practically impossible. The only information available for most wells is that obtained by the driller at the time the well was drilled or by the pump serviceman at the time the pump was repaired. For many wells, this information may be as much as 5 or 10 years old and may not reflect existing water-level conditions. For other wells the information is relatively new. Relating information that has a wide diversification in collection dates and preparing a water-level map from such data is impractical and inaccurate. Thus, there is no county-wide, water-level map accompanying this report.

Ground-water levels, however, can be estimated for many local areas in Oakland County by use of good topographic maps and by keeping the following factors in mind.

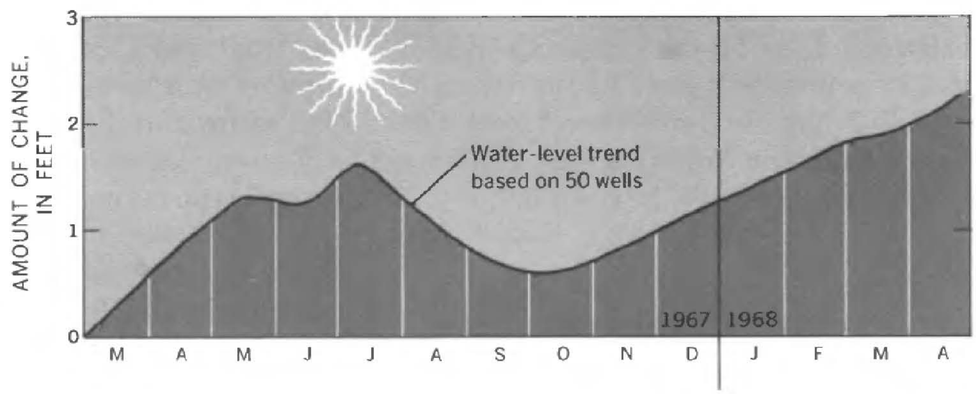
1. The flow in many streams is perennial. This results from ground-water inflow and indicates that the water table in the vicinity of the streams has an altitude that is at least as high as that of the streams.
2. Many lakes are replenished by ground-water inflow indicating conditions similar to those along perennial streams.
3. Between areas where the altitude of the water table is reflected in lakes and streams, the configuration of the water table is a subdued expression of the land-surface topography (fig. 75).



The water table is often a subdued expression of the land surface. FIG. 75

4. The water table fluctuates throughout the year. Figure 76 shows the trend of fluctuations. Water levels usually rise during the winter when evapotranspiration is low and decline during the summer when evapotranspiration is high. Unusually large amounts of precipitation may produce a reversal from the general trend, such as that shown for the month of July (fig. 76).
5. During long periods of reduced precipitation, as from 1960 to 1966, the overall trend of water levels is downward. When precipitation in normal or above, as in 1967 and 1968, the overall trend will be upward.

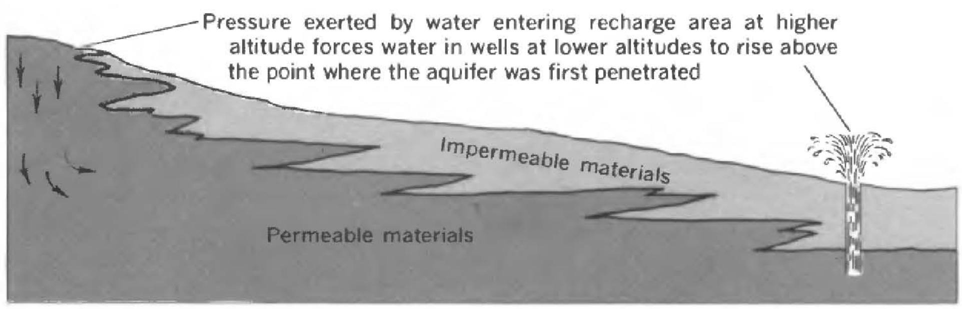
In some local areas determining the altitude of the water table may involve two other factors—artesian conditions and pumping.



Water levels in shallow wells usually decline during the summer months but begin to rise again after the first frost in the autumn. FIG. 76

Artesian conditions

Artesian conditions result when water-bearing permeable materials are confined by overlying impermeable materials. Under these conditions, pressures exerted by water at higher altitudes can cause water to rise in a well above the point where it was first encountered. Figure 77 illustrates in a general way how arte-

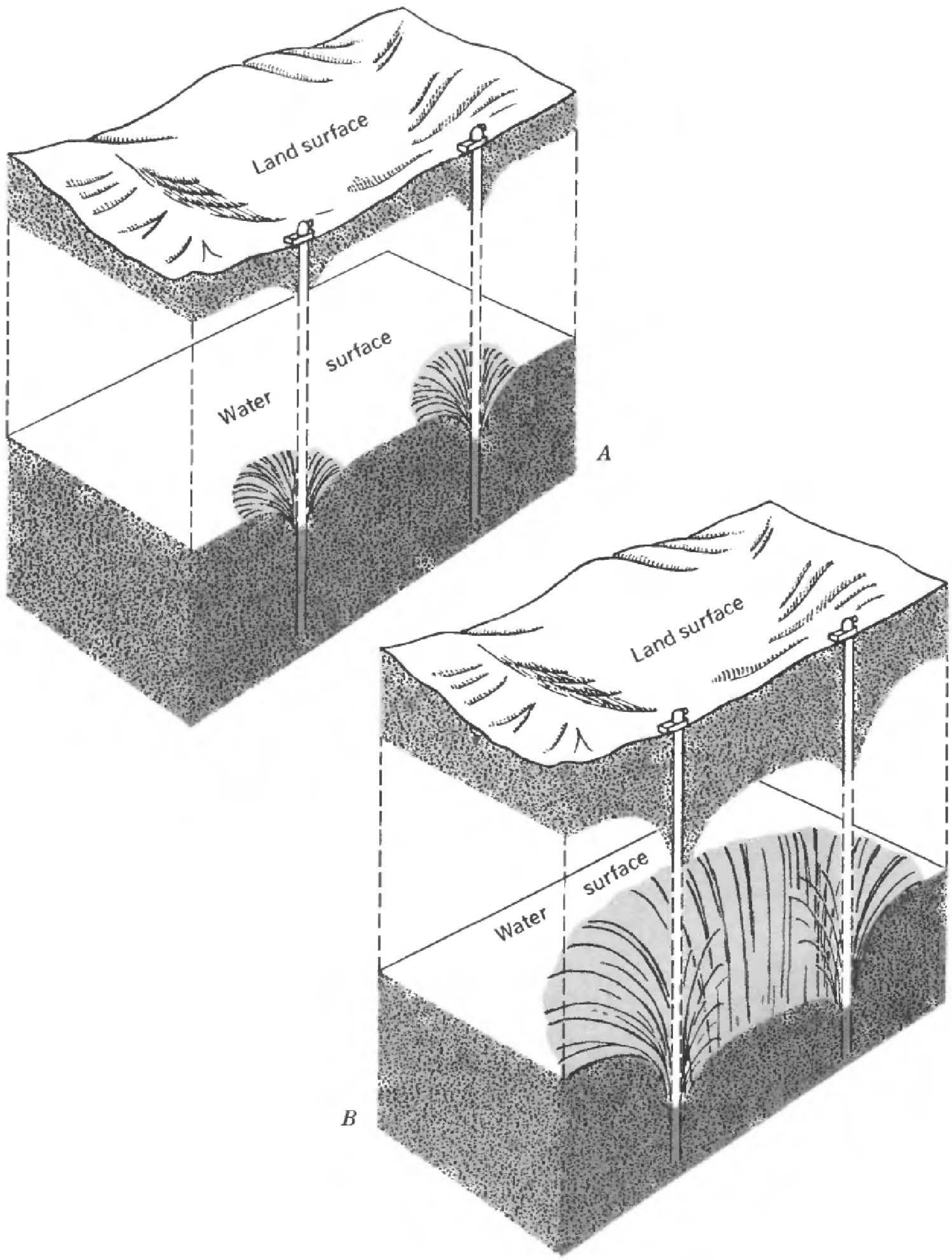


Artesian wells are produced by ground water under pressure. FIG. 77

sian pressures may be produced. Slight artesian rise of water in wells is not unusual; however, a rise to a point where water flows at land surface is not common. Of the several areas of flowing wells in Oakland County, probably the best known are those around Ortonville and Troy (fig. 2). In both these areas there are about a hundred flowing wells with pressures sufficient to raise water levels several feet above land surface.

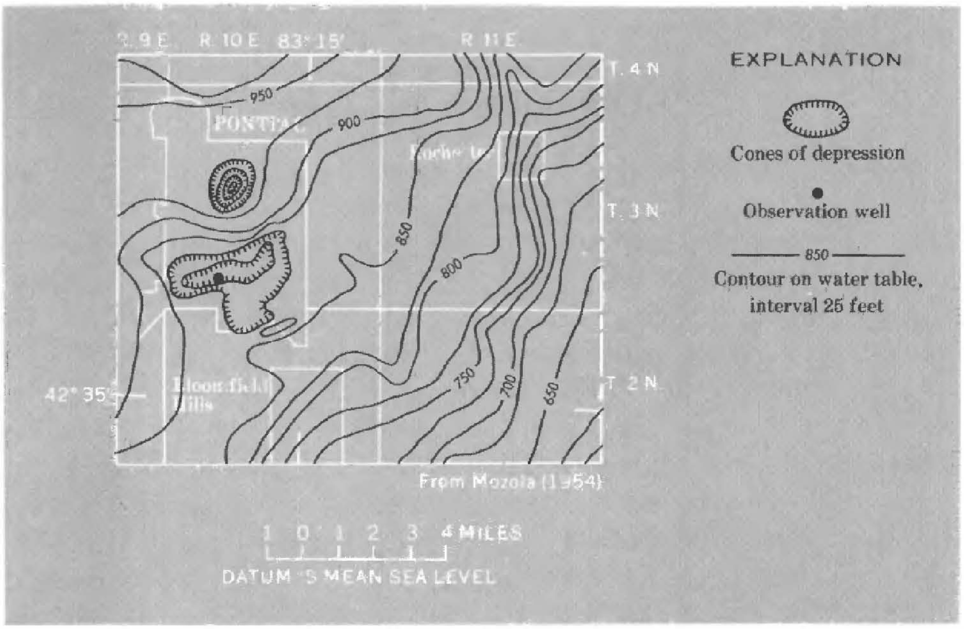
Water levels and pumping

The effects of pumping on ground-water levels are generally well known. If the pumping rate is small, the effect usually is inconsequential. If the pumping rate is large and from several wells, water levels may be lowered considerably over a large area (fig. 78). This is well illustrated by water-level records in the Pontiac area. Prior to 1963 a cone of depression was developed over a widespread area by heavy pumping of ground water for public

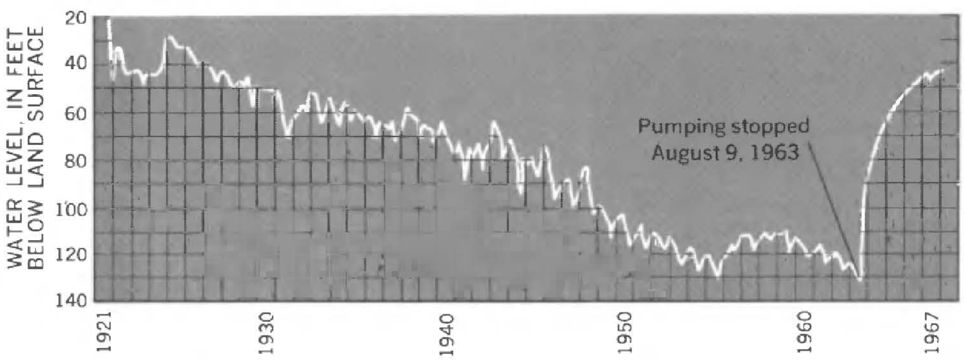


Cones of depression are small when pumpage is small (*A*); however, cones become larger and may coalesce when pumpage is large (*B*). FIG. 78

and industrial supplies. The early development of this cone, as it existed in 1950, is shown in figure 79. Because of the heavy pumping, the water level in one well near the center of the cone of depression was lowered 110 feet (fig. 80). When pumping was stopped in 1963, water levels rose rapidly.



Cones of depression in Pontiac as of 1950. FIG. 79



Water levels in Pontiac have declined as much as 110 feet. FIG. 80

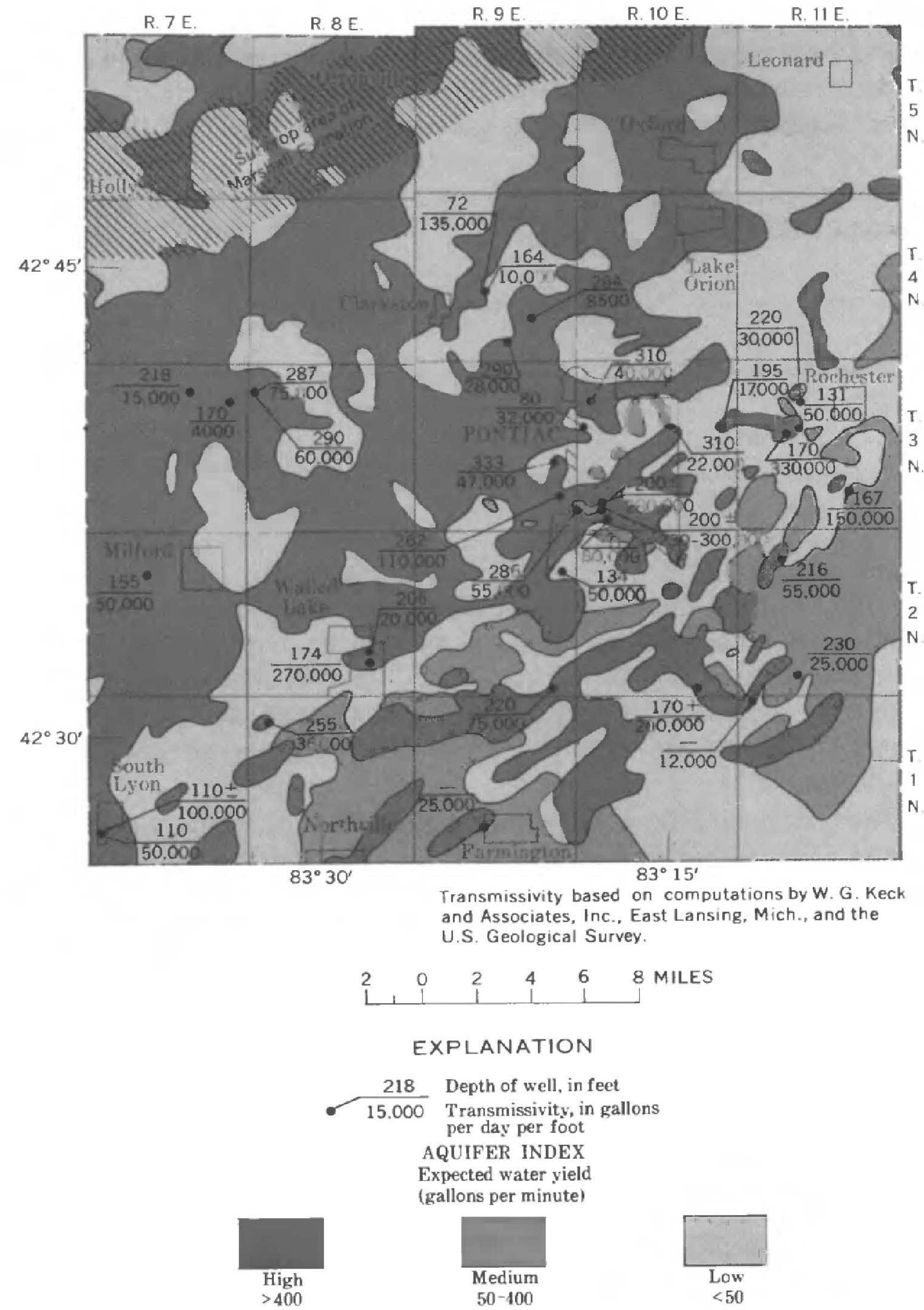
In the county today there are only a few areas of heavy pumping. The water-level changes caused by this pumping are usually confined to the vicinity of the pumping well and in most cases are not extensive enough to affect other wells in the area. Except for the area around Waterford, lowering of water levels by pumping does not appear to be a problem that warrants immediate concern. Even in the Waterford area, lowered water levels may never be a major problem since much of this area is underlain by beds of permeable material that are capable of high yields. However, because Waterford is in a major population and industrial corridor, pumpage of ground water within the next decade or two may increase to the point where the declines in water level will become serious.

HOW MUCH WATER?

The quantity of water that can be pumped from a well is best determined by conducting pumping tests to evaluate the hydrologic characteristics of an aquifer. One such characteristic, expressed as transmissivity, provides a good index of the aquifer's water-yielding capacity. Transmissivities have been computed for more than 2 dozen wells which obtain water from glacial deposits and are shown in figure 81. Because pumping tests are usually associated with some major project, such as a city or industrial water supply, the transmissivities shown are concentrated in certain areas. Nearly all the transmissivities are high and are located in areas that have a high aquifer index. This relationship, although limited, lends credibility to the aquifer-index ratings for materials in other areas of the county. It should be noted that several wells with low transmissivity are in areas with high aquifer indices. This is real in nature but, because data are not complete, many small areas were not delineated in figure 81.

Another method that can be used to estimate the quantity of water that the container will yield is the analysis of actual production records from wells. Such records can be collected for a given well site by conducting a survey of yields of wells in the immediate area. Caution should be taken, however, in using records that show low yields, as higher yields may be possible if larger pumps are used. Also, low yields from some wells may be the result of inadequate well development. Wells that have high yields, such as several hundred gallons per minute, indicate that the container underlying the area adjacent to the well is a good source of water.

Glacial deposits in Oakland County store large quantities of water. On the average, every cubic foot of saturated glacial material contains about 2.5 gallons of water. Thus, a block of glacial materials encompassing an area of 1 square mile and having a thickness of 200 feet will contain about 14.5 billion gallons of



Transmissivities for wells in glacial deposits range from 4,000 to more than 300,000 gallons per day per foot; most of the high transmissivities are in areas where the aquifer indices are high. FIG. 81

water. However, not all of this water is available to wells. Some glacial materials yield large quantities of water, others yield little. The relationship of the aquifer indices, shown in figure 81, to the availability of ground water is given in table 12. The delineation

TABLE 12.—*Availability of ground water from storage in glacial deposits*

[Yields based on a thickness of 200 feet and an areal coverage of 1 square mile]

Aquifer index	Probable quantity available to wells (billion gallons)	Probable yield (mgd per sq mi)	Range of normal yields from a single well (gpm)	Probable life span of efficient operation at maximum normal yields without recharge (years)
High	6–12	0.6–1.5	[1] 400–1,000	12–24
Medium	3–6	.1– .6	50–400	15–30
Low	0–3	0– .1	0–50	0–100

[1] Yields of up to 2,500 gpm are possible at some sites.

of areas in figure 81 is based on data from land surface to a depth of 200 feet. Therefore, in areas where the glacial deposits are thicker than this, wells may penetrate additional aquifers and yields may be somewhat higher than shown. Also, the figures relating to the "life-span of operation" in table 12 are based on water presently in storage. Normal recharge to the aquifer, about 85 million gallons per square mile per year, would extend the life span.

The pertinent factor shown by figure 81 is that the glacial deposits in much of northwestern Oakland County are capable of yielding sufficient water to need most demands within the near future. Areas having high aquifer index values have the potential capability of supplying more than 1 million gallons of water per day per square mile to municipal and industrial needs. Some individual wells within this area are capable of yielding more than 2 million gallons of water per day.

Figure 81 and table 12 can be used to estimate the availability of water in larger areas. As an example, Waterford Township (T. 3 N., R. 9 E.) is comprised of about 30 square miles having a high aquifer index, 5 square miles having a medium aquifer index, and 1 square mile having a low aquifer index. Multiplying the total square miles in each area by the quantity of water per square mile that is available to wells (table 12) and then totaling these values, indicates that the township presently has about 200–400 billion gallons of ground water in storage. Individual wells can pump water from most of the area at a rate of at least 400 gpm for a period of more than 12 years. Recharge from precipitation will extend the length of the pumping period.

Also shown in figure 81 is the areal extent of the Marshall Formation subcrop. Wells that have penetrated this sandstone indicate that it has water-producing characteristics similar to those of glacial materials with a high aquifer index. Within its subcrop area, wells in the Marshall can be pumped at more than 1,000 gpm and thus can meet most demands for water.

Water from sources outside Oakland County could have considerable influence on the quantity of water that will be pumped from ground-water sources within the next few years. Water from the Detroit water system is rapidly becoming available and by 1980 should be within reasonable piping distance of most areas in the county. With this assurance, some industries or municipalities may desire to use local ground-water supplies at a more rapid rate than normal. By so doing, larger quantities of water can be pumped, but the span of efficient operation will be reduced. However, if the available supply is sufficient to fulfill the demands until Detroit water can be utilized, no harm will result. Once ground-water pumpage terminates, recharge to the aquifer will eventually restore ground-water conditions to their prepumping status.

As shown by the preceding discussions, there are many areas in Oakland County capable of yielding moderate to large quantities of ground water. Although the location of these areas and their extent is generally defined; thorough investigations should be conducted on local areas before individual wellsites are selected.

8. Water Quality—A Prime Concern

WHAT IS GOOD WATER?

One of the first questions a person asks when using water from an unknown source is "Is the water good?", that is, "Is the quality of the water such that it can be used without a harmful effect?" Thus, the question "What is good water?" is a prime concern in the discussion of water.

The acceptability of any water has a direct relation to the use for which the water in intended. For instance, muddy, turbid water in not desirable for drinking or recreational purposes, but that same water is acceptable for power generation or commercial navigation. Highly mineralized water is unsuitable for domestic purposes and fish propagation; however, it may be a source of some economically valuable mineral. These comparisons could go on and on through the various water uses and we would find that nearly all water is acceptable for some purpose. Thus, as can be seen, there are no absolute measurements of water quality. "Good water" can be defined only when an intended use of the water is known. Five major categories of water use are used by the State of Michigan (Michigan Water Resources Commission, 1968) to assist in the definition of water quality. They are:

1. Public water supply.
2. Fish, wildlife, and other aquatic life.
3. Recreation.
4. Agriculture.
5. Commercial and industrial.

In our quest for an answer to the question "What is good water?", it is also necessary to use certain measurable parameters of water in order to be quantitative in our evaluation. These parameters can be classified into three major groups, as shown below.

Chemical	*Physical*	*Biological*
Dissolved solids	Color	Bacteria
Hardness	Taste and odor	Viruses
Hydrogen ion concentration (pH)	Turbidity	
Toxic and deleterious substances	Suspended solids	
Dissolved oxygen	Radioactivity	
	Temperature	

Only the chemical and physical groups are discussed in any detail in this report. The biological group, which considers the number and species of living organisms and their environmental interaction, may change rapidly in response to very minor changes in water environment. Consequently, evaluation of the parameters in this group should be made immediately prior to use.

Having some idea of the uses of water and some parameters to measure, we need only a set of standards for parameter evaluation in order to define good water. The U.S. Public Health Service (1962) has suggested such limits or standards for the common parameters in either surface or ground water (table 13). In addition to the standards recommended by the U.S. Public Health Service, the State of Michigan has recently proposed standards (table 14) for the five major water uses. These standards, established primarily for pollution control of streams and lakes, are not completely definitive as they do not give the optimum values

TABLE 13.—*Significance of some chemical and physical parameters commonly associated with water in Oakland County*

[Adapted from U.S. Public Health Service (1962)]

Parameter	Maximum recommended concentration (mg/l)	Significance
Dissolved solids	500	Includes all material in water that is in solution. Amounts up to 1,000 mg/l are generally considered acceptable for drinking purposes if no other water is available.
Iron (Fe)	0.3	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 by softening.
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 for 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 will 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 matter, 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.

of the various parameters. However, they do define the maximum values allowed by law.

The water-use category for which the standards of the U.S. Public Health Service and the State of Michigan are most restrictive is that for domestic water supplies and for fish, wildlife, and other aquatic life. Therefore, by defining the parameters of water that are good for these uses, we have gone a long way toward defining the type of water that is acceptable for most other uses and, thus, water which can be considered to be good.

GOOD WATER IN OAKLAND COUNTY

"The water is good" is a statement that can be applied to the overall quality of water in the lakes, streams, and ground in Oakland County. There are exceptions, but these usually show up only in the southern part of the county, where the water is pol-

TABLE 14.—*Water-quality standards proposed by*

[Adapted from Michigan Water

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

the State of Michigan for five major water uses

Resources Commission (1968)]

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."

luted or where it is being pumped from bedrock. Elsewhere quality-of-water analyses (tables 15 and 16) indicate that most water is within the recommended limits for a public domestic supply.

TABLE 15.—*Concentration of common chemical*

[Dissolved constituents and hardness

	Station	Location	Date	Time	Instantaneous discharge (cfs)	Bicarbonate (HCO_3)
	Streams tributary to Shiawassee River					
4–1437.0.	Shiawassee River near Davisburg	NE¼sec. 12, T. 4 N., R. 7 E.	4–14–66	1500	6.69	254
4–1438.3.	Shiawassee River at Holly	SE¼sec. 29, T. 5 N., R. 7 E.	4–14–66	1000	28.9	248
			7–25–66	1445	5.63	240
	Streams tributary to Flint River					
4–1480.2.	Kearsley Creek near Ortonville	SE¼sec. 18, T. 5 N., R. 9 E.	4–14–66	1350	12.3	246
4–1482.0.	Swartz Creek near Holly	SW¼sec. 15, T. 5 N., R. 7 E.	4–14–66	1100	6.96	241
			7–25–66	1430	.38	246
	Streams tributary to Clinton River					
4–1607.5.	Clinton River at Clarkston	NW¼sec. 20, T. 4 N., R. 9 E.	9–13–67	1020	1.28	203
4–1608.0.	Sashabaw Creek near Drayton Plains.	SE¼sec. 26, T. 4 N., R. 9 E.	4–14–66	1035	15.0	196
4–1610.0.	Clinton River at Auburn Heights	NW¼sec. 36, T. 3 N., R. 10 E.	4–14–66	1400	117	204
			7–26–66	0940	22.1	200
4–1615.4.	Paint Creek at Rochester	SE¼sec. 10, T. 3 N., R. 11 E.	4–14–66	1700	44.0	227
			7–25–66	1635	11.2	262
4–1615.8.	Stony Creek near Romeo	SW¼sec. 31, T. 5 N., R. 12 E.	4–14–66	1130	12.8	212
			7–25–66	1600	1.23	266
4–1618.3.	Clinton River at Yates	SE¼sec. 13, T. 3 N., R. 11 E.	4–14–66	1755	192	226
4–1640.1.	North Branch Clinton River at Almont.	NE¼sec. 28, T. 6 N., R. 12 E.	4–21–67	0750	16.5	231
4–1646.0.	Middle Branch Clinton River near Macomb.	SE¼sec. 2, T. 3 N., R. 12 E.	4–20–67	0920	26	213
	Streams tributary to River Rouge					
4–1660.0.	River Rouge at Birmingham	NW¼sec. 36, T. 2 N., R. 10 E.	4–14–66	1015	8.15	273
			7–25–66	1305	.32	228
4–1660.3.	Franklin Branch at Franklin	NW¼sec. 9, T. 1 N., R. 10 E.	9–13–67	1050	2.32	188
4–1661.0.	River Rouge at Southfield	SW¼sec. 32, T. 1 N., R. 10 E.	4–14–66	0900	27.4	242
			7–25–66	1300	1.98	252
4–1663.0.	Upper River Rouge at Farmington	NW¼sec. 27, T. 1 N., R. 9 E.	4–14–66	1200	6.81	270
			7–25–66	1530	.90	250
	Streams tributary to Huron River					
4–1695.0.	Huron River at Commerce	SE¼sec. 10, T. 2 N., R. 8 E.	4– 6–67	1515	86.3	216
			8–16–67	0850	13.7	225
4–1700.0.	Huron River at Milford	SE¼sec. 9, T. 2 N., R. 7 E.	4–14–66	1145	59.1	242
			7–25–66	1200	34.0	248
4–1705.0.	Huron River near New Hudson	NE¼sec. 1, T. 1 N., R. 6 E.	4–14–66	1440	45	206

TABLE 16.—*Concentration of common chemical*

[Dissolved constituents and hardness given in milligrams per liter. Aquifer: QGO, glacia

Well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Bicarbonate (HCO_3)
01N07E30ACB	118	QGO	12–16–58	-------	15	3.3	370
01N08E21BBBA	102	-------	5– –67	13	16	2.0	352
01N09E17DBDB	293	-------	9–10–59	-------	18	1.2	370
01N10E13ACAB	183	QGO	6–22–54	-------	14	.85	371
01N11E18BACB 2	219	QGO	8–24–29	-------	11	-------	316
02N07E23BDCC	171	QGO	5– –67	12	14	-------	156
02N08E26ABDD	140	QGO	3–28–60	-------	15	1.3	296
02N09E11CABC	80	QGO	4–28–53	11	12	1.0	217
02N10E24AABA	145	QGO	1–20–61	-------	17	.6	394
02N11E20DDDD	125	-------	11–29–38	-------	10	.37	357

Several parameters, such as iron, dissolved solids, hardness in ground water, and temperature of both ground and surface water, may exceed recommended limits but none is so high as to

constituents in surface water in Oakland county
given in milligrams per liter]

Carbonate (CO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Temperature (°C)
							Calcium, magnesium	Noncarbonate			
Streams tributary to Shiawassee River—Continued											
0	86	30	------	------	------	------	250	42	551	8.0	8
0	48	16	0.2	1.7	0.46	314	261	58	518	7.9	7
0	32	34	------	5.0	------	348	238	42	537	7.4	27
Streams tributary to Flint River—Continued											
0	51	18	0.3	0.7	0.02	336	264	62	521	7.7	7
0	60	11	.2	.7	.08	348	264	66	508	7.7	7
0	57	12	.2	1.2	------	326	262	60	518	7.8	25
Streams tributary to Clinton River—Continued											
0	43	25	------	------	------	------	209	43	590	8.2	15
0	57	15	------	------	------	------	234	74	464	7.5	6
0	71	75	0.6	10	1.7	458	263	96	715	7.1	12
0	85	112	1.4	24	------	548	244	80	955	7.3	23
9	64	23	.3	.8	.15	346	271	70	529	8.4	9
0	39	26	------	.6	------	314	254	39	531	8.1	26
0	55	14	------	------	------	------	240	66	467	8.2	8
0	30	17	------	1.0	------	304	254	36	499	7.9	27
0	74	67	.5	8.3	2.2	456	281	96	694	8.2	10
3	64	16	------	------	------	------	267	75	530	8.3	8
0	66	44	------	------	------	------	274	99	640	8.2	7
Streams tributary to River Rouge—Continued											
0	177	107	0.2	2.1	0.38	643	460	237	1,080	7.5	8
0	105	100	------	3.4	------	528	334	147	866	7.2	25
0	50	50	------	------	------	------	212	58	695	8.0	13
0	111	99	------	------	------	------	358	159	914	7.7	7
0	67	94	.3	2.7	------	500	311	104	815	7.3	22
0	121	42	.3	.9	.03	458	384	163	741	7.9	9
0	36	41	------	.5	------	332	262	56	567	8.0	28
Streams tributary to Huron River—Continued											
3	24	17	------	------	------	------	207	27	410	8.4	------
3	29	25	------	------	------	------	224	36	560	8.3	------
0	44	24	0.3	1.4	0.29	320	247	48	516	7.6	8
0	28	30	------	3.6	------	322	234	31	531	7.4	24
12	37	24	.3	1.3	.13	304	234	44	486	8.4	7

constituents in ground water in Oakland County
deposits, outwash; QG, glacial deposits, undifferentiated; MIMA, Marshall Formation]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH
						Carbonate	Noncarbonate		
0	35	7.0	0.0	------	374	335	------	600	7.2
0	2.0	1.0	.6	0.1	300	269	0	516	8.0
0	------	55	.5	4.0	420	275	------	710	7.6
0	42	47	.4	.0	462	306	------	710	7.0
0	4.6	86	------	------	408	180	------	------	------
4	34	2.0	.0	.1	194	169	34	321	8.3
0	------	1.0	.1	------	312	270	------	500	7.5
0	3.0	2.0	.2	.0	186	155	------	400	7.8
0	33	4.0	.2	------	390	340	------	650	7.5
0	5.2	60	------	------	384	255	------	------	------

TABLE 16.—*Concentration of common chemical*

[Dissolved constituents and hardness given in milligrams per liter. Aquifer: QGO, glacial

Well No.	Depth (feet)	Aquifer	Date of collection	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Bicarbonate (HCO_3)
02N11E33DBCA 1	225	QGO	5- 1-36	-------	8.8	-------	289
03N07E18DCBA	85	QGO	6- -67	12	15	-------	308
03N08E23AABD	104	QGO	5- -67	10	12	-------	164
03N09E24ADBA	237	QGO	3-17-53	-------	14	1.6	349
03N10E28AAAA	195	QGO	9-25-50	-------	12	1.2	400
03N11E27DABC	167	QGO	3- 6-59	-------	15	2.4	390
04N07E20CCCD	87	QGO	9-10-66	11	5.8	-------	88
04N08E05BBCB	212	-------	4-20-66	12	19	-------	310
04N09E21CDCA 1	164	QG	3- 6-59	-------	12	1.0	325
04N10E20CACD 2	95	QG	6- -67	11	13	.1	260
04N11E20CBBB	61	QG	3- 3-67	10	13	1.0	202
05N07E19ACAA 1	250	-------	5- -67	11	7	-------	272
05N07E28DBCC	220	MIMA	1-26-61	-------	12	.6	370
05N08E28DDDD	110	QG	5- -67	-------	11	.8	176
05N09E23CBCC	60	QG	5- -67	10	12	.8	160
05N10E26BCBD	73	QG	12-27-54	-------	6	1.4	227
05N11E17CCC	145	QG	6- -67	13	-------	1.5	278

Wells are assigned numbers using a four-segment system of numbers and letters. For example, a wellsite in the NE¼ of the SW¼ of the SW¼ in section 32 of Addison Township in Oakland County is numbered in this report as follows:

05N11E32CCCA

The "05N" designates township, "11E" designates range, and "32" designates the section. The section is divided into quadrants and is lettered counterclockwise as A, B, C, and D. The smaller quadrants are subdivided similarly. The location for most wells shows a four-quadrant breakdown; thus each wellsite is located on a 2.5-acre tract of land. When there is more than one well within a 2.5-acre tract the wells are numbered sequentially.

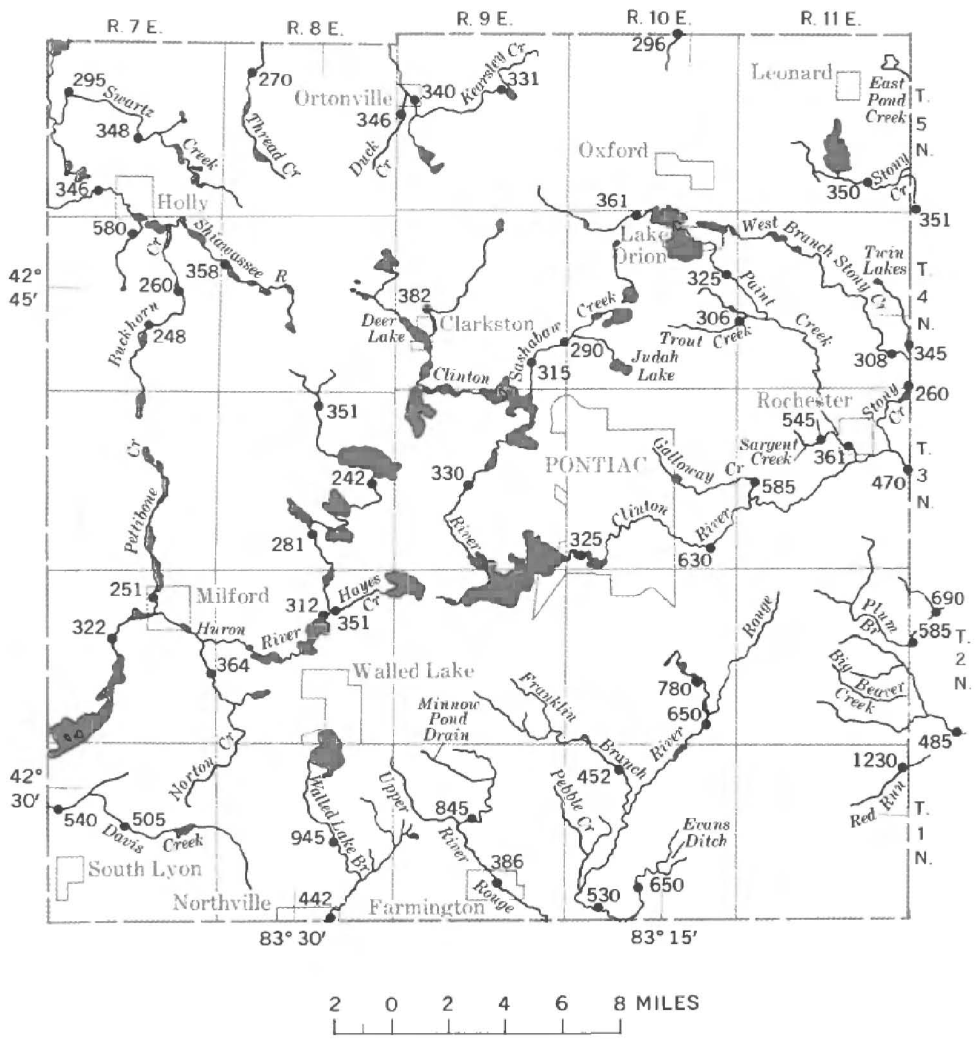
have a toxic effect. For example, dissolved-solids concentrations greater than 500 mg/l are likely to cause accelerated corrosion or scale in plumbing but will cause no known physiological damage. Very high concentrations may be objectionable because they impart a salty or mineral taste to the water. Sometimes high concentrations of dissolved solids indicate influence from outside factors. Thus, the high dissolved-solids content in surface water in the southeastern part of the county (fig. 82) may indicate that the water is being polluted and that the biological aspects of the water are high enough to have physiological significance. Iron concentrations greater than 0.3 mg/1 may cause staining of porcelain fixtures and laundered articles, but it is not physiologically harmful if consumed in drinking. Also, hardness has no generally accepted standards. Its acceptance depends upon what the user has become accustomed to. Iron and hardness do not constitute a serious water-quality problem for domestic and public supply in Oakland County. Where these consituents are objectionably high the water can be treated easily and economically to reduce hardness and iron to an acceptable concentration.

RIGHT: Many streams in the southern and eastern parts of the county exceed the recommended limits for dissolved solids for public supplies. Numerical values indicate total dissolved solids, in milligrams per liter, under low-flow conditions during August 24–25, 1967. FIG. 82

constituents in ground water in Oakland County—Continued

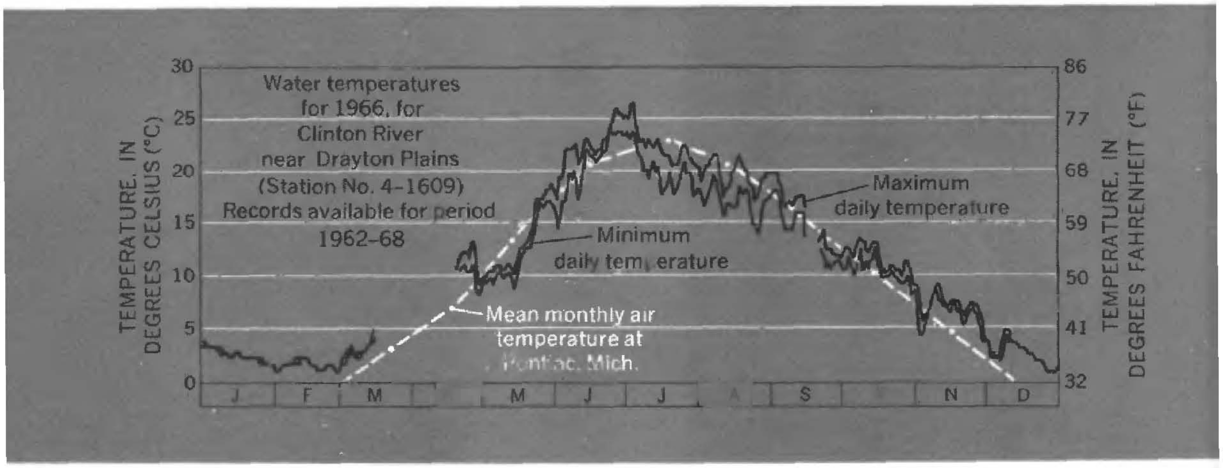
deposits, outwash; QG, glacial deposits, undifferentiated; MIMA, Marshall Formation]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH
						Carbonate	Non-carbonate		
0	1.6	240	-------	------	638	200	--------	---------	-----
0	53	1.0	.3	.1	346	314	62	542	8.2
0	26	6.0	.2	.2	167	150	16	305	8.2
0	63	7.0	1.1	.0	426	325	--------	680	7.5
--------	28	22	.6	------	400	330	--------	---------	-----
0	5.0	4.0	.4	.0	364	302	--------	584	7.4
0	67	10	.9	1.8	196	124	52	314	7.2
0	15	3.0	.7	.7	270	242	0	492	8.0
0	25	17	.2	.0	324	280	--------	600	7.7
0	9.2	20	1.0	.0	269	200	0	464	8.2
0	3.2	43	.6	.0	232	161	0	440	8.2
0	124	570	.4	.6	1,340	379	156	2,380	7.7
0	40	114	.3	.0	554	355	--------	1,000	7.5
0	29	7.0	.2	.0	182	176	32	335	8.2
0	37	6.0	.2	.0	209	170	38	342	8.2
0	49	7.0	-------	------	294	235	--------	500	7.7
0	38	2.0	-------	.1	264	280	52	484	7.9



Temperature has no fixed optimum standard; however, most users prefer water that has a low and constant temperature. Nearly everyone enjoys a drink of cold water, especially on a hot day. Also, water with a low temperature is a necessity for many cooling and manufacturing processes.

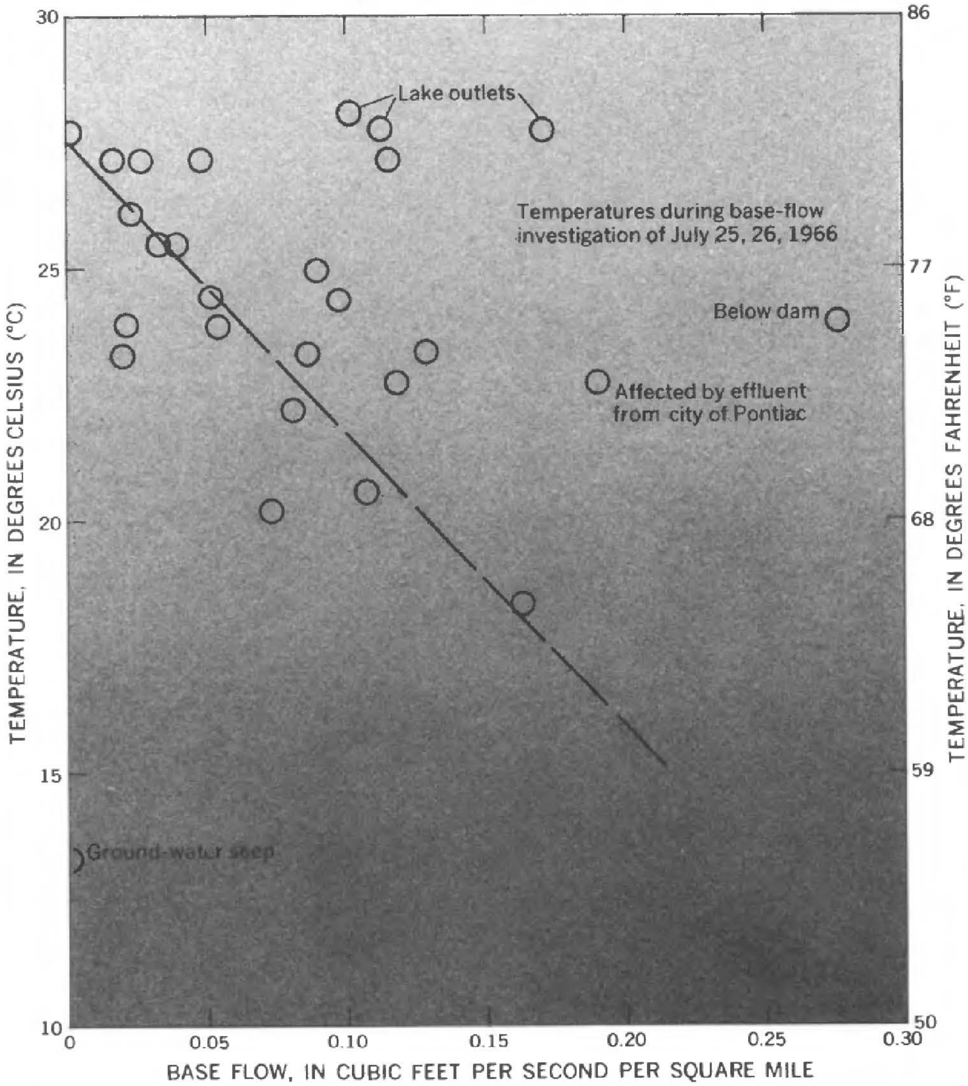
The temperature of water in streams and lakes is affected primarily by the sun's radiation and thus varies considerably from day-to-day and season-to-season (fig. 83). Generally, the average



Temperatures of water in streams vary considerably and often reflect climatic conditions. FIG. 83

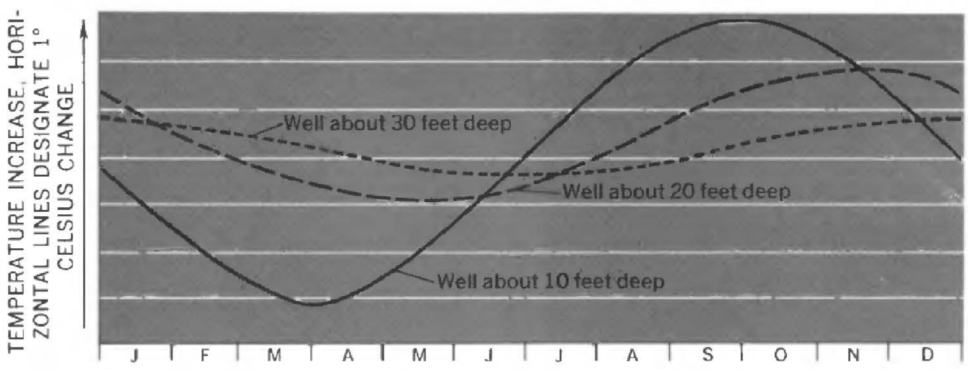
monthly temperature of surface water, except during periods when the water is frozen, will be nearly the same as the average monthly air temperature.

Variations in temperature between surface-water bodies under the same climatic conditions are usually the result of varying amounts of ground-water inflow. Streams with high base-flow discharge usually stay cooler in the summer and warmer in the winter than streams with a low base-flow discharge. Figure 84 illustrates this relationship for a summer period. As shown, streams affected by lakes, dams, and ground water seeps scatter somewhat from the general relationship. Inspection of base-flow discharge (table 5) will, however, indicate in a relative way which rivers might be expected to have cooler water temperatures during the summer. As an example, the base-flow discharge of the Clinton River near Drayton Plains is relatively high, indicating a large contribution of ground water. Consequently, its average summer water temperature is relatively low.



Streams having higher base flows generally have lower summer temperatures. FIG. 84

Temperature of water in the ground is affected by two sources of heat; heat from the sun and heat from the earth's interior. The amplitude or amount of change in temperature depends upon the depth of the water below land surface. As might be expected, water close to the surface shows a greater change than the deeper water. Also, the shallow water changes more rapidly, that is, there is less lag in time between a change in surface temperature and a corresponding increase or decrease in water temperature (fig. 85). At depths less than 60 feet, water temperature is affected primarily by the sun's heat. The average ground-water tem-



Temperature of ground water from shallow wells changes faster and has a larger range than does water from deeper wells. FIG. 85

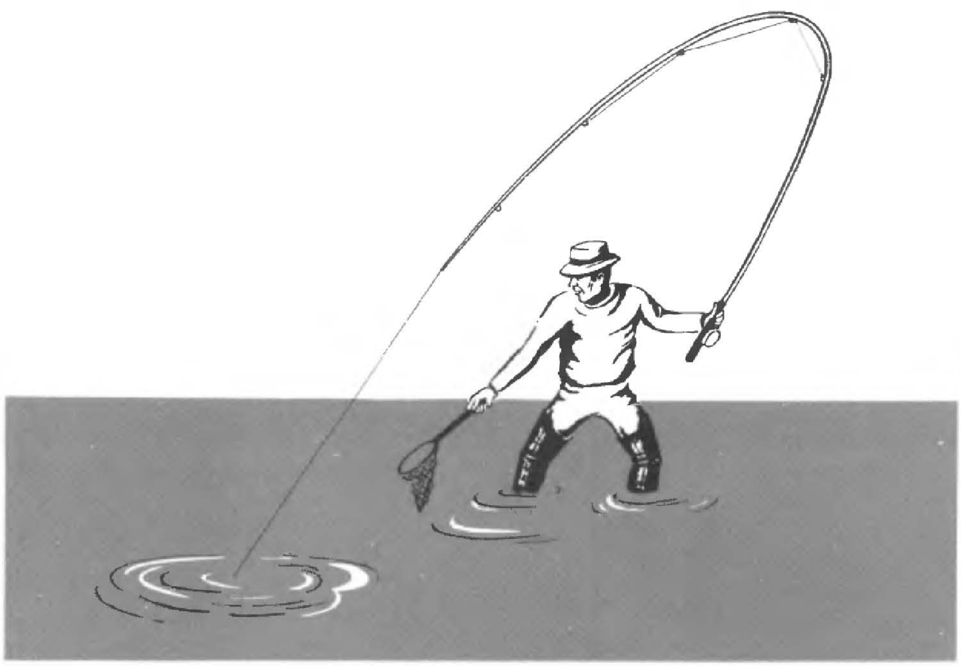
perature in this zone is about 9.1° C; which is very close to the average annual air temperature. Below 60 feet, the water temperature is affected by heat from the earth's interior and increases about 0.9°C for every 100 feet of depth. The approximate temperature of water at depths greater than 60 feet can be calculated by the following formula: Temperature = 9.1°C + 0.009°C per foot (for each foot of depth below 60 feet).

WATER-QUALITY CONTROL

One of the significant causes of water-quality deterioration is the addition of inorganic materials to the water. Other than effluent from some sewage-treatment plants, such additions often occur on a small scale and usually as a side effect to some other activity. Agriculture fertilizers are spread on lawns and golf courses. Chlorides are spread on roads and highways. Septic tanks are used where other sewage facilities are not available. The intended effect of these activities is something other than the destruction of water quality. The final result, however, is that some of the inorganic materials find their way to streams, lakes and ground-water reserviors and the water's quality slowly deteriorates. The change is often undramatic and may continue for years before a serious water problem develops. By then, simple solutions may be impossible. As an example, one of the limiting factors for aquatic plant growth in many lakes is the phosphate ion. When the concentration of this ion reaches a critical value, accelerated plant growth occurs. Although plants use the phosphate ion in the growing process, the ion is again returned to the water when the plants die and decay. Thus, once the ion is present, natural conditions are not likely to remove it. The only method of removal may be the dredging of accumulated plant debris and the pumping of ground water to dilute or flush the lake water—an expensive process. Preventive practices usually are the simplest solution. Thus, management is the prime aspect in maintaining good water quality in Oakland County.

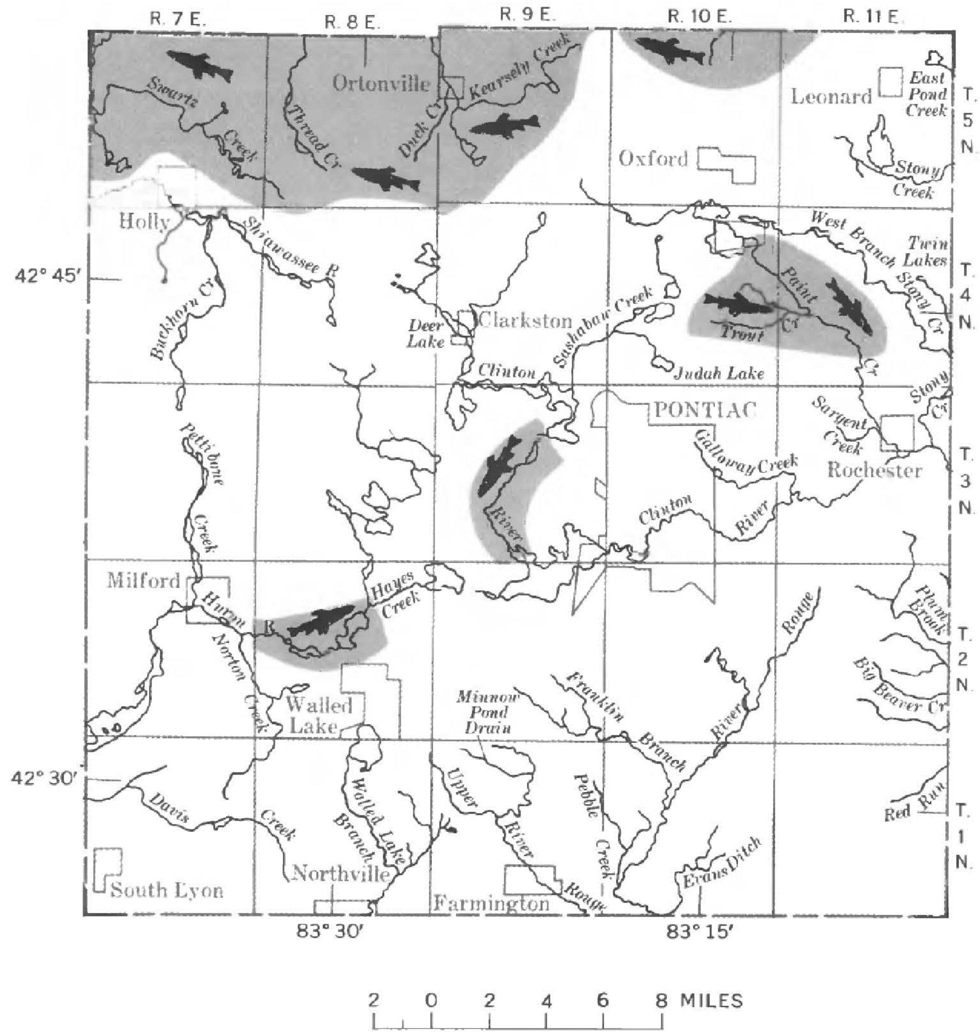
As stated previously, most water in the county, as of 1968, is good. The proposed standards for surface water (table 14) set forth by the State of Michigan are an important step towards assurance of good water in the future.

The most restrictive standards for quality control are those for domestic water supplies and for fish, wildlife, and other aquatic life. Included in these classifications are all natural lakes, as well



as all impoundments with public beaches. They are to be protected for total body contact; all other water is to be protected for partial contact. In addition, all water is to be protected for intolerant, warm-water fish and several areas (fig. 86) are to be protected for intolerant, cold-water fish.

Strict adherence to the proposed water-quality control standards by all people probably will be the one thing that will be of most benefit to the water resources in Oakland County. In the not too distant future, most of the county will have access to Detroit's water-supply system and availability of water for domestic and public supplies will not be a major problem. However, water



Water in some areas is protected for trout. FIG. 86

for recreation and sports will be in greater demand. If an all-out effort is not made toward water-quality control, the amount of usable water in lakes and streams will diminish.

9. The Water Resources Picture

A REVIEW—A LOOK AHEAD

In 1970, there will be about 850,000 people living in Oakland County, and they will use about 100 million gallons of water per day. Thirty years later, the population will have increased to nearly 1,500,000 and daily water use will be about 200 million gallons. Water from the Great Lakes, through the Detroit water system, will supply most of these needs. However, water from local sources will continue to be of importance to many users for water supply, waste dilution, recreation, and esthetics.

As shown in the preceding pages, water resources presently are available to most of Oakland County in sufficient quantities to meet all but the most demanding needs. Ground water can be obtained in much of the county at rates of at least 50 gpm and in many areas at rates of more than 400 gpm. Streams discharge water from the county at an average annual rate of about 575 cfs. The available supplies are large; however, to assure that these resources will continue in abundance and make possible the optimum growth and economic development of the county, consideration of certain aspects regarding the resources are essential. These include:

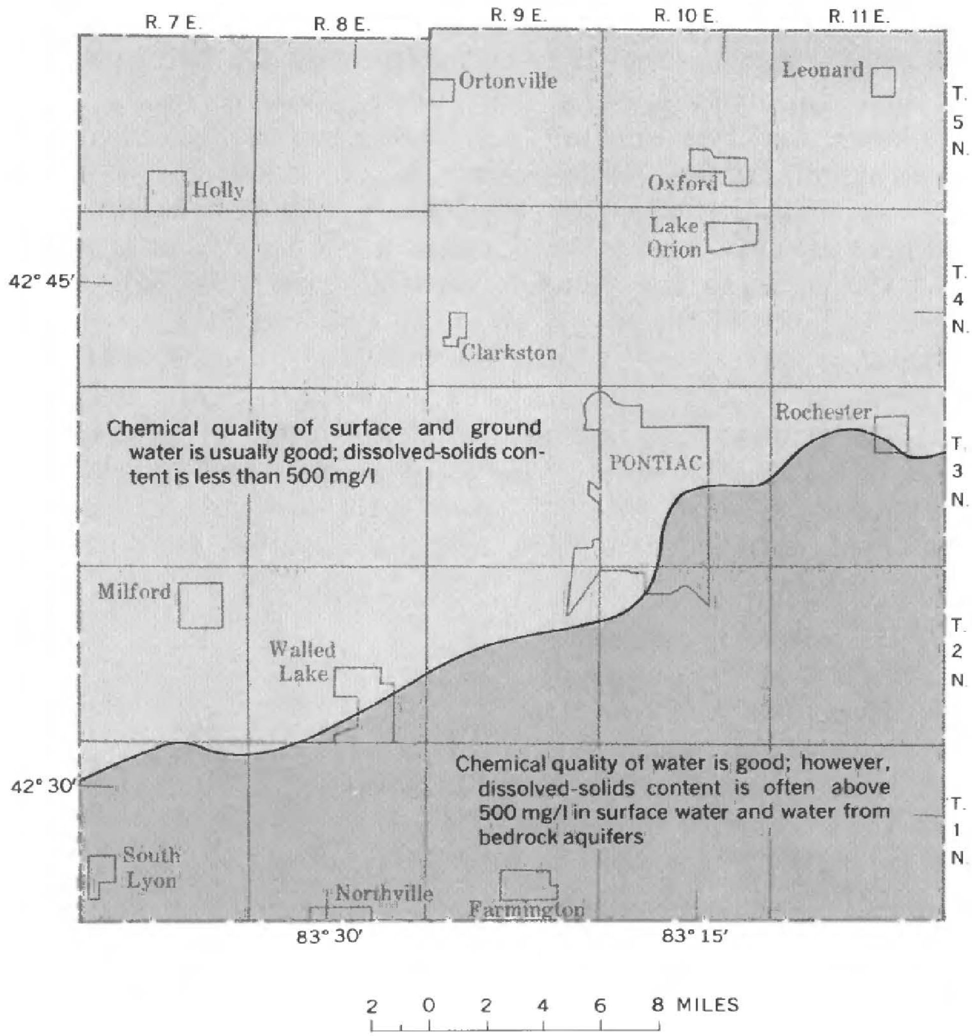
1. Water-quality control,
2. Lake-level improvement,
3. Streamflow augmentation,
4. Flood-plain management,
5. Redefinition of ground-water reservoirs,
6. Use of water from Detroit, and
7. Collection and analysis of basic information.

In the sections that follow there is provided a look, in retrospect, at the major findings presented in this report. Also provided are discussions of some management techniques and areas which require further investigation. These discussions will aid the water manager in his evaluation of the above items in the water-resources picture.

Water-quality control

Water must be of good quality to be usable. In 1968 water in most of the county, if biological aspects are excluded, was of good quality. The concentration of chemical constituents in some lakes, streams, and bedrock aquifers in the southern part of the county exceeded acceptable standards (fig. 87) although not seriously so. In general, the poorer quality water in lakes and streams was found to be in areas that are highly urbanized.

Water-quality control is a subject that should be the concern of everyone, in groups or as individuals. In the preceding chapter certain standards have been set forth to assure good water quality. If these standards are not violated, water in the county should



Good quality water is common in the northern part of the county. FIG. 87

continue to maintain its present good quality—in some areas it will improve. Concerned agencies or groups can readily spot major violations of the standards and with properly enforced control bring them to a halt before serious damage is done. Minor violations, however, which often are unintended, are not easily detected or controlled. In fact, control of some violations will never be possible unless individuals take upon themselves the duty of safe-guarding water resources. Destruction of water quality often is an accumulative process of undramatic stature. Because of this, detection of the early stages of the process may not be possible unless a sound water-quality monitoring program is established. Continuous collection of basic quality information will provide the framework around which a good-water program can exist. Strict water-quality control may be the principal link to plentiful water in the future.

New techniques in color and infrared stereo areal photography may be employed to provide a method of monitoring and differentiating water of different chemical and physical properties within lakes and streams. Because of the numerous lakes in Oakland County, these methods may be the only way to economically appraise this valuable resource. Utilization of photographic techniques also could provide further insight into the interrelationships between surface and ground water. That is, it may be possible to discern areas where ground water in entering a lake or stream and to estimate the rate at which it is entering. From this information, a more definitive analysis of the water resources and the environment in which they occur could be made. The first such photographic reconnaissance would represent conditions as they existed at that time. In the future, additional reconnaissances could be made and, when compared with earlier photos, could be used to evaluate changes that are occurring. Such comparative studies would have significant value in defining the effects of urbanization and pollution on lakes and streams, as well as other, perhaps more gradual changes in these resources.

Lake-level improvement

Lakes are a valuable asset to Oakland County. For them to remain in a desirable and usable condition, maintenance of suitable lake levels, in addition to water-quality control, are essential. Stabilization of lake levels is provided for in Public Act 194 of 1939, as amended. Under this act, legal lake levels can be established and methods most suitable to the situation can be used to maintain the lakes at their legal level. By the end of 1968, three methods were successfully being used for lake-level restoration in Oakland County. These are: (1) control dams on outlets, (2) pumped water from nearby streams or lakes, and (3) pumped water from the ground. These methods may be used with similar success on other lakes.

Before a lake-level restoration project is attempted, a careful study should be made of the geologic and hydrologic conditions in the area of the lake. Basic information on ground-water aquifers and water levels, streamflow, lake levels, and water quality, should be collected and analyzed to determine the feasibility of a restoration project. Then if the project is begun, data collection should be continued so that changes in the hydrologic regimen can be identified. Careful observation of trends in both ground and surface-water levels is the only way to reliably determine the effects of a lake-level improvement project. The results obtained from such observations will be of great importance in determining the feasibility of future projects of this type.

Streamflow augmentation

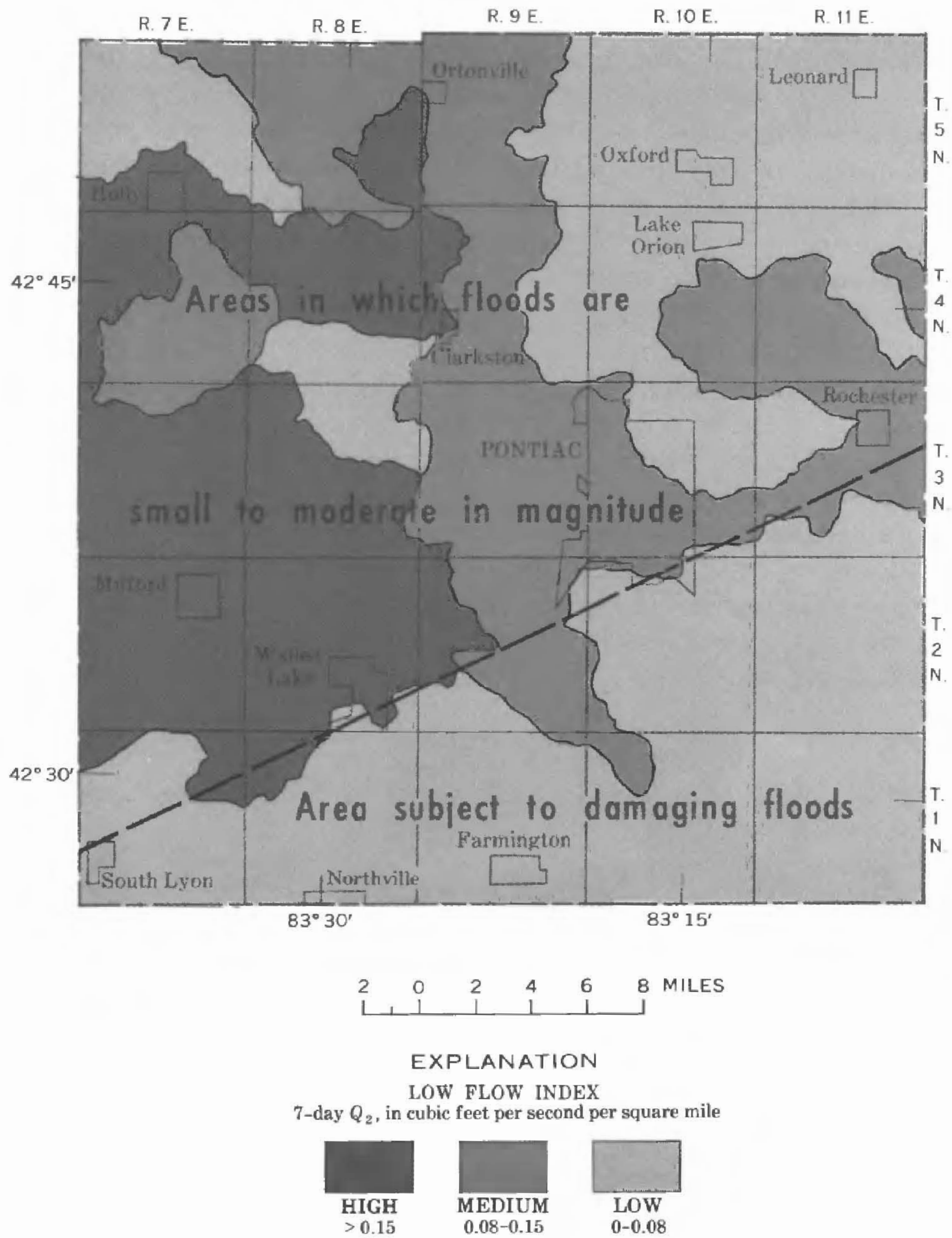
The headwaters of five major river systems rise in Oakland County. These systems radiate in diverse directions from the central part of the county and discharge across each of its sides. Because of this situation, drainage basins are small and runoff is generally inadequate for major water-development projects.

Streamflow varies widely from day-to-day and year-to-year. In the southeastern part of the county these variations are greatest, resulting in frequent flooding and lower base flows (fig. 88). Elsewhere the extremes of flow are moderated somewhat as flood waters are held in temporary storage in lakes and other depressions. Also, in areas of more permeable soil, precipitation infiltrates more readily into the ground. This temporarily stored water later serves to maintain the base flow of streams in these areas.

The flow of streams is variable; thus, the usefulness of streams is often limited—their adequacy for water supply is dependent upon their low-flow characteristics. Most streams in the county recede to undesirably low flows; however, this situation often can be remedied by construction of storage reservoirs. Water from periods of high streamflow can then be captured and utilized to augment low flows during dry periods. The benefits which may be derived from reservoir construction can be evaluated from draft-storage frequency relationships developed for this report. These relationships will provide the water manager with a basis for determining storage requirements for an intended use and for defining the potential of a stream for water supply.

Small reservoirs, holding 1,000 to 3,500 acre-ft of water, can be built at several locations in the county. An inventory of 21 possible sites showed a storage potential of as much as 60,000 acre-ft of water.

Reservoirs, in addition to supplying water for low-flow augmentation, can serve as catchments to reduce floods and lessen flood damages. Other benefits might include recreational uses, improved property values, esthetics, and water supply.



Streamflow variation is greatest in the southeastern part of the county—sustained flows are lower than in most other areas and this part of the county is subject to more severe flooding. FIG. 88

Flood-plain management

Flood plains, with good management and development, can provide significant benefits. These plains can be reserved as "open space" by state, county, or other local governmental agencies.

Such open space can be utilized for parks, parking lots, and recreational facilities during most of the year. Only during periods of flooding, which commonly occur during the spring months, would the plains be unusable. When flooding does occur, evacuation would be easy and property damage would be negligible. In contrast, where flood plains are highly populated there may be severe property damage and possible loss of life. The magnitude and frequency of occurrence of floods are greatest in the southeastern part of the county (fig. 88). Elsewhere, flooding, although not uncommon, is not a serious problem.

Some parts of flood plains can be developed for flood-safe commercial and industrial uses with good management and construction techniques. Maximum probable water heights of future floods can be determined from past records; this data can be used to guide construction of new structures and to provide corrective measures on existing structures. In some cases, the lower parts of new or existing structures can be permanently closed and waterproofed to seal out floodwaters. In other cases, structures can be built on stilts and the lower level used for parking (fig. 89). In

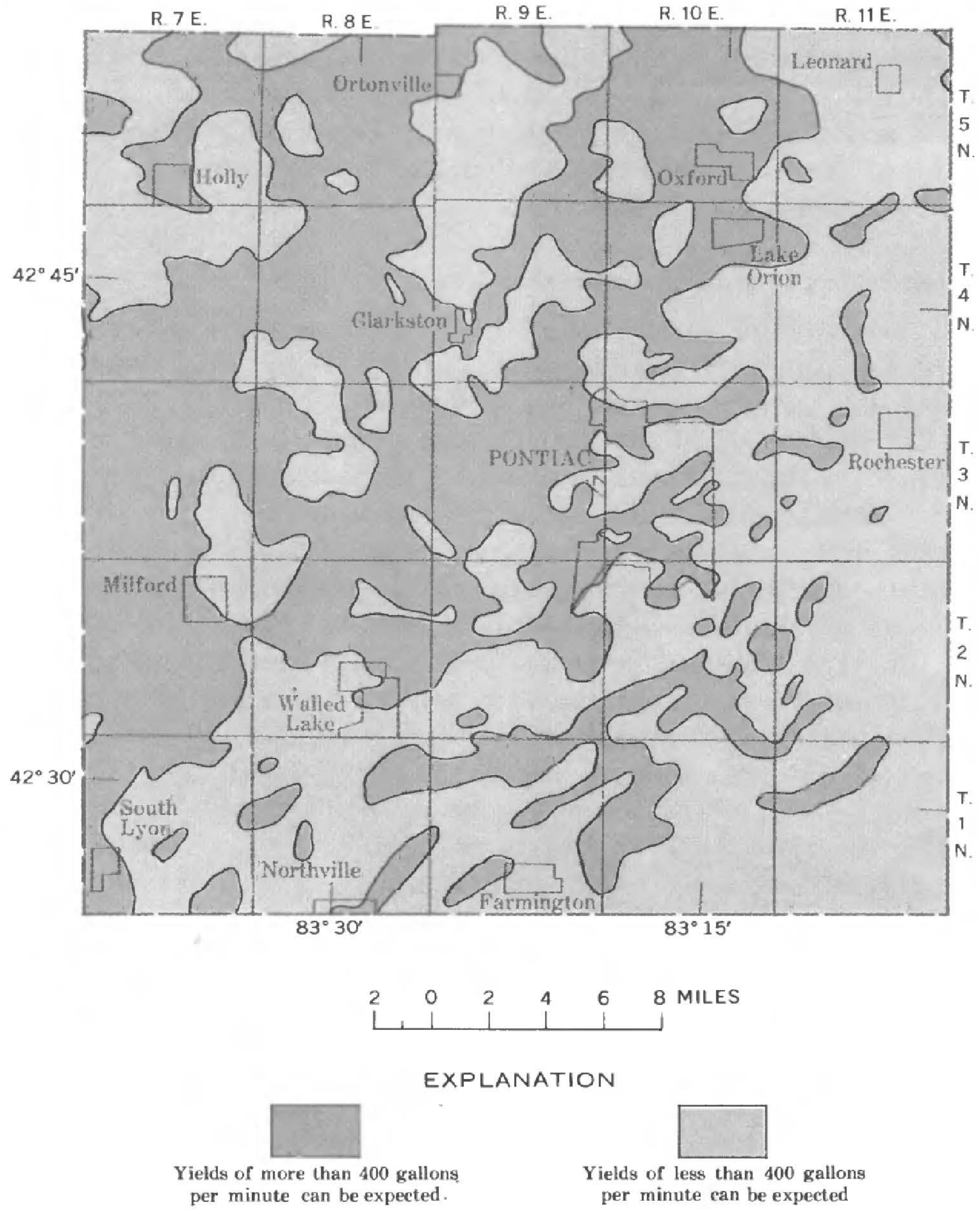
Structure built on stilts reduces possibility of damage by flood water. Notice high-water marks left by stream in flood stage on building supports in right center of photograph. FIG. 89

either case, the structures must be able to withstand the pressures exerted by water under flood conditions. An important consideration for any type of flood-plain construction is that it is properly guided and controlled. It must be recognized that utilization of the flood plain may restrict the flow of water and thus increase the heights of future flood.

Redefinition of ground-water reservoirs

The availability of ground water in Oakland County varies greatly from area to area and with depth. Some wells yield more than 400 gpm, some yield less, and some are dry (fig. 90). These differences in yield are attributable primarily to differences in rock lithologies. Thus, to obtain the best possible picture of ground-water availability, accurate definition of the ground-water reservoirs is necessary. Toward this end, data for many wells were analyzed during the study for the present report. From these analyses, potential yields were defined for 50-foot intervals of depth. The resultant reservoir definition is an accurate accounting based on available data. However, since a new law became effective in 1967 requiring well drillers to submit logs or lithologic logs of all new wells to the State of Michigan, new data on ground-water reservoirs have been accumulating at a rapid rate. Within a short time, it may be necessary to reevaluate the data and redefine the reservoirs in order to have as accurate and as current a picture of the ground-water situation as data permit.

Automatic data processing was used to analyze the basic ground-water information for this report. Information on more than 1,200 wells was processed by use of computers. By this method information could be analyzed using a variety of techniques to assure the best possible interpretation of the information. An added benefit in the use of automatic data processing lies in the fact that data, once prepared for processing, is always available for retrieval and reanalysis. In addition, new data can be readily added to the original stored information; thus, the ground-water picture for the entire county can be reevaluated and made current with a minimum expenditure of time and money. As an example, since the last evaluation of the data, information on another 500 or more wells has become available. These data, when added to the original data, could provide a more detailed definition of the aquifer index maps presented in this report. Manual manipulation of the data would be a long process; whereas, use of the computer is a relatively short and easy procedure.



Wells in some areas yield more than 400 gallons per minute; wells in other areas yield less. FIG. 90

Use of water from Detroit

As shown in this report, much of Oakland County contains sufficient water to supply most needs; however, local heavy uses may deplete local supplies. When this occurs, other sources capable of producing large supplies of good water may be sought. Such a source, the Detroit water system, is rapidly becoming available and by 1980 should be within reach of most areas in the county.

In 1969, the Detroit system supplied more than 80 percent of the water for large domestic and industrial supplies in the southeast part of the county. This system is capable of providing a reliable and abundant supply of good quality water. Whether or not a changeover to this system in other parts of the county is desirable must be based on economic, political, and legal factors which differ for each community or user. Local sources may be more economical for some users for many years. However, the fact that water is available from the Detroit system is assurance of future dependable water resources.

Collection and analysis of basic information

Further assurance that the county's water resources will serve the future can be provided by a well-designed, continuous program of basic data collection and analysis. Primarily, such a program involves the collection of new information as it is related to, and described under, the six major aspects of water discussed previously. This type of program will provide an up-to-date bank of information and will point out changes that may be occurring in the water regimen. The information gained will provide the basis for sound management decisions.

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