WATER RESOURCES ACTIVITIES

IN MICHIGAN, 1988

Compiled by T. J. Spicer

U.S. GEOLOGICAL SURVEY

Open-File Report 88-340

Prepared in cooperation with

State and Federal agencies

Lansing, Michigan
1988

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

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Foreword

For the past 88 years, the U.S. Geological Survey has collected data on the water resources of Michigan. During the winter of 1900-01, a Survey employee visited the State to measure the flow of streams, and to select sites for establishing 13 gaging stations. For the next quarter of a century the program remained small, and much of the Survey's work was related to municipal needs and water-power requirements. State agency cooperation in the data-collection effort began in 1930, and with it began the development of a close and unique Federal-State relationship. Although early programs were largely related to the flow of streams, subsequent interest resulted in the collection of ground-water and water-quality information, as well as interpretive studies of water resources locally and statewide. Support for the program has fluctuated throughout its existence, largely in response to economic conditions. During the early 1980's, due to a number of factors, the program decreased. Improved economic conditions during the past two years, and strong support from governmental units, universities, and industry, seems to have reversed the trend. Prospects for the future look bright.

T. Ray Cummings

District Chief

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IN MICHIGAN

1988

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INTRODUCTION

This report was compiled to provide information on the water resources activities of the U.S. Geological Survey in Michigan.

The U.S. Geological Survey

The U.S. Geological Survey (USGS) was established by an act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geological structure, mineral resources, and products of national domain". An integral part of that original mission includes publishing and disseminating the earth-science information needed to understand, plan the use of, and manage the Nation's energy, land, mineral, and water resources.

Since 1879, the research and fact-finding role of the USGS has grown and been modified to meet the changing needs of the Nation it serves. As part of that evolution, the USGS has become the Federal Government's largest earth-science research agency, the Nation's largest civilian mapmaking agency, the primary source of data on the Nation's surface- and ground-water resources, and the employer of the largest number of professional earth scientists. Today's programs serve a diversity of needs and users.

Along with its continuing commitment to meet the growing and changing earth-science needs of the Nation, the USGS remains dedicated to its original mission to collect, analyze, interpret, publish, and disseminate unbiased information about the natural resources of the Nation. One of the Nation's

most important natural resources is water.

Water Resources Division's Mission and Program

The mission of the Water Resources Division is to provide the hydrologic information and understanding needed for the optimum utilization and management of the Nation's water resources for the overall benefit of the people of the United States. This is accomplished, in large part, through cooperation with other Federal and non-Federal agencies by:

Collecting, on a systematic basis, data needed for the continuing determination and evaluation of the quantity, quality, and use of the Nation's water resources.

Conducting analytical and interpretive water-resource appraisals describing the occurrence, the availability, and the physical, chemical, and biological characteristics of surface and ground water.

Conducting supportive basic and problem-oriented research in hydraulics, hydrology, and related fields of science to improve the scientific basis for investigations and measurement techniques, and to understand hydrologic systems sufficiently well to quantitatively predict their response to stress, either natural or manmade.

Disseminating water data and results of these investigations and research through reports, maps, computerized information services, and other forms of public releases.

Coordinating the activities of Federal agencies in the acquisition of water data for streams, lakes, reservoirs, estuaries, and ground waters.

Providing scientific and technical assistance in hydrology to other Federal agencies, to State and local agencies, to licensees of the Federal Energy Regulatory Commission, and to international agencies on behalf of the Department of State.

WATER RESOURCES ACTIVITIES IN MICHIGAN

The water-resources program in Michigan is, in part, planned and funded with local and state agencies through cooperative programs. If a proposed project is mutually advantageous to the Geological Survey and an agency, the Geological Survey may enter into a formal cooperative agreement to collect needed information. In most cases, costs are shared equally between the Geological Survey and the cooperator. These cooperative programs are reviewed annually, and, thus, are responsive to the current needs in the state. In Michigan, the program is conducted in cooperation with the following agencies or units of government:

Michigan Department of Natural Resources (MDNR)
  Geological Survey Division
  Land and Water Management Division
Michigan Department of Transportation
Michigan Department of Agriculture

City of Ann Arbor
City of Battle Creek
City of Cadillac
City of Clare
City of Coldwater
Village of Elsie
City of Flint
Genesee County
Huron County
Huron-Clinton Metropolitan Authority
Imlay City
City of Kalamazoo
Kalamazoo County
City of Lansing
Macomb County
City of Mason
City of Negaunee
City of Norway
Oakland County Drain Commission
Otsego County Road Commission
City of Portage
City of Ypsilanti
Wayne County

The U.S. Geological Survey also performs work for other Federal agencies, the cost of which is borne by the requesting agency. Currently work is underway for the following:

U.S. Air Force

U.S. Environmental Protection Agency

U.S. Army Corps of Engineers

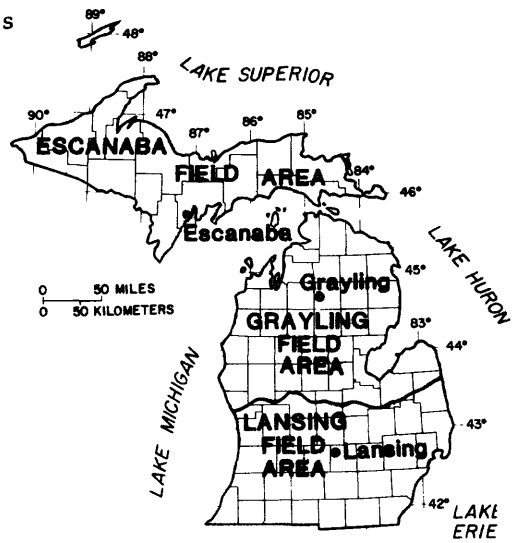
U.S. Coast Guard

National Park Service

District Office Organization

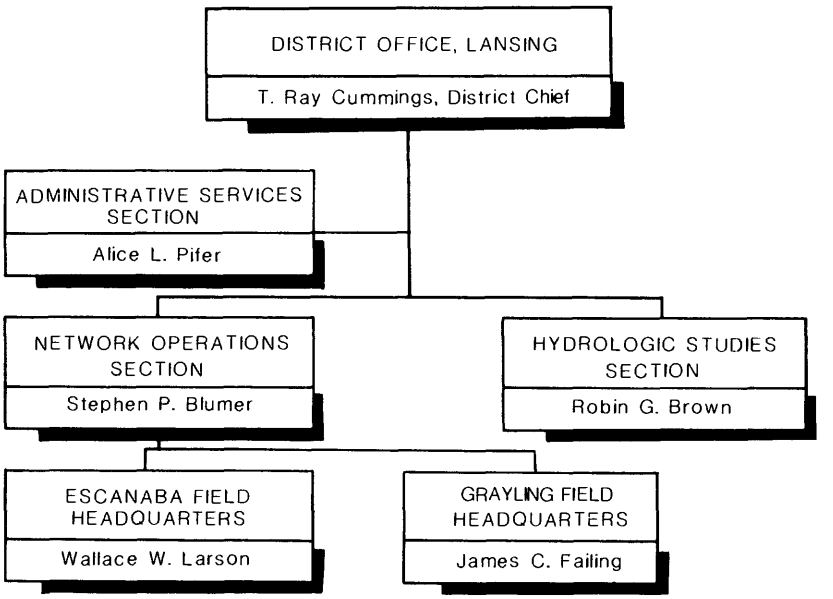
The Michigan District office of the U.S. Geological Survey's Water Resources Division is located in Lansing, Michigan; field headquarters are located in Escanaba and Grayling (fig. 1).

Figure 1.--U.S. Geological Survey Water Resources Division offices in Michigan.



The District has 34 employees. The employees consist of professional hydrologists that represent a variety of scientific backgrounds, including engineering, chemistry, geology, and mathematics. The hydrologists are supported by an experienced staff of hydrologic and illustrations technicians.

District operations are grouped into three sections--administrative services, hydrologic studies, and network operations (fig. 2). The function and major purpose of each section are described in the following paragraphs.



Office	Phone	Address
Lansing	(517) 377-1608	6520 Mercantile Way, Suite 5 Lansing, Michigan 48911
Escanaba	(906) 786-0714	205 State Office Building Escanaba, Michigan 49829
Grayling	(517) 348-8291	P.O. Box 485 Grayling, Michigan 49738

Figure 2.--Michigan District organization chart and office addresses.

Administrative Services Section

This section provides administrative support to the Michigan District office and is responsible for:

- Budget formulation and execution,
- Preparation of financial summaries of cooperative programs,
- Assistance in personnel management of the District,
- Maintenance of all administratie files, vehicle control, and property records,
- Insuring that staff members are familiar with regulations pertaining to administrative functions of the Geological Survey.

Hydrologic Studies Section

This section analyzes and interprets hydrologic data as they relate to the problems of water-resources management and development. Present activities include studies of surface- and ground-water conditions in specified areas, investigations of the chemical, physical, and biological properties of water, studies related to ground-water contamination, land-use studies, and miscellaneous investigations to assist community and state planning agencies in management decisions. This section also conducts geohydrologic investigations to determine availability, quantity, quality, and use of water within the state; these investigations generally are of short duration, areal in nature, and require a thorough understanding of hydrology.

In addition to the above work, reports on the results of geohydrologic investigations are processed within this section prior to publication. Several different publication outlets are used to accommodate the diversity of subject matter. Most reports are published in a formal series of the U.S. Geological Survey or cooperating agency.

Network Operations Section

This section is responsible for the collection and publication of hydrologic data including records of stream discharge, ground-water levels, and quality of water. Data are collected as part of a statewide network, and

are used in projects designed to appraise the water resources of the state. Reports containing these data are published annually. Hydrologic data are also stored in the Survey's computer storage file called WATSTORE. Surface-water, ground-water, and quality of water data are available for tabular presentation, statistical manipulation, or graphical display. The thousands of records collected each year provide indispensable information on stream stage, discharge, sediment concentration and load, chemical quality of water, precipitation, and ground-water levels.

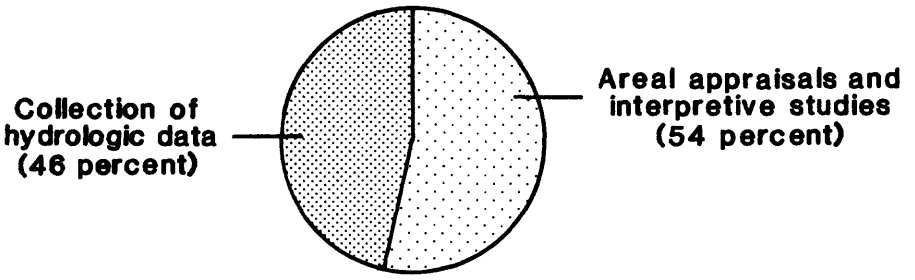
Regional Aquifer Systems Analysis Office

In addition to activities described above, a Regional Aquifer Systems Analysis (RASA) office has been established in Lansing to conduct a 5-year study of the major aquifers in the Michigan Basin, and to define the occurrence of saline waters that underlie fresh waters throughout the Lower Peninsula. R. J. Mandle, the RASA project chief, is supported by a staff of two hydrologists headquartered at the Lansing District office. Mr. Mandle can be reached at (517) 377-1608.

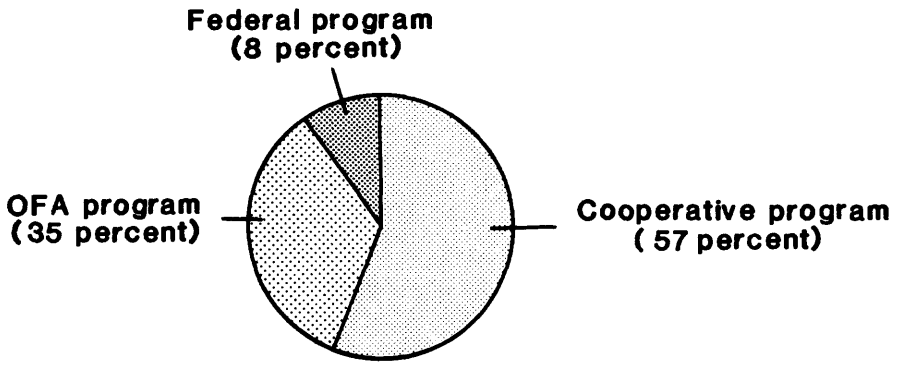
Types of Funding

Funding for the water-resources programs falls into two broad categories. In the 1988 Fiscal year, about half of the program is composed of hydrologic-data collection--operation of surface-water gaging stations, measurement of ground-water levels, and collection of samples for chemical and physical analysis. These data are largely collected on a routine basis at fixed sites. Periods of data collection vary from several months to many years. Areal appraisals and interpretive studies, which constitute slightly more than a third of the program, consist of a variety of investigations. Some may be statewide in character, others address very localized problems. Such studies may range from complex, highly technical mathematical models of

surface-water or ground-water systems, to reconnaissance appraisals of water resources.



The water-resources program is supported by funds or services provided by State and local agencies. As part of the Federal-State Cooperative program, State and local funds are matched on a 50-50 basis by funds appropriated to the Geological Survey by Congress for that purpose. Other Federal agencies (OFA) also support data collection and studies; direct appropriations to the Geological Survey (Federal program) are also available. In Fiscal year 1988, the financial support for work in Michigan amounts to about $2,400,000. It is distributed as follows:



INFORMATION IN THIS REPORT

This report consists of four sections: (1) current projects, (2) hydrologic conditions, (3) hydrologic-data stations, and (4) sources of information. The current-projects section contains information concerning the status of all projects that are presently active. The section on hydrologic-data stations gives locations where surface-water and ground water-data are collected and the types of records available. The hydrologic-conditions section provides general statewide information on water resources. The sources-of-information section contains a listing of publications resulting from work done by the Geological Survey and cooperating organizations.

(PAGE 11 FOLLOWS)

CURRENT PROJECTS

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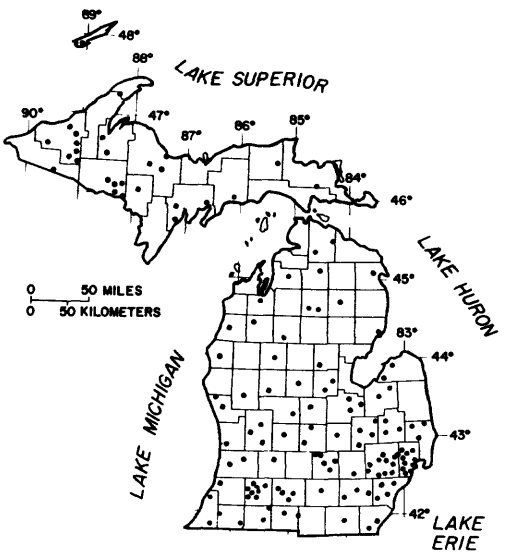
SURFACE-WATER STATIONS



PROJECT NO. - MI 001

PROBLEM: Surface-water information is needed for purposes of surveillance, planning, design, hazard warning, water supply, hydroelectric power, flood control, irrigation, bridge and culvert design, wildlife management, pollution abatement, flood-plain management, and water-resources development. To provide this information, an appropriate data base is necessary.

OBJECTIVES: (1) Collect surface-water data sufficient to satisfy needs for current-purpose uses, such as assessment of water resources, operation of reservoirs or industries, forecasting, disposal of wastes and pollution controls, discharge data to accompany water-quality measurements, compact and legal requirements, and research or special studies and (2) collect data necessary for analytical studies to define the statistical properties of, and trends in, the occurrence of water in streams, lakes, and bays.

APPROACH: Standard methods of data collection are used as described in the series, "Techniques of Water Resources Investigations of the United States Geological Survey." Partial-record gaging are used instead of complete-record gaging where it serves the required purpose.

RESULTS LAST YEAR: Data were collected at, and published for, the number of stations given in the following table:

Station classification	Number of stations
Stream stations	223
Continuous record:	
Discharge and stage	136
Stage only	1
Partial record:	
Peak (maximum) flow only	52
Low (minimum) flow only	33
Peak and low flow	1
Lake and reservoir stations	29
Stage and contents	5
Stage only	24
Total	252

PLANS THIS YEAR: Gaging-station network will continue in operation. New stations will be constructed as projects develop and existing stations will be relocated, reequipped, and modernized to improve quality of record, or discontinued to meet changing needs of projects and cooperators and to fulfill network-evaluation requirements.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

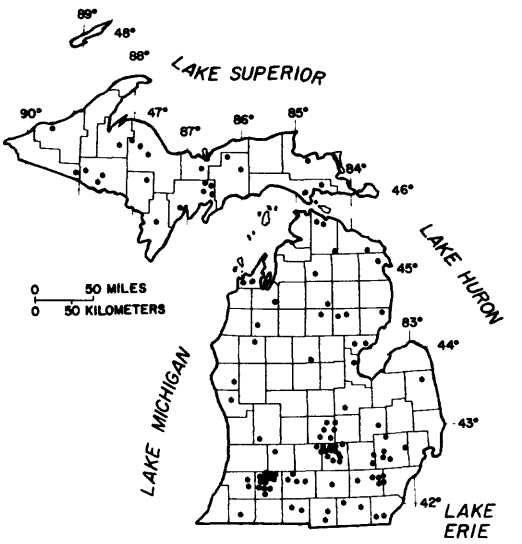
PROJECT CHIEF: Stephen P. Blumer

PERIOD OF PROJECT: Continuous

COOPERATING AGENCIES:
Michigan Department of Agriculture
Michigan Department of Natural Resources
Michigan Department of Transportation
Local units of government
U.S. Army Corps of Engineers

REPORTS COMPLETED: Data included in U.S. Geological Survey annual hydrologic-data report "Water Resources Data for Michigan".

GROUND-WATER STATIONS



PROJECT NO. - MI 002

PROBLEM: Long-term water-level records are needed to evaluate the effects of climatic variations on the recharge to and discharge from ground-water systems, to provide a data base from which to measure the effects of development, to assist in the prediction of future supplies, and to provide data for management of the resource.

OBJECTIVES: (1) Collect sufficient water-level data to provide a minimum long-term data base so that the general response of the hydrologic system to natural climatic variations and induced stresses is known and potential problems can be defined early enough to allow proper planning and management, and (2) provide a data base against which the short-term records acquired in areal studies can be analyzed. This analysis must provide an assessment of the ground-water resource, allow prediction of future conditions, detect and define pollution and supply problems, and provide the data base necessary for management of the resource.

APPROACH: Evaluation of regional geology allows broad, general definition of aquifer systems and their boundary conditions. Within this framework and with some knowledge of stress on the system in time and space and of the hydrologic properties of the aquifers, a decision can be made on the most advantageous locations for observation of long-term system behavior. This network can be refined as records become available and detailed areal studies of the ground-water system more closely define the aquifers, their properties, and the stresses to which they are subjected.

RESULTS LAST YEAR: Water levels were measured in, and published for, the number of wells given in the following table:

Station classification	Number of stations
Observation wells:	
Recording	58
Nonrecording	53
Total	111

PLANS THIS YEAR: Continue to operate network and evaluate station requirements for most effective network.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

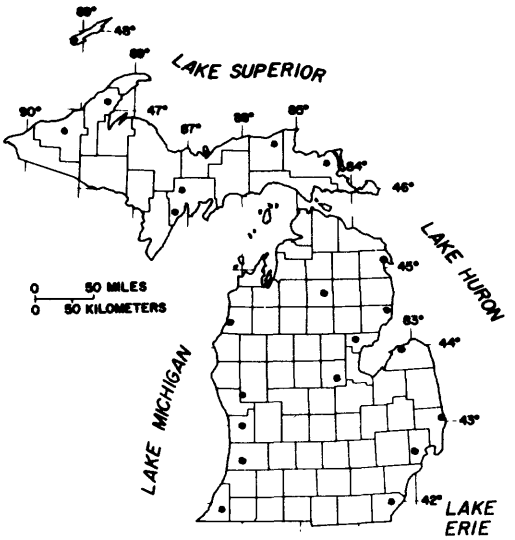
PROJECT CHIEF: Gary C. Huffman

PERIOD OF PROJECT: Continuous

COOPERATING AGENCIES:
Michigan Department of Natural Resources
Local units of government
Other Federal agencies

REPORTS COMPLETED: Data included in U.S. Geological Survey annual hydrologic-data reports "Water Resources Data for Michigan" and "Ground-Water Data for Michigan".

WATER-QUALITY STATIONS



PROJECT NO. - MI 003

PROBLEM: Water-resource planning and water-quality assessment require a nation-wide base of information. To obtain this information, the chemical and physical quality of surface water and ground water must be defined and monitored. In addition, long-term sampling stations representing the numerous hydrological accounting units in Michigan must be operated to meet the objectives of the National Stream Quality Accounting Network (NASQAN).

OBJECTIVES: (1) Provide current and long-term data sufficient to describe water-quality conditions of surface and ground water in Michigan that are needed by planning and management agencies, (2) improve the water-quality data base in Michigan so that future assessments can be more effective, (3) operate the National Stream Quality Accounting Network, and (4) collect samples from wells throughout the state to establish a base against which future water-quality data can be compared and against which the effect of new and additional stresses can be evaluated.

APPROACH: Operate a network of water-quality stations to meet the needs of the State of Michigan and the objectives of national programs. Standard methods of data collection will be used.

RESULTS LAST YEAR: Data were collected at, and published for, the number of data types given in the following table:

Surface water:

Data classification	Number of sites
Physical data (daily frequency):	
Water temperature	1
Specific conductance	0
Chemical data:	
Inorganic constituents	19
Organic constituents	1
Pesticides	1
Radiochemical data	2
Biological data	19

Ground water:

Physical data:	
Water temperature	6
Specific conductance	23
pH	23
Chemical data:	
Inorganic constituents	23
Organic constituents	23
Radiochemical data	23

Several types of data were collected at some sites.

PLANS THIS YEAR: Continue network in operation. Number of collection sites, frequency of data collection, and parameters to be measured will be adjusted if and as necessary, in consultation with cooperating agencies, to keep network in line with current needs for water-quality data.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

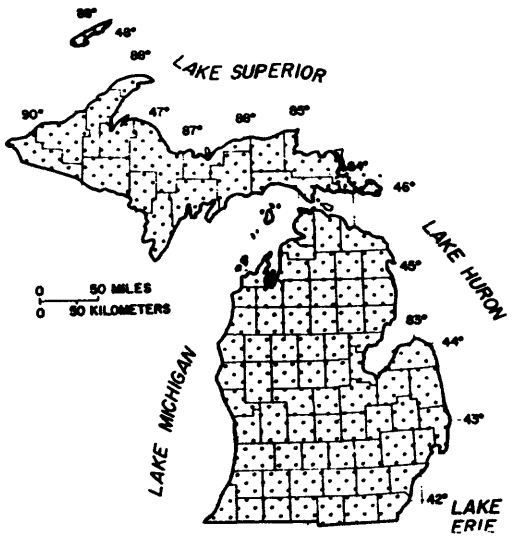
PROJECT CHIEF: Stephen P. Blumer

PERIOD OF PROJECT: Continuous

COOPERATING AGENCIES: Michigan Department of Natural Resources

REPORTS COMPLETED: Data included in U.S. Geological Survey annual hydrologic-data reports "Water Resources Data for Michigan" and "Ground-Water Data for Michigan".

SEDIMENT STATIONS



PROJECT NO. - MI 004

PROBLEM: Water-resources planning and water-quality assessment require a nationwide base level of relatively standardized information. Sediment concentrations and discharges in rivers and streams must be defined and monitored.

OBJECTIVES: (1) Establish and operate a network of daily and periodic fluvial sediment stations to provide spatial and temporal averages and trends of sediment concentration, sediment discharge, and particle size of sediment being transported by streams. Define yields and transport characteristics for the principal drainage basins in the state, (2) contribute to a national bank of sediment data for use in broad federal planning and action programs, and (3) provide data for federal management of interstate and international waters.

RESULTS LAST YEAR: Sediment data were collected, analyzed and prepared for publication for several NASQAN and miscellaneous stream-measurement sites.

PLANS THIS YEAR: Sediment data will be collected at existing NASQAN stations and new stations will be established to meet the need of new projects.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

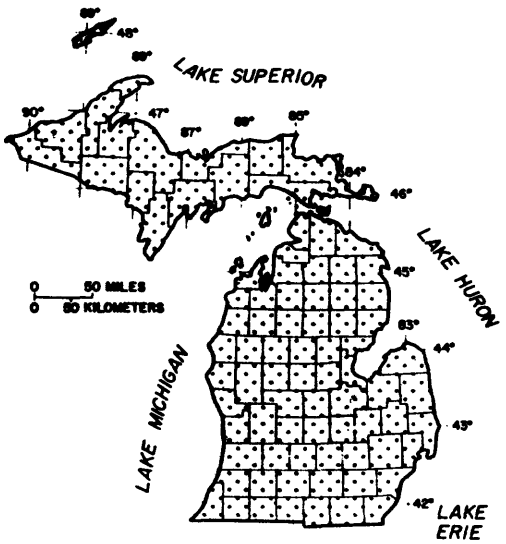
PROJECT CHIEF: Stephen P. Blumer

PERIOD OF PROJECT: Continuous

COOPERATING AGENCIES: Michigan Department of Natural Resources

REPORTS COMPLETED: Data included in U.S. Geological Survey annual hydrologic-data report "Water Resources Data for Michigan".

FLOOD INSURANCE STUDIES



PROJECT NO. - MI 006

PROBLEM: The National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 provide for the operation of a flood insurance program. The Federal Emergency Management Agency (FEMA) needs flood studies in selected areas to determine applicable flood insurance premium rates.

OBJECTIVE: To conduct the necessary hydrologic and hydraulic evaluations to define flood plains, and to present the results in an appropriate format.

APPROACH: To conduct the necessary evaluation or to conduct surveys by ground or photogrammetic methods. Determine flood-discharge frequency relationships using local historical information, gaging-station records, step-backwater models or by other acceptable methods and furnish the results in reports prepared to FEMA specifications.

RESULTS LAST YEAR: Hydrologic and hydraulic evaluations completed for Villages of Colon, Vernon, Northport, City of St. Louis, and Townships of Castleton, Lockport, Nottawa, Taymouth, and Victor.

PLANS THIS YEAR: No flood insurance studies currently being conducted.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

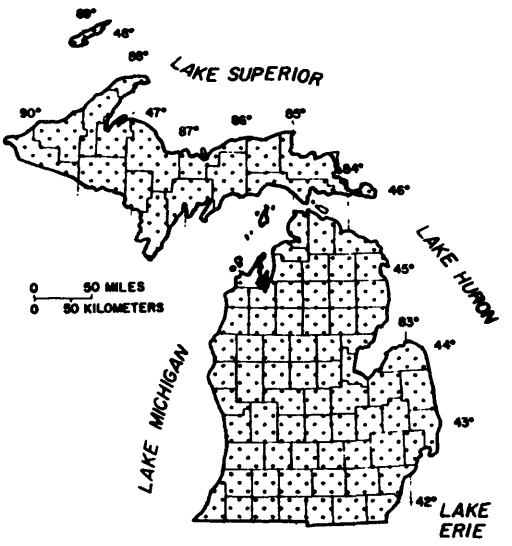
PROJECT CHIEF: David J. Holtschlag

PERIOD OF PROJECT: Continuous

COOPERATING AGENCIES: Federal Emergency Management Agency

REPORTS COMPLETED:
Flood insurance study, Village of Colon, MI
Flood insurance study, Village of Vernon, MI
Flood insurance study, Village of Northport, MI
Flood insurance study, City of St. Louis, MI
Flood insurance study, Township of Castleton, MI
Flood insurance study, Township of Lockport, MI
Flood insurance study, Township of Nottawa, MI
Flood insurance study, Township of Taymouth,MI
Flood insurance study, Township of Victor, MI

WATER USE



PROJECT NO. - MI 007

PROBLEM: Michigan waters are under stress from increasing demands for domestic, industrial, agricultural, and other uses, and from demands for greater protection of water quality. Competition for water dictates that available supplies are matched with uses most beneficial to the common good.

Water-user information for Michigan has been collected in the past for inclusion in the annual ground-water report and in miscellaneous reports of the Michigan Department of Natural Resources. There has been little standardization of data or of methods used in collecting the data. Standards of accuracy vary over a wide range. Because water-use data are being used increasingly for planning and making long-range forecasts, and in making estimates of water available from different sources, there is a need to coordinate efforts, systematize the approach to data collection, and develop standards of accuracy for the dissemination and use of these data.

OBJECTIVES: (1) Provide water-use information for the optimum utilization and management of the state's water resources for the overall benefit of the people of Michigan and the Nation. The system will be responsive to the data needs of local users, the Geological Survey, and other Federal agencies, (2) collect, store, and disseminate water-use data to complement data on availability and quality of the state's water resources, and (3) develop and operate a system to handle the data.

APPROACH: Responsibilities are divided between the State of Michigan and the U.S. Geological Survey to reflect the most efficient means of meeting the objectives of the program. Direction, management, and standards development to meet the National needs are the responsibility of the U.S. Geological Survey. Field activities for the acquisition and storage of the data are the primary responsibility of the State.

RESULTS LAST YEAR: Compiled data for estimated use of water in the United States, 1985. National Water Summary state article on water use was prepared.

PLANS THIS YEAR: Complete a public water supply data base. Develop framework for county level water-use data compilation. Re-inventory irrigators to update irrigation water use report.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

PROJECT CHIEF: Michael J. Sweat

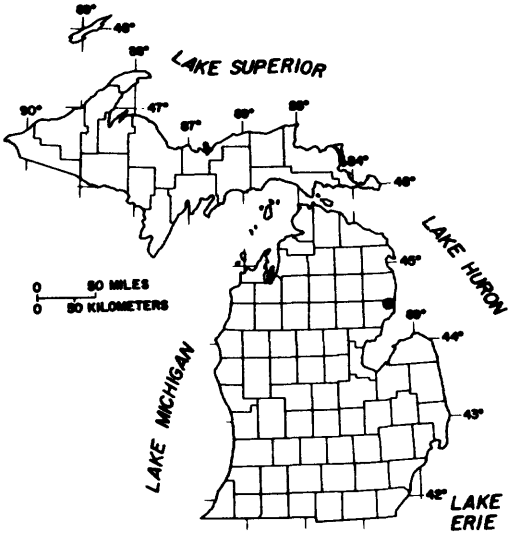
PERIOD OF PROJECT: Continuous

COOPERATING AGENCY: Michigan Department of Natural Resources

REPORTS IN PROGRESS: Revisions of reports on irrigation in Michigan and municipal water withdrawals have been started.

REPORTS PUBLISHED: (1) D. J. Bedell and R. L. Van Til, 1979, Irrigation in Michigan, 1977: Michigan Department of Natural Resources, Water Management Division; (2) D. J. Bedell, 1982, Municipal water withdrawals in Michigan, Michigan Department of Natural Resources, Water Management Division; (3) R. L. Van Til and G. Scott, 1986, Water use for thermoelectric power generation in Michigan: Michigan Department of Natural Resources, Engineering and Water Management Division.

GROUND-WATER STUDY OF
WURTSMITH AIR FORCE BASE, MICHIGAN



PROJECT NO. - MI 032

PROBLEM: Volatile hydrocarbons have been found at several places in the ground-water system at Wurtsmith Air Force Base. Continued study of newly detected problems is required to permit Air Force Base management to assess present remedial action and, if necessary, institute new action.

OBJECTIVES: (1) Determine the rate and direction of ground-water flow at Wurtsmith Air Force Base, (2) determine the extent and distribution of contaminants in the ground-water system, (3) investigate all suspected sources of ground-water contamination, including past and present landfill areas, (4) investigate sites for developing new Base water supplies, (5) refine previously developed mathematical ground-water flow model, (6) establish data base and statistically analyze historic data, and (7) conduct literature survey of ground-water sampling methods.

APPROACH: (1) Conduct soil gas surveys at sites where ground-water contamination is known or suspected, (2) install water-quality monitoring wells and collect samples of soil for chemical analysis at seven sites, (3) assemble and summarize literature on sampling techniques, and (4) statistically analyze historic ground-water quality data using techniques developed by WRD's Branch of Systems Analysis.

RESULTS LAST YEAR: Study of newly detected contamination was continued, and an examination of potentially hazardous waste sites begun as part of the Air Force's Installation Restoration Program. Created a data base for historic water-quality data. Literature survey completed.

PLANS THIS YEAR: Continue investigations of contamination of water by fuel substances in western part of the Base, and define plume associated with fire training area. Begin statistical analysis of water quality data. Prepare administrative report to the U.S. Air Force.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Northeastern Lower Peninsula, Michigan

PROJECT CHIEF: T. Ray Cummings

PERIOD OF PROJECT: April 1987 to September 1988

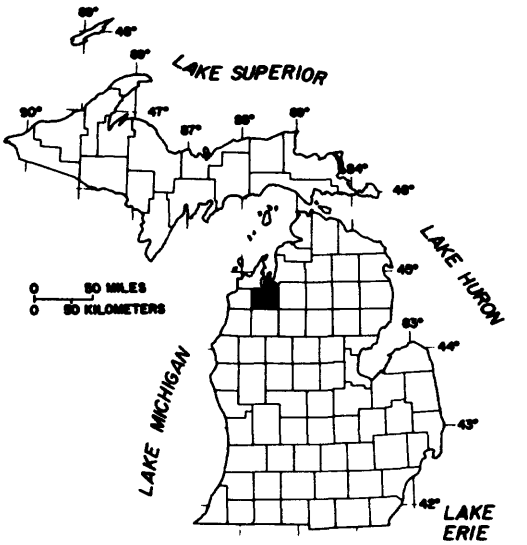
COOPERATING AGENCY: U.S. Air Force

REPORTS COMPLETED: J. R. Stark, T. R. Cummings, and F. R. Twenter, 1983, Ground-water contamination at Wurtsmith Air Force Base, Michigan: U.S. Geological Survey Water-Resources Investigations Report 83-4002.

T. R. Cummings and F. R. Twenter, 1986, Assessment of ground-water contamination at Wurtsmith Air Force Base, Michigan, 1982-85: U.S. Geological Survey Water-Resources Investigations Report 86-4188, 120 p., 3 pls., 55 figs.

REPORTS IN PROGRESS: Cummings, T. R., and Holtschlag, D. J., 1988, Installation Restoration Program, Phase III, Wurtsmith Air Force Base: U.S. Geological Survey Administrative Report.

WATER RESOURCES OF GRAND TRAVERSE COUNTY, MICHIGAN



PROJECT NO. - MI 040

PROBLEM: An increased demand for water by irrigators, municipalities, and industries is affecting economic development in parts of Grand Traverse County, the world's largest producer of cherries. Irrigation alone has increased by more than 300 percent since 1970. The effect of this expansion is unknown, and available information is inadequate to provide a basis for solving problems when they occur. Deteriorating ground-water quality at some places is likely related to use of fertilizer. Studies have shown that nitrate levels in heavily irrigated areas have made water unsuitable for domestic use.

OBJECTIVES: (1) Determine the quantity and quality of ground water and surface water, with particular attention to the use of water for irrigation, and the causes of contamination, (2) evaluate the chemical characteristics of precipitation and integrate this information into hydrologic assessments, (3) relate quality of ground water to land use, with emphasis on agricultural use, (4) relate, if possible, the transport of dissolved and sorbed substances and suspended sediment by streams to agricultural practices and land use, and (5) use mathematical models, where appropriate, to better understand the ground-water system.

APPROACH: (1) Evaluate available data contained in State, county, and USGS files, (2) make routine discharge measurements at 15 stream sites 10 to 12 times per year, at 10 miscellaneous sites three times per year, and at several sites as needed during high flow, (3) measure ground-water levels at about 50 sites and install twenty 4-inch, twenty-five 2-inch, and two 6-inch wells, (4) install recording rain gages at two sites, (5) collect water-quality data from about 250 wells, 15 lakes, and 25 streams, (6) measure quality of precipitation, (7) develop mathematical models for assessing local ground-water conditions, and (8) analyze and evaluate data; write report.

RESULTS LAST YEAR: All field data collected, and analysis begun.

PLANS THIS YEAR: Complete data analysis; write and publish Water-Resources Investigations Report.

HEADQUARTERS OFFICE: Lansing, Michigan.

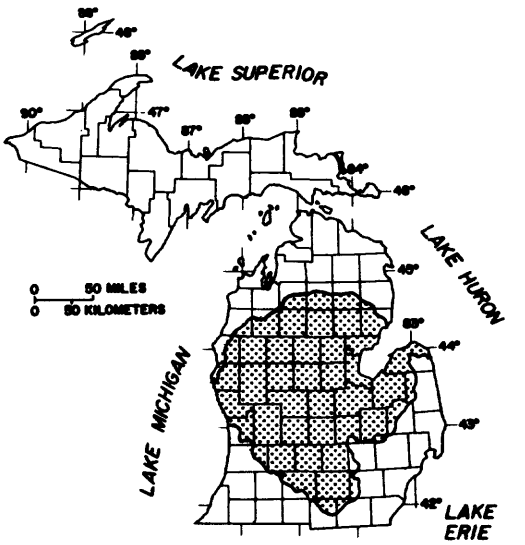
FIELD LOCATION: Northwest Lower Peninsula, Michigan

PROJECT CHIEF: Norman G. Grannemann

PERIOD OF PROJECT: May 1984 to August 1988

COOPERATING AGENCIES:
Michigan Department of Natural Resources
Grand Traverse County

MICHIGAN BASIN REGIONAL
AQUIFER SYSTEM ANALYSIS



PROJECT NO. - MI 041

PROBLEM: About half of Michigan's population depends on ground water as the source of domestic and public supply. The potential for development of supplies in large areas of glacial deposits and bedrock aquifers in the Lower Peninsula, however, is not well defined. Additionally, saline water underlies the freshwater aquifers over the entire extent at an indeterminate depth. Migration of saline water resulting from excessive pumping or drilling boreholes too near the transition from freshwater to saline water has caused abandonment of wells. The two primary bedrock aquifers, the Marshall and Saginaw Formations, are used extensively where they contain freshwater. In the Lansing area water levels are as much as 160 feet below prepumping levels. A better understanding of the hydrogeology and the occurrence of fresh and saline water is necessary for effective management of the region's ground-water resources.

OBJECTIVES: (1) Describe the geologic, hydrologic, and chemical quality characteristics of water-bearing rocks in the central part of the Michigan Basin, (2) delineate the vertical and areal extent of saline water and identify areas subject to saline-water contamination, (3) using computer models, simulate the three-dimensional movement of ground water through the aquifers under study, (4) relate ground-water chemistry to rock mineralogy and ground-water movement through the use of geochemical models and laboratory analysis of rock and water chemistry, (5) develop a computer data base for appropriate data describing the aquifer systems, (6) using results of this study, evaluate future management of the fresh ground-water resources of the study area.

APPROACH: (1) Develop a detailed work plan and review existing literature, (2) compile pertinent data from all sources, (3) using borehole geophysical and geologic logs, define the geologic framework, (4) using borehole geophysical logs, water-quality analyses, and surface geophysics, delineate transition from fresh to saline ground water, (5) develop a density-dependent ground-water flow model to simulate regional ground-water movement, (6) where appropriate, develop small-scale solute transport models to test hypotheses regarding movement of saline ground water, (7) collect ground-water samples for laboratory analysis to define regional ground-water chemistry, (8) collect rock samples for laboratory analysis to define rock chemistry and mineralogy to define rock-water interactions that may be occurring.

RESULTS LAST YEAR: Collected 368 ground-water samples for complete dissolved inorganic analysis. Oxygen-18 and Deuterium were sampled and analyzed for at each site. Carbon-13 was sampled and analyzed for at 50 of these sites. Compiled and reviewed existing ground-water quality analyses. A regional ground-water quality computer data base of 1221 analyses has been created.

One hundred and three vertical-electric soundings have been made using DC resistivity and 25 using the time domain electromagnetic method. Six hundred and ninety one separate borehole geophysical logs have been compiled and analyzed in mapping geologic formation tops. Resistivity, dual-induction and neutron-porosity log suites from the log files have been analyzed in mapping the transition from fresh to saline ground water and in estimating ground-water resistivity. Over 900 driller's logs from oil and gas wells have been examined in mapping geologic formation tops.

A variable-density modification for the USGS modular finite-difference ground-water flow model has been developed.

PLANS THIS YEAR: Collect ground-water samples for analysis of selected isotopes in designated areas in the study area. Analyze ground-water quality analyses in data base. Continue geologic framework mapping. Continue analyzing results of DC resistivity survey and delination of freshwater-saline water transition zone using the time domain electromagnetic method. Develop and refine the regional ground-water flow model. Map the water table and potentiometric surfaces for the Saginaw and Marshall Formations. Determine the history, rate and distribution of ground-water pumping throughout the study area.

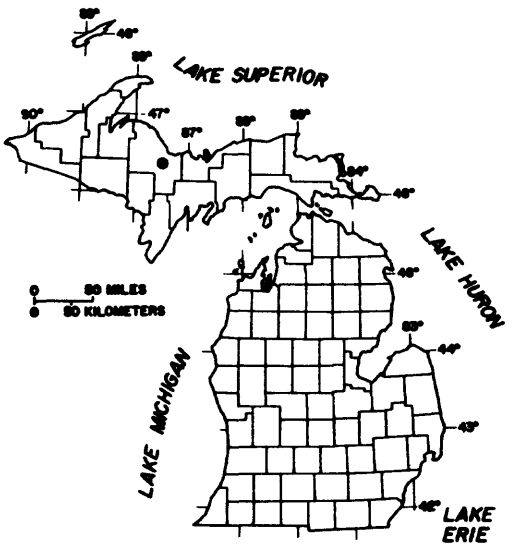
HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Lower Peninsula, Michigan

PROJECT CHIEF: Richard J. Mandle

PERIOD OF PROJECT: October 1985 to September 1990.

HYDROGEOLOGY OF
K.I. SAWYER AIR FORCE BASE,
MICHIGAN



PROJECT NO. - MI 043

PROBLEM: Information on the hydrogeology at K.I. Sawyer Air Force Base is inadequate for description and evaluation of potential problems, for management and protection of Base water resources, and for development of needed Base water-supply capacity. Volatile and aromatic hydrocarbons have been found in ground water at several locations on the Base, and in Silver Lead Creek. Additional information on the hydraulics of the ground-water system and movement and dispersion of contaminants are needed to trace contaminants to their origin and to predict movement of contaminants in ground water.

OBJECTIVES: (1) Determine geologic conditions at and near K.I. Sawyer Air Force Base, (2) determine direction and rate of ground-water flow, (3) determine chemical characteristics of ground-water flow, (3) determine chemical characteristics of ground water, including both organic and inorganic substances, (4) locate source or sources of contaminants, (5) determine extent and distribution of contaminants both on soils and in ground water, and (6) determine if there is a relation between trichloroethylene detected in ground water and trichloroethylene detected in Silver Lead Creek.

APPROACH: (1) Evaluate available geologic and hydrologic data, (2) using geophysical techniques, determine altitude of bedrock surface and lithologic characteristics of glacial deposits, (3) install wells on Base and in surrounding area, (4) make routine water-level measurements, either weekly, monthly, or with recording equipment, (5) conduct pumping tests on selected wells to determine hydraulic properties of the aquifer, (6) collect water samples from wells for analysis of volatile and aromatic hydrocarbons and common dissolved substances (make field measurements of specific conductance, pH, and temperature).

RESULTS LAST YEAR: Phase II, Stage 1 report transmitted to U.S. Air Force. Soil-gas chromatographs were obtained at about 200 locations. Based on the soil-gas chromatography and analysis of data from the Phase II, Stage 1 study, 47 new observation wells were drilled. Water from each well was analyzed for potential contamination. Soils from 11 wells and 17 separate borings were analyzed for potential contamination. Water and sediment samples from Silver Lead Creek, Big Creek, and a tributary to Big Creek were collected and analyzed for possible contamination. Water-levels were measured in all new wells and most other wells on the Base.

PLANS THIS YEAR: Continue to evaluate data and prepare report.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Central Upper Peninsula, Michigan

PROJECT CHIEF: Norman G. Grannemann

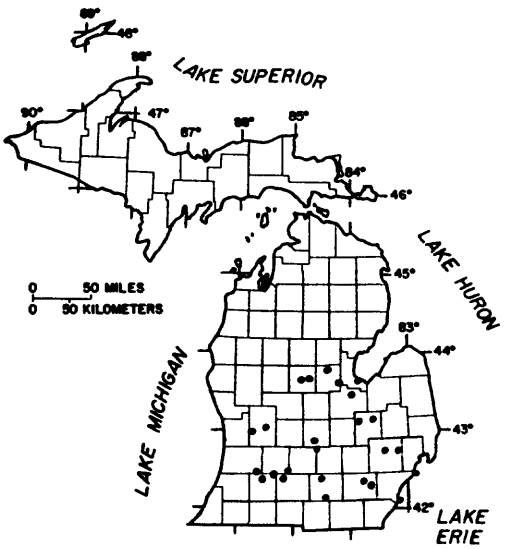
PERIOD OF PROJECT: April 1985 to April 1988

COOPERATIVE AGENCY: U.S. Air Force

REPORTS IN PROGRESS: An Administrative Report meeting U.S. Air Force Phase II, Stage 2 requirements under the Installation Restoration is near completion.

REPORTS PREPARED: "Hydrogeology of K.I. Sawyer Air Force Base, Michigan", an administrative report to the U.S. Air Force.

WATER QUALITY TRENDS OF MICHIGAN STREAMS



PROJECT NO. - MI 044

PROBLEM: A major effort has been made by the State of Michigan in the past 10 years to control the discharge of pollutants to streams in urban areas. Costly treatment facilities have been installed and regulations developed to protect water quality. The effectiveness of pollution control efforts, however, has not been assessed by rigorous analysis of data obtained at monitoring stations. Thus, decisions affecting the management of stream-water quality must be made without the guidance and benefit such study would provide. A trend analysis of major water-quality characteristics is needed.

OBJECTIVES: (1) Determine trends in concentration and transport for 9 selected water-quality characteristics at 23 stream sites in 11 urban areas by determining the average concentration and whether monotonic or step trends occur in flow-adjusted water-quality characteristics at the sites and within urban areas, (2) compare trends to known changes in basin characteristics, and (3) outline possible strategies for improving the water-quality monitoring network.

APPROACH: (1) Retrieve water-quality data from USEPA's STORET file, (2) develop fortran program code to manipulate and transform water-quality data for processing, (3) compute univariate statistics and develop box plots for each constituent, (4) flow adjust concentration data for all monitoring sites, (5) use raw and/or flow-adjusted concentration and transport data to conduct non-parametric tests for time-series trends, (6) analyze changes in concentration and transport within urban areas based on differences between upstream and downstream sites, (7) relate observed trends to changes in pollution-abatement facilities, regulations, or other variables, and (8) identify strategies to improve the data-collection network.

RESULTS LAST YEAR: Completed data analyses and report preparation.

PLANS THIS YEAR: None.

HEADQUARTERS: Lansing, Michigan

FIELD LOCATION: Statewide

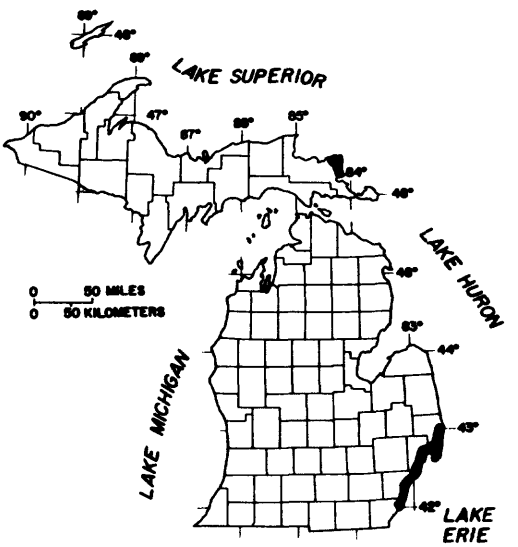
PROJECT CHIEF: David J. Holtschlag

PERIOD OF PROJECT: March 1985 to January 1987

COOPERATING AGENCIES: Michigan Department of Natural Resources

REPORTS COMPLETED: "Changes in water quality of Michigan streams near urban areas, 1973-84", U.S. Geological Survey Water-Resources Investigations Report 87-4035.

GROUND-WATER MOVEMENT NEAR UPPER GREAT LAKES CONNECTING CHANNELS



PROJECT NO. - MI 045

PROBLEM: Information on the movement of ground water to Great Lakes connecting channels in Michigan is inadequate for an evaluation of its impact on the water quality of the channels. Contaminants from landfills, waste-disposal sites, and areas of known ground-water contamination could be a significant factor in determining water quality of the Great Lakes. In areas adjacent to the St. Marys River, Lake St. Clair, the St. Clair River, and the Detroit River, more than 100 hazardous-waste sites lie within 10 miles of the channels. Five of these sites are on the National Priority List. Upward movement of chemical substances from deep geologic strata, either from natural sources or from areas where deep injection of wastes has occurred, is also a possibility.

OBJECTIVES: (1) Determine the geologic conditions near connecting channels, (2) determine configuration of the water table and direction of ground-water flow, (3) determine the chemical and physical characteristics of ground water, with particular attention to the characteristics near known hazardous-waste sites, (4) assess the movement of dissolved substances from deep geologic strata to the connecting channels, and (5) assess the ground-water contribution of contaminants and natural occurring substances in the connecting channels.

APPROACH: Data collection and analyses activities were conducted in three phases to meet the requirements of the United States-Canadian agreements developed by the project Management and Activities Integration Committees. Phase I was concerned with assembling data and identifying sites where ground-water contamination is suspected or known; phase II consisted of a preliminary designation of potentially hazardous sites; and phase III consisted of site specific investigation for prioritizing waste sites and calculating loading.

PLANS THIS YEAR: Draft project proposals for investigations in two areas requiring more thorough study. Obtain Director's approval for completed reports.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Eastern Upper Peninsula and southeastern Lower Peninsula

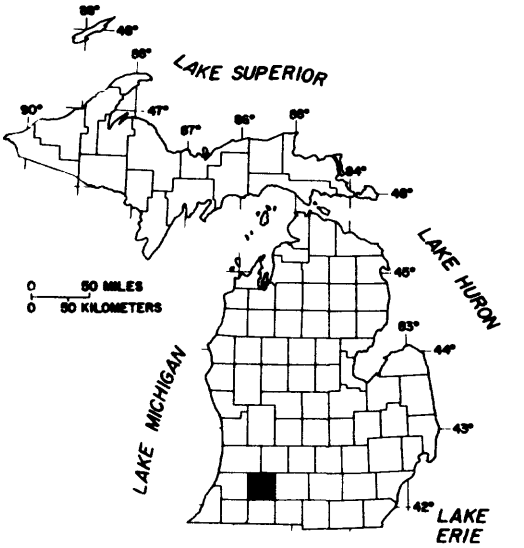
PROJECT CHIEFS: John L. Gillespie and Denise H. Dumouchelle

PERIOD OF PROJECT: July 1985 to December 1987

COOPERATING AGENCY: U.S. Environmental Protection Agency

REPORTS COMPLETED: Administrative report to the U.S. Environmental Protection Agency completed; Water-Resources Investigations Report completed.

GROUND-WATER PROTECTION IN
KALAMAZOO COUNTY, MICHIGAN



PROJECT NO. - MI 046

PROBLEM: Studies by the State of Michigan have identified 46 sites in Kalamazoo County where ground-water contamination has or is likely to occur. Many of the compounds contaminating ground water are chlorinated hydrocarbons, fuel subtances, or plating wastes. Irrigation increased about 400 percent in the 1970's, with a commensurate increase in the use of fertilizers and pesticides. Relations between geology, hydrology, land and water use, and ground water have not been established. The source of recharge for specific ground-water reservoirs is not well known. Strategies for protecting ground water cannot be developed until such relationships are understood.

OBJECTIVE: (1) To determine the geologic and hydrologic conditions that influence the quality and quantity of ground water, (2) to relate information on ground-water quality to land and water use, cultural activity, and surface-water resources, (3) to relate, to the extent possible, the movement of chemical substances in the ground-water system to the hydrology of the area, (4) to delineate recharge areas and identify areas susceptable to ground-water contamination from surface and subsurface sources, (5) to better define location, extent, and character of confining beds and determine their relation to the vertical and horizontal movement of ground water and contaminants.

APPROACH: (1) Evaluate available hydrologic and geologic data contained in State, county, and USGS files. (2) Collect ground-water level data routinely at about 50 sites. (3) Install approximately thirty five 4-inch wells. (4) Install digital recorders on three wells. (5) Collect water-quality data from about 50 wells. (6) Install Bedfort rain gage at one site. (7) Collect precipitation and dry fallout samples at two sites. (8) Make discharge measurements at about 20 stream sites approximately three times per year. (9) Collect samples for chemical analysis at the time discharge measurements are made. (10) Analyze and evaluate data; write report.

RESULTS THIS YEAR: Thirty-five ground water wells drilled. Four ground-water recorders installed. Precipitation, surface-water, and ground-water samples collected. Water-table map generated.

PLANS THIS YEAR: Relate information on ground-water quality to the geology, hydrology, land and water use. Delineate principal recharge areas and in conjunction with water-quality and land-use data, identify areas susceptable to ground-water contamination. Write and publish the report.

HEADQUARTERS OFFICE: Lansing, Michigan

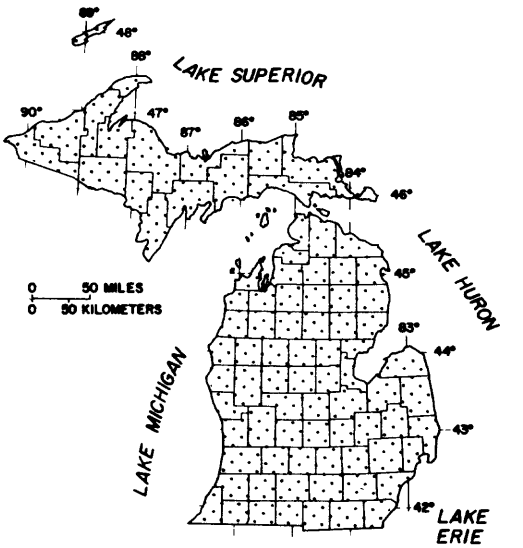
FIELD LOCATION: Southwest Lower Peninsula, Michigan

PROJECT CHIEF: Stephen J. Rheaume

PERIOD OF PROJECT: March 1986 to September 1988

COOPERATING AGENCIES: Michigan Department of Natural Resources
Kalamazoo County

CHEMICAL AND PHYSICAL CHARACTERISTICS
OF NATURAL GROUND WATERS IN MICHIGAN



PROJECT NO. - MI 047

PROBLEM: Detailed information on the chemical and physical characteristics of natural ground waters is inadequate. Substantial data need to be obtained to establish baseline conditions against which long-term changes in water quality can be judged, and for properly evaluating the degree and severity of contamination when it occurs. Information is also critical to support development of ground-water protection strategies, and to ensure their successful implementation. Systematic methods of integrating new data with those collected earlier, and of analyzing their significance, need to be developed.

OBJECTIVES: (1) To determine, evaluate, and describe the chemical and physical characteristics of natural ground waters in Michigan. (2) to establish a procedure for rapidly updating statistical summaries of file data, and to make the information available to users on request. (3) to better understand the relation of ground-water quality to statewide geochemical conditions.

APPROACH: (1) Ground waters will be sampled at selected sites to define water-quality characteristics of aquifers statewide. (2) Approximately 30 samples will be collected each year. (3) Field analyses of specific conductance, temperature, dissolved oxygen, pH and alkalinity will be made. (4) Laboratory analyses will be performed for common substances, trace metals, pesticides, and tritium. (5) Results of chemical analyses, and analyses made prior to 1986, will be stored in a separate file and updated as new results become available. P-Stat or IMSL will be used to update statistical summaries, graphically display results, and provide hard copy. (6) Analyze and evaluate data; write reports.

RESULTS LAST YEAR: File created for storage of data; chemical analyses of water from wells were made.

PLANS THIS YEAR: Complete and publish revision of 1980 report. Began analysis of data for final interpretive report.

HEADQUARTERS OFFICE: Lansing, Michigan

FIELD LOCATION: Statewide

PROJECT CHIEF: T. Ray Cummings

PERIOD OF PROJECT: January 1986 to September 1990.

COOPERATIVE AGENCY: Geological Survey Division,
Michigan Department of Natural Resources

REPORTS IN PROGRESS: "Natural ground water quality in Michigan: A summary of data", U.S. Geological Survey Water-Resources Investigations Report

REPORTS PUBLISHED: Cummings, T. R., 1980, Chemical and physical characteristics of natural ground waters in Michigan: A preliminary report: U.S. Geological Survey Open-File Report 80-953, 34 p., 12 figs.

HYDROLOGIC CONDITIONS

Most of Michigan has water resources sufficient to meet present needs. Much of the State is bounded by water and annual precipitation ranges from 28 to 36 inches (fig. 3). Eight to 16 inches of precipitation becomes surface runoff (fig. 4) and 9 to 15 inches recharges the ground-water reservoir; the remainder is returned to the atmosphere by evapotranspiration. The discharge of streams is shown in figures 5 and 6; the availability of ground water is shown in figures 7 and 8. Fresh water withdrawals from both surface- and ground-water sources average about 15 billion gallons per day. Nearly 97 percent is from surface-water sources; particularly from the Great Lakes and connecting waters. Largest municipal withdrawals are in the heavily populated counties in the southern part of the State (fig. 9). Glacial deposits are the source of municipal ground-water supplies in most of the State (fig. 10). In some parts of the State, the base of fresh ground water is less than 200 feet deep (fig. 11), and some wells produce salty water.

The Michigan Department of Natural Resources has identified more than 1,700 sites where ground water has been contaminated or is suspected. A wide range of contaminants is involved. At many sites, chlorinated hydrocarbons and hydrocarbons that are contained in fuel substances are the contaminants. Nitrates from surface sources have contaminated domestic ground-water supplies in concentrations of as much as 30 mg/L at some locations in the Lower Peninsula (Cummings and others, 1984).

The current program of the Michigan District of the U.S. Geological Survey is effectively addressing many water-resource issues and is providing the hydrologic information needed for the best utilization and long-term management of the Nation's water resources. Hydrologic-data stations, at which data are collected for surface water, ground water, and water quality, are located throughout the State.

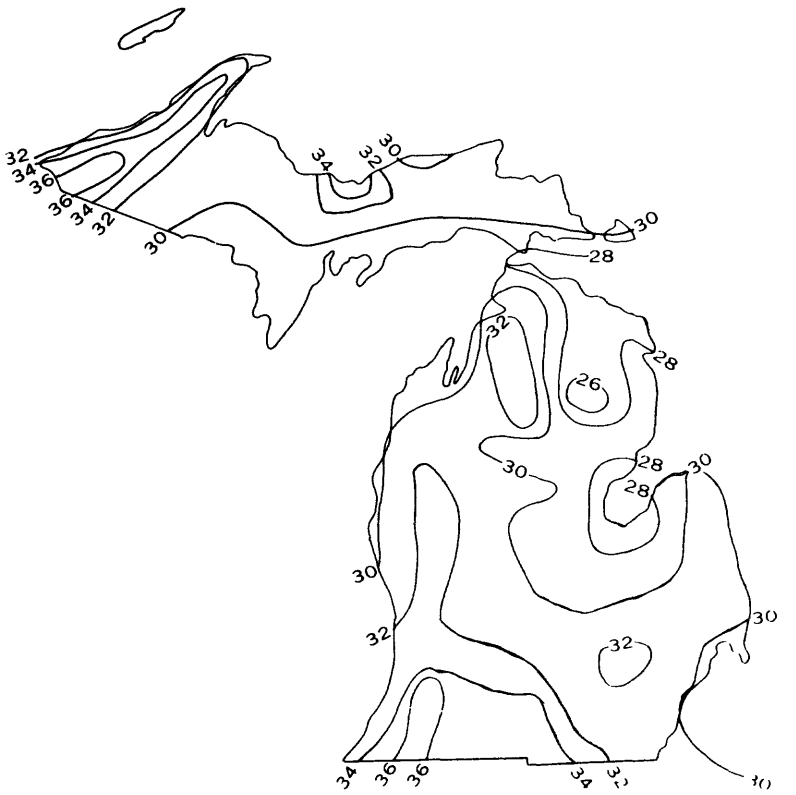


Figure 3.--Average annual precipitation (in inches) (Date from National Weather Service--NOAA).

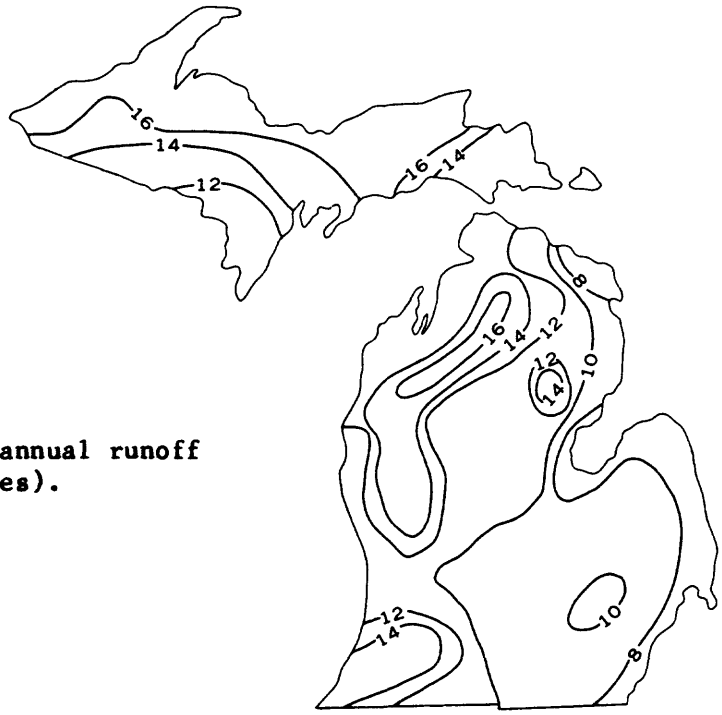


Figure 4.--Average annual runoff (in inches).

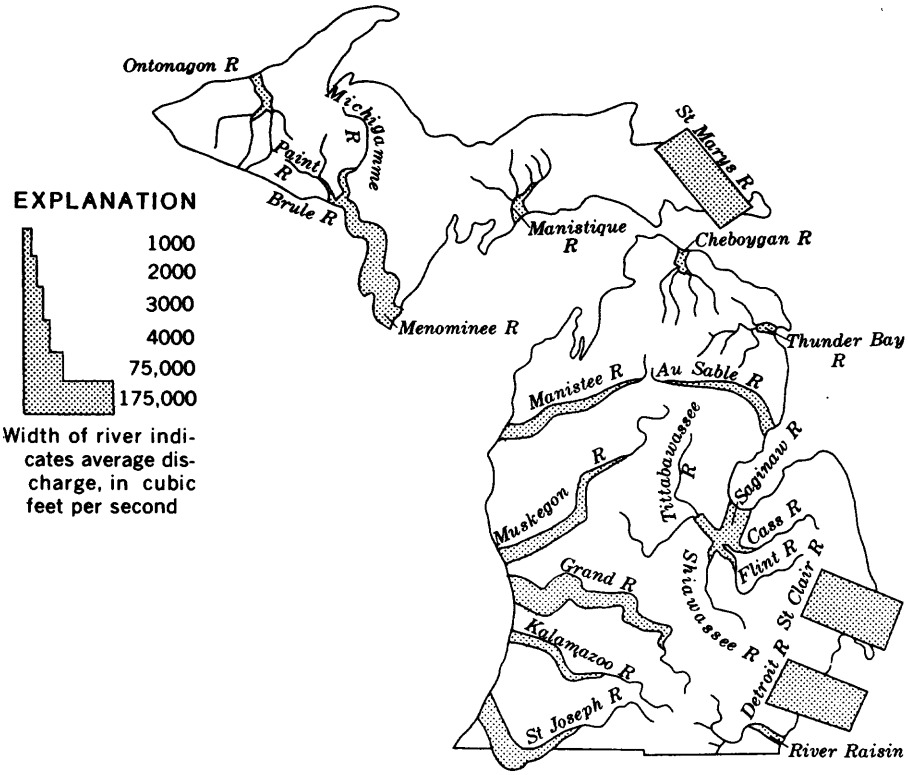


Figure 5.--Average discharge of streams (For streams draining an area of 1000 square miles or more at mouth).

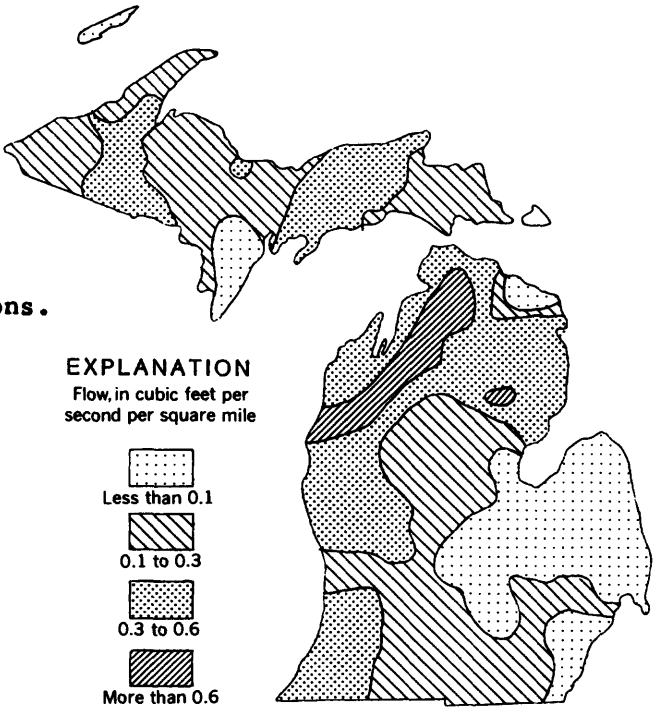


Figure 6.--Low-flow conditions.

EXPLANATION

Throughout most of these areas wells in bedrock will yield less than 10 gallons per minute. Locally, wells 6 inches or more in diameter may yield several tens of gallons per minute

Throughout most of these areas wells 6 inches or more in diameter in bedrock will yield from 10 to 100 gallons per minute. Locally, wells may yield less than 10 gallons per minute or more than 100 gallons per minute

Throughout most of these areas wells 8 inches or more in diameter in bedrock will yield from 100 to 500 gallons per minute. Locally, wells will yield less than 100 or more than 500 gallons per minute

Throughout most of these areas wells 10 inches or more in diameter in bedrock will yield more than 500 gallons per minute

Throughout most of these areas wells in bedrock will yield water that is too highly mineralized for domestic or public supplies-dissolved solids content of more than 1,000 milligrams per liter. Locally, the water may be of relatively good chemical quality. In general, the water becomes more mineralized with an increase in depth

As in the glacial drift the water in the bedrock is usually hard and may contain iron locally. With increasing depth water tends to become more mineralized

Figure 7.--Availability and quality of ground water in bedrock.

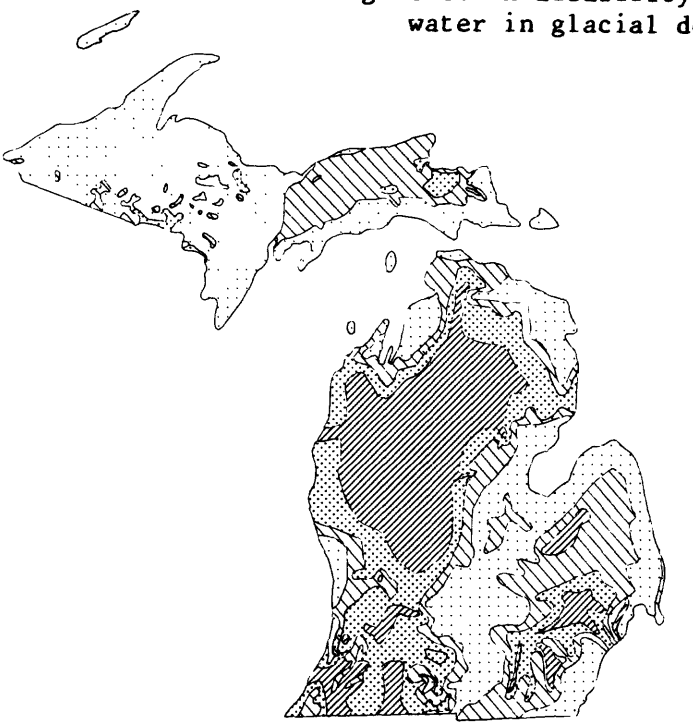
EXPLANATION

Throughout most of these areas wells in glacial deposits will yield less than 10 gallons per minute. Locally, wells 6 inches or more in diameter may yield several tens of gallons per minute and in places, especially where sand and gravel deposits occur along streams, will yield more than 100 gallons per minute

Throughout most of these areas wells 6 inches or more in diameter in glacial deposits will yield from 10 to 100 gallons per minute. Locally wells may yield less than 10 gallons per minute, and in places, especially where sand and gravel deposits occur along streams, will yield several hundred gallons per minute

Throughout most of these areas wells 8 inches or more in diameter in glacial deposits will yield from 100 to 500 gallons per minute. Locally, wells will yield less than 100 gallons per minute, and in places, especially where sand and gravel deposits occur along streams, will yield more than 500 gallons per minute

Throughout most of these areas wells 10 inches or more in diameter in glacial deposits will yield more than 500 gallons per minute



Water in the glacial deposits is of generally good quality although hard and may contain iron locally

Figure 8.--Availability of ground water in glacial deposits.

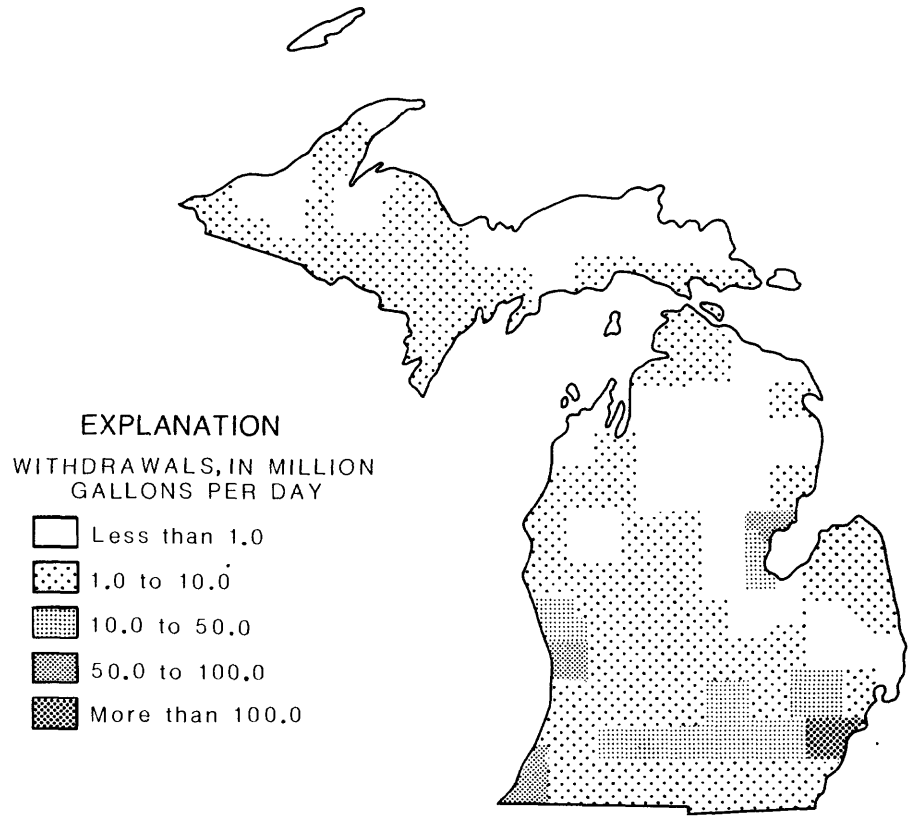


Figure 9.--Municipal water withdrawals, 1978.

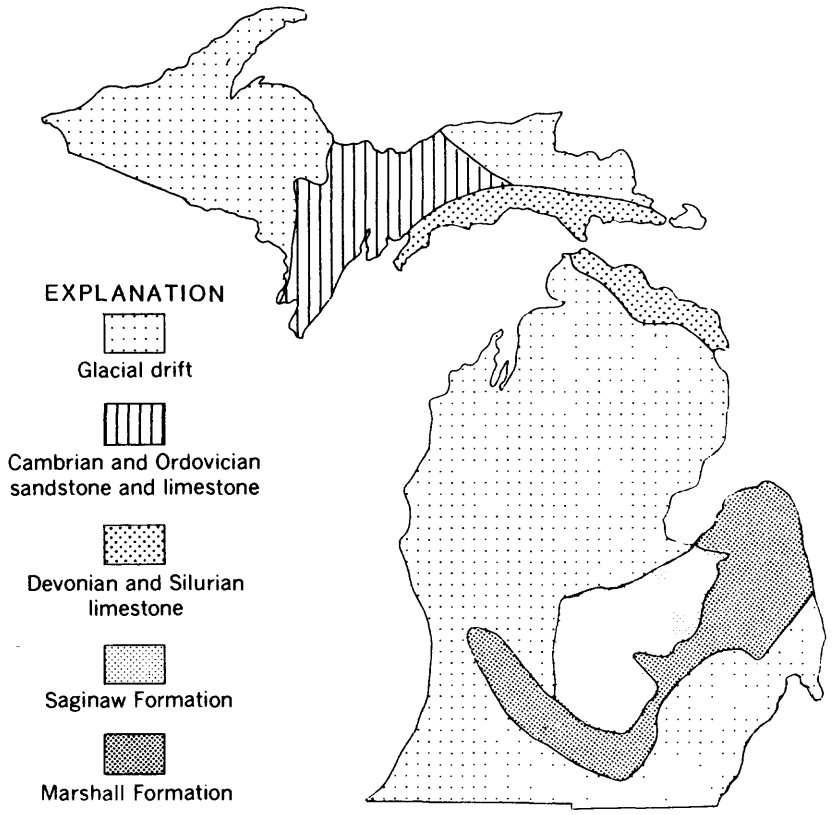
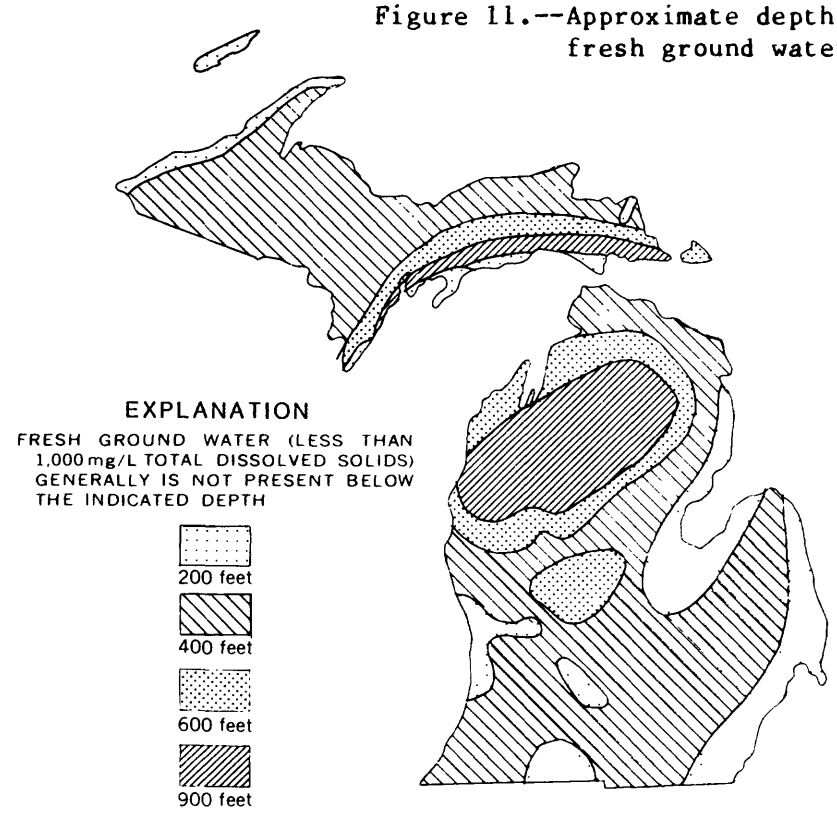


Figure 10.--Principal sources of public ground-water supplies.

Figure 11.--Approximate depth to base of fresh ground water.



HYDROLOGIC-DATA STATIONS

Hydrologic-data stations are maintained by the Geological Survey at selected key locations throughout Michigan to constitute a basic-data network for obtaining records on stream discharge or stage, reservoir and lake storage, ground-water levels, and the quality of surface and ground water. Every year stations are added and others are terminated; thus, the Geological Survey has both a current and historical file of hydrologic data. Much of the information collected is stored in the Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) and are available to water planners and other involved in making decisions affecting the State's water resources.

Surface-Water Stations

In table 1, the station number is a permanent numerical designation for surface-water stations that has been adopted on a nationwide basis by the Geological Survey. Stations are numbered and listed in a downstream direction along the main stem. All stations on the tributary entering above a main-stem station are listed before that station. A tributary entering between two main-stem stations is listed between them.

Table 1.--Surface-water hydrologic data stations

Station number	Station name	Type of data[1]
04001000	Washington Creek at Windigo, MI	Q1CPTR
04033000	Middle Branch Ontonagon River near Paulding, MI	Q1
04033500	Bond Falls Canal near Paulding, MI	Q1
04034000	Bond Falls Reservoir near Paulding, MI	14
04034500	Middle Branch Ontonagon River near Trout Creek, MI	Q1
04035500	Middle Branch Ontonagon River near Rockland, MI	Q1
04036000	West Branch Ontonagon River near Bergland, MI	Q1
04037500	Cisco Branch Ontonagon River at Cisco Lake Outlet, MI	Q1
04040000	Ontonagon River near Rockland, MI	Q1CS
04040500	Sturgeon River near Sidnaw, MI	Q1
04041000	Perch River near Sidnaw, MI	2
04041500	Sturgeon River near Alston, MI	Q1
04043050	Trap Rock River near Lake Linden, MI	Q1
04044200	Carp Creek at Ishpeming, MI	2
04044400	Carp Creek near Negaunee, MI	3
04044609	Sand River Wildlife Flooding at Sand River, MI	1
04044813	Two Hearted River near Paradise, MI	2
04045500	Tahquamenon River near Tahquamenon Paradise, MI	Q1CS
04045538	West Branch Waiska River near Brimley, MI	2
04045559	East Branch Waiska River near Brimley, MI	2
04045580	St. Marys River above Sault Ste. Marie, MI	MCSR
04046000	Black River near Garnet, MI	2
04056500	Manistique River near Manistique, MI	Q1
04057510	Sturgeon River near Nahma Junction, MI	Q1
04057580	Whitefish River near Rapid River, MI	3
04057800	Middle Branch Escanaba River at Humboldt, MI	Q1
04057811	Greenwood Reservoir near Greenwood, MI	14
04057813	Greenwood Diversion near Greenwood, MI	Q1
04057814	Greenwood Release near Greenwood, MI	Q1
04057900	Black River near Republic, MI	2
04058120	Green Creek near Palmer, MI	3
04058190	Schweitzer Reservoir near Palmer, MI	14
04058200	Schweitzer Creek near Palmer, MI	Q1
04058940	Escanaba River near St. Nicholas, MI	1
04059000	Escanaba River at Cornell, MI	Q1CS
04059034	Escanaba River near Wells, MI	3
04059400	Tenmile Creek at Perronville, MI	2
04059500	Ford River near Hyde, MI	Q1CS
04061000	Brule River near Florence, WI	Q1
04061500	Paint River at Crystal Falls, MI	Q1
04062000	Paint River near Alpha, MI	Q1
04062300	Michigamme River near Republic, MI	2
04062500	Michigamme River near Crystal Falls, MI	Q1
04063000	Menominee River near Florence, WI	Q1
04065800	Menominee River near Vulcan, MI	Q1
04096272	Beebe Creek near Hillsdale, MI	2
04096340	St. Joseph River at Clarendon, MI	2

Table 1.--Surface-water hydrologic data stations--Continued

Station number	Station name	Type of data	Station number	Station name	Type of data
04096400	St. Joseph River near Burlington, MI	Q1	04108645	Rabbit River at Hamilton, MI	2
04096515	Hog Creek near Allen, MI	Q1	04108800	Macatawa River near Zeeland, MI	Q1
04096517	Hog Creek tributary near Allen, MI	3	04109000	Grand River at Jackson, MI	Q1
04096600	Coldwater River near Hodunk, MI	Q1	04111379	Red Cedar River near Williamston, MI	Q1
04096900	Nottawa Creek near Athens, MI	Q1	04111500	Deer Creek near Dansville, MI	Q1
04097170	Portage River near Vicksburg, MI	2	04112000	Sloan Creek near Williamston, MI	Q1
04097195	Gourdneck Canal near Schoolcraft, MI	Q1	04112500	Red Cedar River at East Lansing, MI	Q1
04097540	Prairie River near Nottawa, MI	Q1	04112700	Sycamore Creek near Mason, MI	2
04099000	St. Joseph River at Mottville, MI	Q1	04113000	Grand River at Lansing, MI	Q1
04101500	St. Joseph River at Niles, MI	Q1CS	04113090	Carrier Creek near Grand Ledge, MI	2
04101800	Dowagiac River at Sumnerville, MI	Q1	04114500	Looking Glass River near Eagle, MI	Q1
04102500	Paw Paw River at Riverside, MI	Q1	04114594	Maple River near St. Johns, MI	3
04102700	South Branch Black River near Bangor, MI	Q1	04115000	Maple River at Maple Rapids, MI	Q1
04103010	Kalamazoo River near Marengo, MI	Q1	04115265	Fish Creek near Crystal, MI	Q1
04105000	Battle Creek at Battle Creek, MI	Q1	04116000	Grand River at Ionia, MI	Q1
04105500	Kalamazoo River near Battle Creek, MI	Q1	04117000	Quaker Brook near Nashville, MI	2
04105700	Augusta Creek near Augusta, MI	Q1	04117500	Thornapple River at Hastings, MI	Q1
04106000	Kalamazoo River at Comstock, MI	Q1C	04118000	Thornapple River near Caledonia, MI	Q1
04106180	Portage Creek at Portage, MI	Q1C	04118500	Rogue River near Rockford, MI	Q1
04106300	Portage Creek near Kalamazoo, MI	Q1	04119000	Grand River at Grand Rapids, MI	Q1
04106320	West Fork Portage Creek near Oshtemo, MI	Q1	04119055	Plaster Creek at Grand Rapids, MI	2
04106400	West Fork Portage Creek at Kalamazoo, MI	Q1	04119160	Buck Creek at Grandville, MI	2
04108500	Kalamazoo River near Fennville, MI	Q1CS	04119300	Grand River near Eastmanville, MI	MCS
04108600	Rabbit River near Hopkins, MI	Q1	04120295	Black Creek near Muskegon, MI	23

Table 1.--Surface-water hydrologic data stations--Continued

Station number	Station name	Type of data
04121239	Clam River at Cadillac, MI	3
04121300	Clam River at Vogel Center, MI	Q1
04121500	Muskegon River at Evart, MI	Q1
04121900	Little Muskegon River near Morley, MI	Q1
04122000	Muskegon River at Newaygo, MI	Q1
04122030	Muskegon River near Bridgeton, MI	MCS
04122100	Bear Creek near Muskegon, MI	Q1
04122200	White River near Whitehall, MI	Q1
04122230	North Branch Pentwater River near Pentwater, MI	2
04122500	Pere Marquette River at Scottville, MI	Q1
04124000	Manistee River near Sherman, MI	Q1
04124500	East Branch Pine River near Tustin, MI	2
04126000	Manistee River near Manistee, MI	Q1
04126520	Manistee River at Manistee, MI	MCS
04126600	Betsie River near Benzonia, MI	2
04127000	Boardman River near Mayfield, MI	Q1
04127800	Jordan River near East Jordan, MI	Q1
04127850	Boyne River near Boyne City, MI	2
04127918	Pine River near Rudyard, MI	Q1
04128000	Sturgeon River near Wolverine, MI	Q1
04129000	Pigeon River near Vanderbilt, MI	Q1
04130500	Black River near Tower, MI	Q1
04135000	Thunder Bay River near Alpena, MI	Q1CS
04135500	Au Sable River at Grayling, MI	Q1
04135700	South Branch Au Sable River near Luzerne, MI	Q1
04136500	Au Sable River at Mio, MI	Q1
04137500	Au Sable River near Au Sable, MI	Q1
04139000	Houghton Creek near Lupton, MI	2
04140200	Klacking Creek near Selkirk, MI	2
04140500	Rifle River at Selkirk, MI	2
04141100	Shepards Creek near Selkirk, MI	2
04142000	Rifle River near Sterling, MI	Q1CS
04143900	Shiawassee River at Linden, MI	Q1
04144500	Shiawassee River at Owosso, MI	Q1
04146000	Farmers Creek near Lapeer, MI	Q1
04146020	South Branch Flint River near Millville, MI	2
04146063	South Branch Flint River near Columbiaville, MI	Q1
04146450	North Branch Flint River near Columbiaville, MI	3
04147000	Holloway Reservoir near Otisville, MI	14
04147500	Flint River near Otisville, MI	Q1
04148140	Kearsley Creek near Davison, MI	Q1
04148265	Kimball Drain near Swartz Creek, MI	2
04148500	Flint River near Flint, MI	Q1
04148610	Cole Creek near Flushing, MI	2
04148640	Armstrong Creek near Montrose, MI	2
04149000	Flint River near Fosters, MI	Q1
04150500	Cass River at Cass City, MI	Q1
04150800	Cass River at Wahjamega, MI	Q1
04151500	Cass River at Frankenmuth, MI	Q1

Table 1.--Surface-water hydrologic data stations--Continued

Station number	Station name	Type of data
04152238	South Branch Tobecco River near Beaverton, MI	Q1
04154000	Chippewa River near Mount Pleasant, MI	Q1
04155000	Pine River at Alma, MI	Q1
01415550	Pine River near Midland, MI	Q1
04156000	Tittabawassee River at Midland, MI	Q1
04156100	Tittabawassee River near Midland, MI	MCS
04157000	Saginaw River at Saginaw, MI	Q1
04158000	Columbia Drain near Sebewaing, MI	Q1
04159010	Pigeon River near Caseville, MI	Q1CS
04159130	St. Clair River at Port Huron, MI	MCS
04159500	Black River near Fargo, MI	Q1
04159900	Mill Creek near Avoca, MI	Q1
04160350	Pine River near Rattle Run, MI	2
04160570	North Branch Belle River at Imlay City, MI	Q1
04160600	Belle River at Memphis, MI	Q1
04160800	Sashabaw Creek near Drayton Plains, MI	Q1
04160900	Clinton River near Drayton Plains, MI	Q1
04161000	Clinton River at Auburn Heights, MI	2
04161100	Galloway Creek near Auburn Heights, MI	Q1
04161500	Paint Creek near Lake Orion, MI	2
04161540	Paint Creek at Rochester, MI	Q1
04161580	Stony Creek near Romeo, MI	Q1
04161760	West Branch Stony Creek near Washington, MI	2
04161790	Stony Lake near Washington, MI	14
04161800	Stony Creek near Washington, MI	Q1
04162010	Red Run near Warren, MI	Q1
04162900	Big Beaver Creek near Warren, MI	Q1
04163400	Plum Brook at Utica, MI	Q1
04164000	Clinton River near Fraser, MI	Q1
04164010	North Branch Clinton River at Almont, MI	2
04164050	North Branch Clinton River near Romeo, MI	2
04164100	East Pond Creek at Romeo, MI	Q1
04164150	North Branch Clinton River near Meade, MI	2
04164200	Coon Creek near Armada, MI	2
04164300	East Branch Coon Creek at Armada, MI	Q1
04164350	Highbank Creek near Armada, MI	2
04164360	East Branch Coon Creek near New Haven, MI	2
04164400	Deer Creek near Meade, MI	2
04164450	McBride Drain near Macomb, MI	2
04164500	North Branch Clinton River near Mount Clemens, MI	Q1
04164600	Middle Branch Clinton River near Macomb, MI	2
04164800	Middle Branch Clinton River at Macomb, MI	2
04165200	Gloede Ditch near Waldenburg, MI	2
04165500	Clinton River at Mount Clemens, MI	Q1CS
04166000	River Rouge at Birmingham, MI	Q1
04166100	River Rouge at Southfield, MI	Q1
04166200	Evans Ditch at Southfield, MI	Q1
04166300	Upper River Rouge at Farmington, MI	Q1
04166500	River Rouge at Detroit, MI	Q1
04167000	Middle River Rouge near Garden City, MI	Q1

Table 1.--Surface-water hydrologic data stations--Continued

Station number	Station name	Type of data	Station number	Station name	Type of data
04168000	Lower River Rouge at Inkster, MI	Q1	04174950	Willow Run near Rawsonville, MI	Q1
04168660	Frank and Poet Drain at Trenton, MI	2	04175600	River Raisin near Manchester, MI	Q1
04168800	Huron River near Andersonville, MI	2	04175950	Wolf Creek near Adrian, MI	3
04170000	Huron River at Milford, MI	Q1	04175960	South Branch River Raisin near Adrian, MI	2
04170500	Huron River near New Hudson, MI	Q1	04176000	River Raisin near Adrian, MI	Q1
04172000	Huron River near Hamburg, MI	Q1	04176400	Saline River near Saline, MI	2
04173250	Mill Creek near Lima Center, MI	2	04176500	River Raisin near Monroe, MI	Q1C
04174050	Huron River at Delhi Mills, MI	P	04176605	Otter Creek at LaSalle, MI	Q1
04174500	Huron River at Ann Arbor, MI	Q1			

1/ TYPE OF DATA:

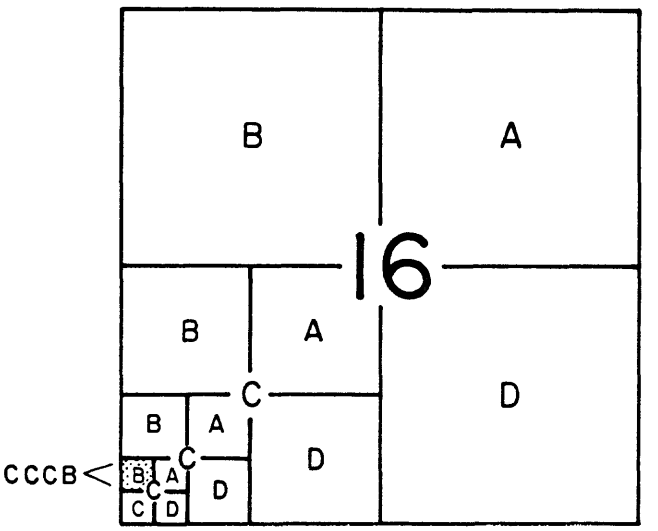
Surface-water data:
- Q - Daily discharge.
- 1 - Stage.
- 2 - Peak stage and discharge.
- 3 - Low flow.
- 4 - Reservoir contents.
- M - Miscellaneous.

Quality analyses:
- C - General chemical, organic, and biological analyses.
- S - Sediment analyses.
- P - Pesticide.
- T - Temperature.
- R - Radiochemical.
- D - Partial chemical analysis.

Ground-Water Stations

Table 2 lists the ground-water stations established as part of the State-wide observation network. In addition to ground-water information collected at sites listed in table 2, chemical analyses of ground water have been collected at other locations in the State. Further information is available upon request.

The well-numbering system for Michigan indicates the location of wells within the rectangular subdivision of the land with reference to the Michigan meridian and base line. The first two segments of the well number designate township and range, the third segment of the number designates the section, and the letters A through D designate successively smaller subdivisions of the section as shown below. Thus, a well designated as 32N 6E 16CCCB would be located to the nearest 2.5 acres (1 hectare) and would be within the shaded area in section 16.



For many wells in this report, locations are only given to the nearest 40-acre (16 hectares) tract, for example, 16CC. In the event that two or more wells are located in the same tract, a sequential number designation is added--for example, 16CC1, 16CC2, 16CC3, etc.

Table 2.--Ground-water hydrologic data stations

County	Well number[1]	Name of well	Depth (ft)	Aquifer[2]	Type of data[3]
Alger	45N 19W 25BDCD1	CCC	66	GLCL	Q,QC
Alpena	32N 06E 23DDDA1	Alpena State Forest	88	GLCL	R,QC
Arenac	19E 05E 07DABA1	Omer, D	185	SGNW	M,QC
	07DABA2	Omer, S	21	GLCL	M,QC
Baraga	48N 32W 12DD	WEP 14	10	GLCL	M
Barry	04N 09W 05DA	Solomon Road	131	GLCL	Q
Bay	17N 04E 22DCAA1	Pinconning Twp.	110	SGNW	M,QC
Branch	06S 06W 18CCCD1	Coldwater Twp.	56	GLCL	M,QC
	22CABA1	Coldwater Test 4	113	GLCL	R
Calhoun	01S 07W 10BB	Sabin	12	GLCL	W
	32BDCC1	Penfield Twp.	95	MRSL	R,QC
	32DABD	Battle Creek	127	MRSL	D
	02S 06W 25AA	Marshall	59	MRSL	M
Cass	08S 14W 17BA	Little	55	GLCL	M
Cheboygan	33N 01W 26DABB1	Pigeon River CCC	164	GLCL	R,QC
	39N 03W 29CBCB1	Mackinaw, D	125	DUND	M,QC
	39N 03W 29CBCB2	Mackinaw, S	55	GLCL	M,QC
Chippewa	46N 04W 24DAAD1	Raco	54	GLCL	R
Clare	17N 04W 34DCAD	Clare	91	GLCL	R
Clinton	05N 02W 31CBBA1	Capital City Airport	195	SGNW	R,QC
	32DC	Quarantine Farm	135	SGNW	M
	06N 01W 3BB2	Sleepy Hollow 5	62	GLCL	I
	06N 02W 16DDAD1	MSHD, U.S. 27	23	GLCL	M
	07N 01W 34CC	Sleepy Hollow 7	32	GLCL	I
Crawford	25N 01W 15DDCD1	Eldorado	56	GLCL	R,QC
Delta	39N 23W 28AC	Schemmel	530	MNSG	R
	41N 18W 31CD	Isabella	250	LMSN	M
	42N 18W 17ABBD	Cooks CCC	60	GLCL	Q
	42N 19W 20AA	Pollack CCC	134	GLCL	Q
	43N 19W 24BB	Clarage	405	TBRV	Q
Dickinson	43N 28W 32ADAB1	Felch	31	GLCL	M,QC
Eaton	03N 03W 02BA	Lansing, Stiefel	66	GLCL	R
	04N 03W 12CD	Robins Road	381	SGNW	R
Genesee	06N 07E 09DCCC1	Fisher Body No.2	385	SGNW	R,QC
Grand Traverse	26N 09W 14ABAA1	Fife Lake State Forest	80	GLCL	R,QC
Hillsdale	07S 02W 10BDDD1	Pittsford Game Area	20	GLCL	M,QC
	07S 02W 15BCBA1	Osseo	150	OTSH	M,QC
Ingham	02N 01E 34DB	Dansville Game Area	87	GLCL	Q
	02N 01W 05BCAB1	Mason	210	SGNW	R,QC
	03N 01E 07DDCA1	Lotte	184	SGNW	M
	02W 23BCBD	Holt	188	SGNW	R
	04N 01W 16DAD	Meridian Twp.	398	SGNW	M
	28BCAD1	Okemos	125	SGNW	R
	04N 02W 9BD	Lansing, Seymour	401	SGNW	R
	16DA	Lansing, Cedar	417	SGNW	R
	17AB	Lansing, Logan	424	SGNW	R
	21BA3	Lansing, Scott Park	400	SGNW	R

Table 2.--Ground-water hydrologic data stations--Continued

County	Well number	Name of well	Depth (ft)	Aquifer	Type of data
Ingham (cont.)	04N 02W 22BC	Lansing, P-5	338	SGNW	M
	24CA	Spartan Village	453	SGNW	R
	27BB	Fenner Arboretum	215	SGNW	R
	02W 31CC	Maybell Street	204	SGNW	M
Iosco	24N 07E 13ADAD1	Oscoda	69	GLCL	M,QC
Iron	43N 35W 11AD	WMP 23	47	GLCL	M
	20DC	WMP 25	48	GLCL	M
	44N 37W 14BB	CCC Camp	102	GLCL	Q
Jackson	03S 01W 11AA1	Jackson - 4a, Belden	360	SGNW MRSL	D
Kalamazoo	02S 10W 04D	Kalamazoo, Campbell	13	GLCL	R
	09B	Kalamazoo, Schoonover	21	GLCL	R
	02S 11W 20BB2	Kalamazoo, Kendall	106	GLCL	R
	28AA	Kalamazoo, Maple	245	GLCL	R
	31CD	Kalamazoo, Colony	226	GLCL	R
	36CB	Kalamazoo, Emerald	226	GLCL	R
	03S 11W 04AD1	Kalamazoo, A-D	135	GLCL	R
	04AD2	Kalamazoo, A-S	40	GLCL	R
	14AA	Upjohn 28	233	GLCL	R
	22BBCD	Portage	102	GLCL	R
	12W 11BD	Kalamazoo, Atwater	248	GLCL	R
	04S 11W 11AD1	Kalamazoo,Sabo, D	300	GLCL	R
Kalamazoo	04S 11W 11AD2	Kalamazoo,Sabo,S	38	GLCL	R
	03CDDA1	Prairie View Park	190	GLCL	R,QC
Kent	05N 12W 04DCCD1	Wyoming, Wobma	86	GLCL	R,QC
	10N 12W 13DD	Rouge River Game Area	30	GLCL	Q
Lake	20N 13W 13ACAC1	Irons	58	GLCL	M,QC
Leelanau	28N 14W 08DDCA1	Sleeping Bear,D	138	GLCL	M,QC
	18BABB1	Sleeping Bear,S	60	GLCL	M,QC
Lenawee	05S 01E 12DDBD1	Onstead Game Area	39	GLCL	M
	06S 04E 08DDBA1	Fisher Body	81	GLCL	R,QC
Livingston	01N 06E 13DBAB1	American Aggregate	29	GLCL	R,QC
Mackinac	41N 05W 23BC	Round Lake CCC	47	SLINT	Q
	42N 02W 07AABB1	Pontchartrain CCC	102	MNSQ	R,QC
Marquette	47N 28W 03CCDC1	Ely Township	75	GLCL	R,QC
	49N 30W 22AC	WMP 13	17	GLCL	M
Menominee	37N 26W 19DADA1	Carney	17	GLCL	Q,QC
Monroe	07S 06E 15ACAA1	Petersburg, rock	73	DRRV	M,QC
	15ADBB1	Petersburg Game Area	17	GLCL	M
Muskegon	11N 15W 34ADDD1	Muskegon Game Area	31	GLCL	Q,QC
Oakland	02N 07E 05BA	Honeywell Lake Road	44	GLCL	R
	08E 18DBAD1	Proud Lake Park	45	GLCL	R,QC
	03N 07E 05DA	Fish Lake Road	49	GLCL	R
	10E 13AC	Oakland Univ.	183	GLCL	R
	05N 08E 08ACAC1	Holly Recreation Area	42	GLCL	M

Table 2.--Ground-water hydrologic data stations--Continued

County	Well number	Name of well	Depth (ft)	Aquifer	Type of data
Oceana	13N 15W 18AAAA1	Hesperia	79	OTSH	R,QC
Ogemaw	23N 01E 02BAAA1	Rose City Road,D	105	GLCL	Q
	02BAAA2	Rose City Road,S	20	GLCL	Q,QC
Ontonagon	51N 41W 08BDBC1	Silver City	100	FRED	Q,QC
Otsego	30N 03W 19ABBB1	Gaylord	90	OTSH	M,QC
Presque Isle	33N 06E 8BBBB1	Styma	61	TRVR	Q,QC
Roscommon	24N 02W 20BABA1	Exp. Station	14	GLCL	R,QC
Saginaw	10N 01E 22DADA1	Marion Springs,D	210	SGNW	R,QC
Sanilac	13N 13E 12ADAA1	Minden Game Area	130	MRSL	R,QC
Schoolcraft	45N 13W 16CCCB1	Seney	154	LMSN	R,QC
	47N 16W 30BBBB1	Cusino CCC	57	PRDC	R,QC
Van Buren	02S 13W 02BBCD1	Almena, D	108	GLCL	M
	02BBCD2	Almena, S	44	GLCL	M
Washtenaw	02S 03E 09DAAB2	Waterloo Park	48	GLCL	R,QC
	03S 06E 16BCCD1	Ann Arbor and pesticide analyses	55	GLCL	R,QC
	07E 05BB	Ypsilanti, Supericr	69	GLCL	R
	09ADBC1	Ypsilanti,Gilbert	94	GLCL	R
	24CA1	Ypsilanti Township 104	87	GLCL	R
	24CD	Ypsilanti Township 117	75	GLCL	R
Wexford	22N 12W 13BA	Harrietta Fish Hatchery	141	GLCL	R

1/ Local well number: For explanation of well numbers see introduction to table.

2/ Aquifer:

GLCL - Glacial deposits; Pleistocene
OTSH - Outwash; Pleistocene
SGNW - Saginaw Formation; Middle Pennsylvanian
MRSL - Marshall Formation; Lower Mississippian
TRVR - Traverse Group; Middle and Upper Devonian
DUND - Dundee Formation; Middle Devonian
DRRV - Detroit River Group; Lower Devonian
SLINT - Saline Formation; Middle and Upper Silurian
MNSQ - Manistique Group Middle Silurian
LMSN - Upper Ordovician limestones
TBRV - Black River and Tenton Groups; Middle Ordovician
PRDC - Prairie du Chien Group; Lower Ordovician
MNSG - Munising Sandstone; Upper Cambrian
FRED - Freda Sandstone; Precambrian

3/ Type of data:

Ground-water levels: R - Continuous record
D - Daily measurement
W - Weekly measurement
M - Monthly measurement
Q - Quarterly measurement
A - Annual measurement
I - Intermittently

Quality analyses: QC - General chemical, organic,

SOURCES OF INFORMATION

The U.S. Geological Survey publishes an annual series of reports, "Water Resources Data for Michigan," in which hydrologic data collected for each water year (October 1 to September 30) are included. The Survey publishes another annual series of reports "Ground-Water Data for Michigan", in which ground-water data collected for each calender year are included. These reports are available upon request to the District Chief. Topographic maps showing areas inundated by 100-year floods are available from the District office. Additional information on surface- and ground-water conditions in Michigan is given in reports shown in the following published reports listing (table 3). Inquires concerning the availability of these reports should be addressed to:

District Chief
Water Resources Division
U.S. Geological Survey
6520 Mercantile Way, Suite 5
Lansing, Michigan 48911
Telephone: (517) 377-1608
(FTS) 374-1608

or

Director
Michigan Department of Natural Resources
Stevens T. Mason Bldg.
Box 30028
Lansing, Michigan 48909
Telephone: (517) 373-2329

or

Chief Hydrologist
U.S. Geological Survey
420 National Center
Reston, Virginia 22092

Table 3.--Published reports

Allen, W. B., 1977, Flowing wells in Michigan, 1974: Michigan Geological Survey Information Series Report 2, 27 p., 5 figs, 2 pls., 16 refs.

Allen, W. B., Miller, J. B., and Wood, W. W., 1972, Availability of water in Kalamazoo County, Michigan: U.S. Geological Survey Water-Supply Paper 1973, 129 p., 36 figs, 9 pls., 34 refs.

Ash, A. D., and others, 1958, Sloan-Deer Creek Basins--Report 1, Hydrologic studies of small watersheds in agricultural areas of southern Michigan: Michigan Water Resources Commission, 77 p., 17 maps, 13 figs., 9 tables.

Bedell, D. J., and Van Til, R. L., 1979, Irrigation in Michigan, 1977: Michigan Department of Natural Resources, Water Management Division, 44 p., 10 figs., 5 tables, 13 refs.

Bedell, D. J., 1982, Municipal water withdrawals in Michigan: Michigan Department of Natural Resources, Water Management Division, 43 p., 14 figs., 2 tables, no refs.

Bent, P. C., 1970, A proposed streamflow data program for Michigan: U.S. Geological Survey Open-File Report, unnumbered, 44 p., 5 figs., 8 tables, 1 pl.

Bent, P. C., 1971, Influence of surface glacial deposits on streamflow characteristics: U.S. Geological Survey Open-File Report, unnumbered, 37 p., 5 tables, 11 refs.

Brown, E. A., and Stuart, W. T., 1951, Ground-water resources of the glacial deposits in the Bessemer Area, Michigan, 1950: Michigan Geological Survey Progress Report 14, 68 p., 8 figs., 8 tables, 8 refs.

Croskey, H. M., and Holtschlag, D. J., 1983, Estimating generalized flood skew coefficients for Michigan: U.S. Geological Survey Water-Resources Investigation Report 83-4194, 27 p., 4 figs., 4 tables, 6 refs.

Cummings, T. R., 1973, Relation of channel slope to reaeration of Michigan streams: U.S. Geological Survey Open-File Report, unnumbered, 19 p., 5 figs., 1 table, 4 refs.

Cummings, T. R., 1980, Chemical and physical characteristics of natural ground waters in Michigan: A Preliminary report: U.S. Geological Survey Open-File Report 80-953, 34 p., 12 figs., 5 tables, 13 refs.

Cummings, T. R., 1984, Estimates of dissolved and suspended substance yield of stream basins in Michigan: U.S. Geological Survey Water-Resources Investigations Report 83-4288, 57 p., 4 figs., 14 tables, 2 refs.

Cummings, T. R., and Miller, J. B., 1982, Time of travel of the Flint River, Utah Dam to Highway M-13, Michigan: U.S. Geological Survey Open-File Report 82-853, 21 p., 1 pl., 11 figs., 4 tables.

Cummings, T. R., Twenter, F. R., and Holtschlag, D. J., 1984, Hydrology and land use in Van Buren County, Michigan: U.S. Geological Survey Water-Resources Investigations Report 84-4112, 124 p., 31 figs., 2 pls., 4 tables, 25 refs.

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