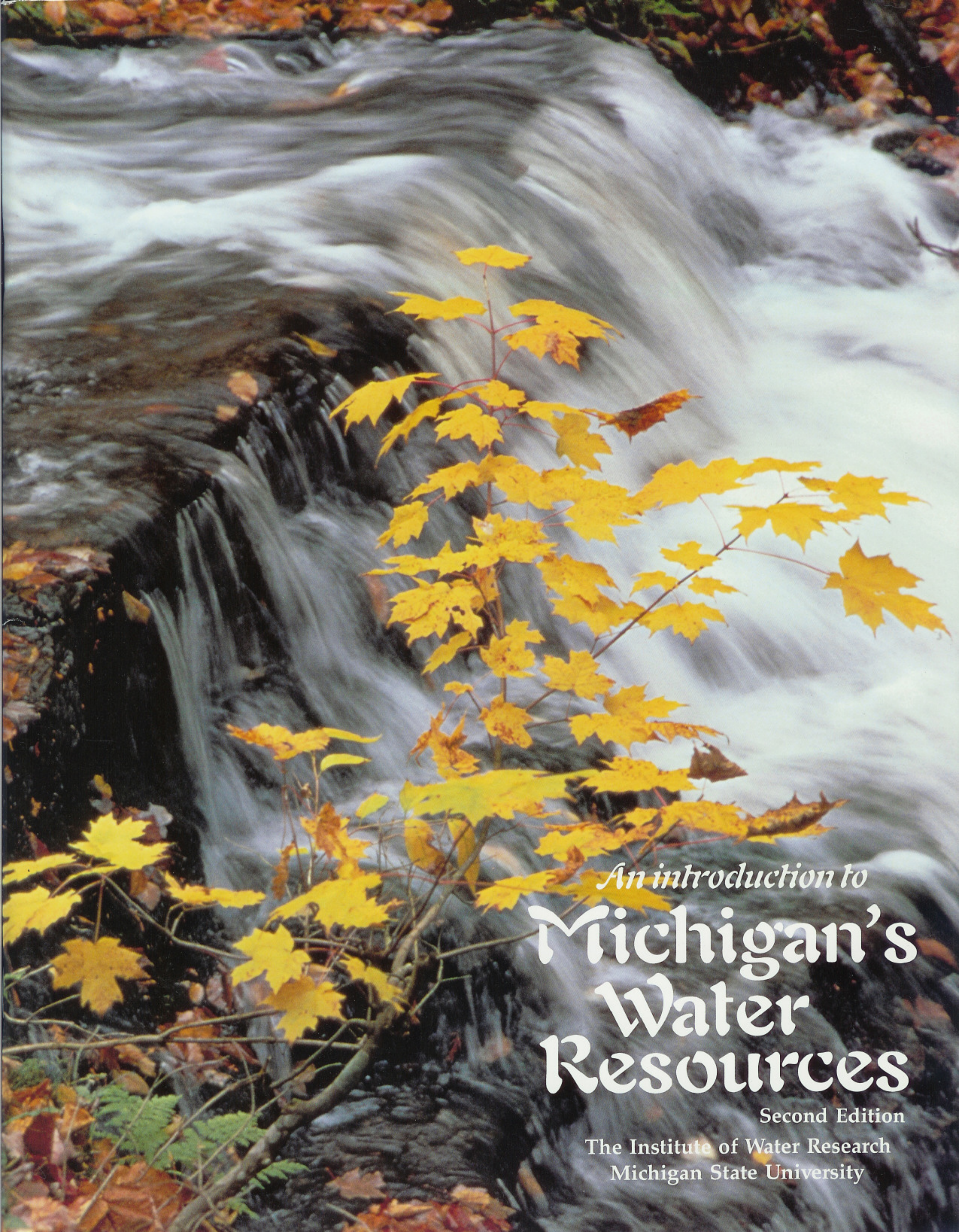

An introduction to

Michigan's Water Resources

Second Edition

The Institute of Water Research
Michigan State University

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Contents

Disclaimer Statement

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Preface

As Michigan citizens have become increasingly aware of and interested in the quantity and quality of the state's waters, the Institute of Water Research has recognized the need for a single document that describes the state's water resources. This was reinforced by the recommendation of the Great Lakes and Water Resources Planning Commission for a program to educate concerned citizens and local officials on all aspects of the waters of Michigan. This publication was designed to contribute to the fulfillment of that need.

The result of this project is *An introduction to MICHIGAN'S WATER RESOURCES,* a single comprehensive document describing the availability, distribution, quality, and uses of Michigan's water resources. Written for citizens and government officials, as well as students, this document strives to provide a foundation for understanding the hydrologic cycle and human influences on it. The maps, illustrations, and text give an overview of inland surface water, groundwater, and the Great Lakes. Economic and environmental trade-offs are discussed, and choices concerning alternative management practices are left to the reader. However, other sources such as "Water Resources for the Future: Michigan's Action Plan" do provide recommendations and plans for management of the state's water resources.

The process of compiling the materials revealed a vast amount of information on this subject scattered throughout many publications. In condensing it into a single document, much of the detail was omitted and concepts were simplified. Together, the text, maps, and graphics are intended to offer the reader an overview of the scientific concepts but not the comprehensive detail required to draw conclusions and formulate a plan of action for a particular situation. In this second edition, maps, facts, and figures depicting Aquifer Vulnerability, Act 307 Sites of Environmental Contamination, and Distribution of Act 307 Sites by Source have been updated to reflect the current state of knowledge.

Michigan's unique geographical location provides a wealth of freshwater resources which contribute to the diverse agricultural, industrial, and recreational opportunities of the state. However, a myriad of activities can stress this fragile resource and lead to further degradation of our waters. Therefore, to manage the state's water resources properly, government officials and the general public need to understand the interactions among the many aspects of the water cycle. It is hoped that this publication will serve as an educational link in that process.

This project was supported, in part, by the U.S. Geological Survey, U.S. Department of the Interior under the State Water Resources Research Program (P.L. 98-242).

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FIGURE 1-1. Major Lakes and Rivers

1 Place of Great Waters

Water has always been Michigan's most important and distinguishing resource. Since earliest times, Native Americans fished these waters for food and traveled by canoe along well established water routes. Early European exploration of Michigan took French traders along northern waterways where they sought a new trade route to the riches of China. These Voyageurs traveled north on Lake Huron, up the St. Marys River and into Lake Superior. The first centers of trade were established in Sault Ste. Marie and St. Ignace, and later in Detroit. Although they found riches, it was not China they had discovered, but *Michi Gama*, place of *Great Waters*.

Not only does the origin of the state's name lie in this Native American term, but many Michigan cities derive their meaning from nearby waters. Grand Rapids, Big Rapids, Bay City and Harbor Springs are a few examples. *Detroit* is French for *of the strait* and describes its position on the Detroit River which connects Lake St. Clair with Lake Erie (Figure 1-1).

If you seek a pleasant peninsula, look about you. The state motto reflects that Michigan's geography is dominated by water. Its land mass consists of two peninsulas. The lower peninsula, in the shape of a mitten, is bounded by Lake Michigan on the west and Lake Huron and Lake Erie on the east. The upper peninsula lies between Lake Superior on the north and Lakes Michigan and Huron on the south.

Michigan ranks 23rd in size among the fifty states with a land area of 58,216 square miles. Of the state's official total water and land area of 96,791 square miles, roughly 40 percent is covered by the Great Lakes, and over 1,000 square miles are inland lakes and ponds. With 3,288 miles of Great Lakes shoreline, Michigan has a longer coastline than any state except Alaska.

In addition, Michigan has over 35,000 mapped inland lakes with a surface area of one-tenth of an acre or more. Houghton Lake is the largest inland lake encompassing over 30 square miles. Gogebic Lake, the upper peninsula's largest lake, and the state's sixth largest, covers 20 square miles.

More than 200 Michigan rivers with a total length of 36,350 miles flow to the Great Lakes, and some of the best sport fishing in the country is available along their banks. The Au Sable River, for example, is a premier fly-fishing stream.

Wetlands are also essential to much of Michigan's wildlife. Marshes, swamps, bogs and coastal wetlands provide a habitat for Canada geese, blue herons, ducks, and beavers, along with a variety of plants such as sundew, lady's slipper, and pitcher plant. Wetlands are also important for controlling water levels and maintaining water quality downstream. A rare ten acre salt marsh along the Maple River supports vegetation normally found only in the coastal marshes of the Atlantic seaboard. This salt marsh was produced by an upwelling of groundwater through salt formations that lay hundreds of feet below the land surface.

Michigan's water also provides an environment rich in unique and beautiful physical features. Islands, parks, bridges, sand dunes and some 150 waterfalls are highlights of Michigan's landscape. Isle Royale, Beaver Island, the Manitou Islands, Mackinac Island, and Belle Isle are just a few of Michigan's picturesque islands. Whether a wilderness preserve or an urban park, they are a world apart from the mainland. Tahquamenon Falls is perhaps Michigan's most spectacular waterfall. East of the Mississippi, Tahquamenon's Upper Falls, which are 200 feet wide with a plunge of nearly 50 feet are second in size only to

Niagara Falls. The Mackinac Bridge was built to span the Straits of Mackinac and connect Michigan's two peninsulas. The Soo Locks made modern shipping possible around the St. Marys Falls at Sault Ste. Marie. These engineering accomplishments are examples of the efforts made to overcome obstacles presented by water and the pervasive changes which can result from such intervention.

Water's unique qualities as a resource make it critical to protect, yet it is profoundly difficult to manage. We cannot survive without freshwater and our standard of living is largely dependent on an adequate supply of clean water. Land ownership entitles us to make reasonable use of both groundwater and the surface water adjacent to the land, but individuals do not own the water. Because water is mobile and flows among lakes, streams, and groundwater, the use one landowner makes of water affects the quality and amount available to other users. Agricultural irrigation, an industry's use of water in manufacturing, and a rural homeowner's septic system can all overlap in needs and uses of water.

Surrounded by the largest source of freshwater available in the world, Michigan residents have a special responsibility to act as careful and willing stewards of their water resources. In order to act responsibly, Michigan citizens and leaders need a thorough understanding and special appreciation of water to properly manage and adequately protect it now and in the future.

The Hydrologic Cycle

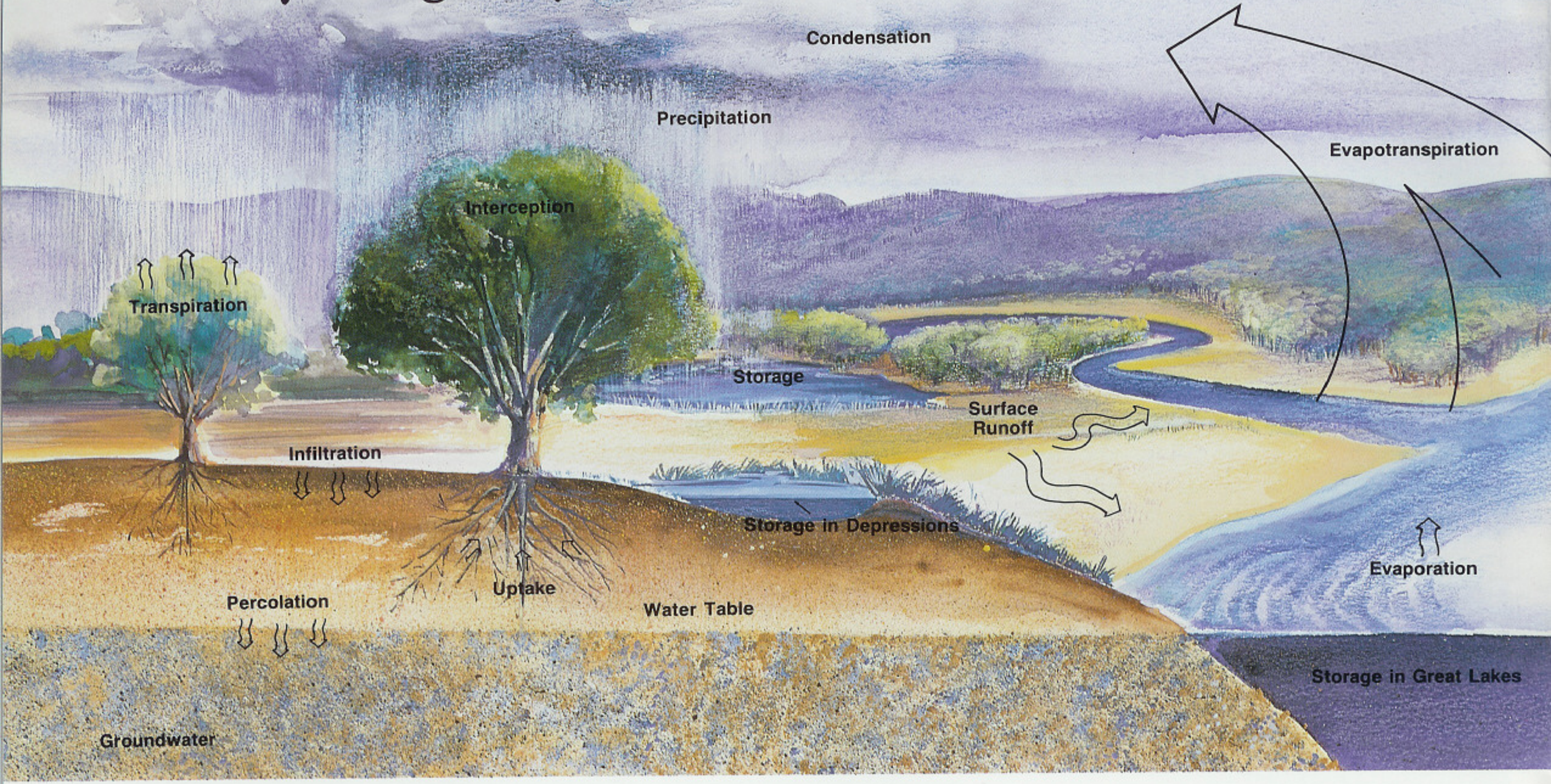


FIGURE 1-2. Water continuously travels between the atmosphere, the surface, and below ground. This movement, driven by the energy of sun and the force of gravity, supplies the water needed to support life.

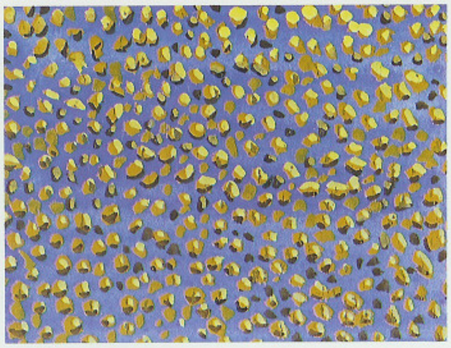
From a raging stream during spring snowmelt, to a gentle summer rain, to the slow movement of water through the ground, the water around us is in constant motion. The movement and endless recycling of water between the atmosphere, the land surface, and underground is called the hydrologic cycle (Figure 1-2). Understanding the hydrologic cycle is basic to understanding all water and is a key to the proper management of Michigan's water resources.

Following the Pathways

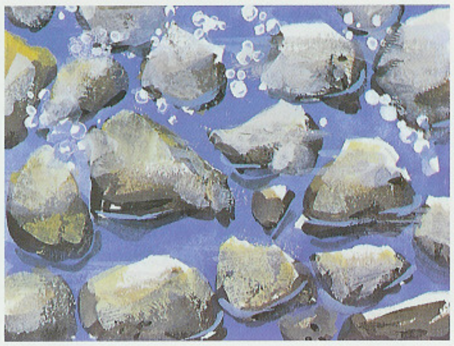
Water that falls to the ground as precipitation follows many paths on its way back to the atmosphere. The water may be intercepted and taken up by plants; it may be stored in small depressions or lakes; it can infiltrate the soil; or it can flow over the surface to a nearby stream channel. The energy of the sun may evaporate the water directly back into the atmosphere, or the force of gravity may pull it down through the pores of the soil to be stored for years as slowly moving groundwater. Some of the water flowing through the ground returns to the surface to supply water to springs, lakes, and rivers. In Michigan, most of the water entering rivers and streams eventually flows to the Great Lakes. Nearly all water in the Great Lakes flows to the St. Lawrence River and eventually to the Atlantic Ocean. Water completes the hydrologic cycle by evaporating from the surface to re-enter the atmosphere.

Precipitation

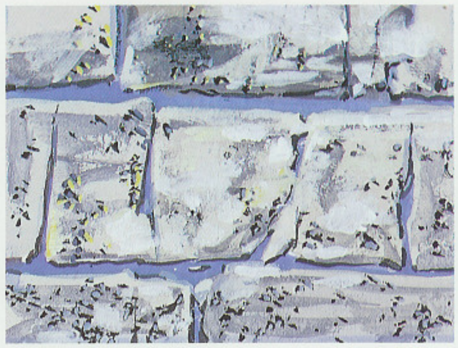
Water vapor is transported by winds and air currents through the atmosphere. When the air mass cools sufficiently, the water vapor condenses into clouds, and a portion falls to the ground as precipitation in the form of snow, rain, sleet, or hail.



Sand



Gravel



Limestone

FIGURE 1-3. The amount and location of pore spaces determine how fast water will flow through soil or rock.

What is a Watershed?

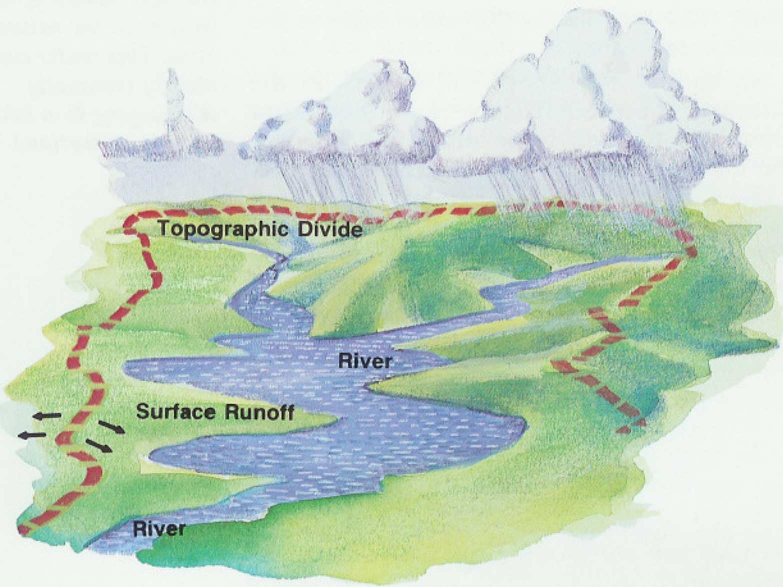


FIGURE 1-4. Watersheds are defined by topographic divides which separate surface flow between two water systems. All of the land which eventually drains to the same lake or river is in the same watershed.

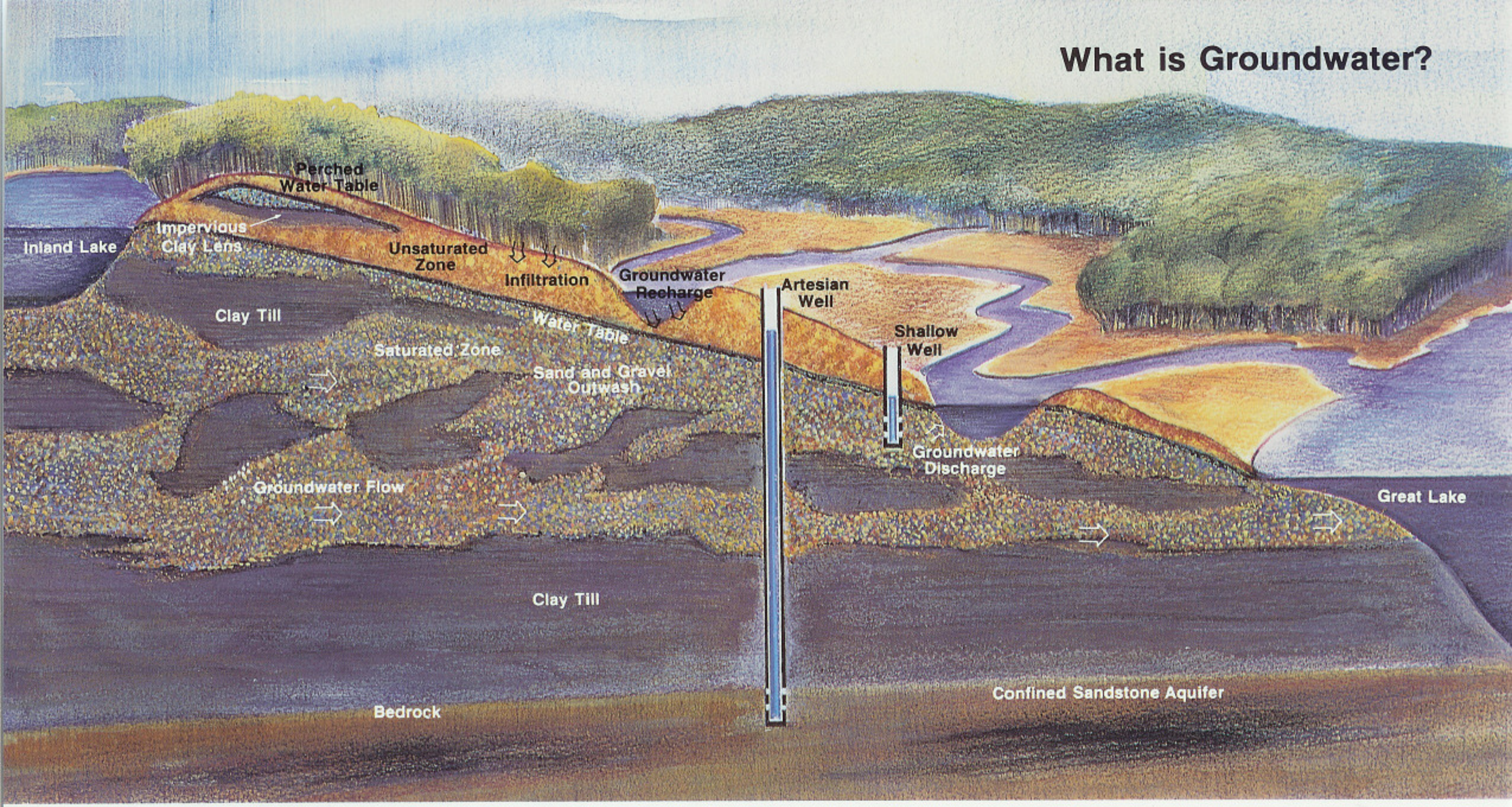
Evaporation and Transpiration

Water reaching the surface of the ground can return to the atmosphere as vapor through the process of evaporation. Water in streams and lakes or held in soil near the surface may also evaporate. Water used by plants may return to the atmosphere as vapor through transpiration which occurs when water passes through the leaves of plants. Collectively known as evapotranspiration, both evaporation and transpiration occur in greatest amounts during periods of high temperatures and wind, dry air, and sunshine.

Infiltration and Soils

Several factors influence the rate and amount of water that infiltrate soil. Soil is made up of tightly packed particles which can be of many shapes and sizes (Figure 1-3). As water reaches the land surface, it can seep downward through the pores between soil particles. A high porosity soil has the ability to hold large amounts of water due to the presence of many pore spaces. If the pores are well connected and allow water to flow easily, the soil is said to be permeable. The size and shape of clay particles along with the arrangement of the pores between these particles cause clay soils to resist infiltration. Sands and gravels allow more rapid infiltration due to porosity and high permeability.

The initial water content of the soil is also important. In general, water infiltrates drier soils more quickly than wet soils. The intensity of a storm, or the length of time during which precipitation occurs, can also influence infiltration. If rain or snowmelt reaches the soil surface faster than it can seep through the pores, then the water pools at the surface, and may run downhill to the nearest stream channel. This limitation on the soil's capacity to allow infiltration is one of the reasons why short, high intensity storms produce more flooding than do lighter rains over a longer period of time.



Surface Runoff and the Watershed

That portion of water which does not infiltrate the soil but flows over the surface of the ground to a stream channel is called surface runoff. Water always takes the path of least resistance, flowing downhill from higher to lower elevations, eventually reaching a river or its tributaries. All of the land which eventually drains to a common lake or river is said to be in the same watershed (Figure 1-4). Watersheds are defined by topographic divides which separate surface flow between two water systems. Use of the watershed as a water management unit continues to gain support because all of the water-related issues which arise for a particular lake, river, or watershed can then be managed as a whole.

Groundwater

Where water infiltrates the ground, gravity pulls the water down through the pores until it reaches a depth in the ground where all of the spaces are filled with water (Figure 1-5). At this point, the soil or rock is said to be saturated, and the water level which results is called the water table. The water table is not always at the same depth below the land surface. During periods of high precipitation, the water table can rise. Conversely, during periods of low precipitation and high evapotranspiration, the water table falls. The area below the water table is called the saturated zone, and the water there is called groundwater. The area above the water table is the unsaturated zone.

An aquifer consists of soil or rock in the saturated zone that can yield significant amounts of water. In an unconfined aquifer the top of the aquifer is defined by the water table. Confined aquifers are bound on the top by impermeable material, such as clay. Water in a confined aquifer is normally under pressure and can cause the water level in a well to rise above the water table. If the water rises above the ground surface it is said to be a flowing artesian well. A perched water table occurs when water is held up by a low permeability material and is separated from a second water table below by an unsaturated zone (Figure 1-5).

In the saturated zone, groundwater flows through the pores of the soil or rock both laterally and vertically. The ease with which water moves through the ground is influenced by the glacial and bedrock geology of an area. In Michigan, glaciers covered much of the land surface and left behind till, outwash, and lacustrine (lake) deposits. Till is a mixture of soil and rock ranging in size from clay particles to boulder-size rocks. Tills generally have low permeability due to the presence of clay. Outwash consists primarily of highly permeable

FIGURE 1-5. Groundwater is the water that exists in the pore spaces of the soil or rock in the saturated zone. This water can move slowly eventually discharging to a lake, stream, or wetland.

sand and gravel that allow groundwater to flow easily. Lacustrine deposits can be clay, silt, or sand, and their permeability depends on the sediment type.

The type of bedrock formations under glacial deposits also influences groundwater movement. Sandstone can transmit water if the pores between grains are connected, giving the rock a high permeability. Limestones fractured with many connecting cracks can also transmit water easily. Fine grained rocks such as shale and slate generally have a low permeability.

Water moving from an aquifer and entering a stream or lake is called groundwater discharge, whereas any water entering an aquifer is called recharge. In Michigan, groundwater typically discharges from aquifers to replenish rivers, lakes, or wetlands. An aquifer may receive recharge from these sources, an overlying aquifer, or more commonly from precipitation followed by infiltration. The recharge zone is that area, either at the surface or below the ground, which provides water to an aquifer and may encompass most of the watershed.

All of the above and below ground areas that drain to the same lake or stream are in the same watershed. Land use activities in a watershed can affect the quality of the groundwater, especially through infiltration of pollutants, and can affect surface water quality as contaminants are carried with groundwater discharge. Understanding the factors which influence the rate and direction of groundwater flow helps to determine where good water supplies exist and how contaminants migrate.

The Human Influence

In the days of fur trading and canoe travel, the impact of human activity on water moving through the hydrologic cycle was minimal. In the early 1800s, with the discovery of copper and iron ore reserves in the upper peninsula and the development of Michigan's territorial lands, a noticeable impairment and exploitation of Michigan's natural resources began. Today, the water resources of the state still suffer from early mining activities. For example, disfiguring tumors on the fish in Torch Lake in Houghton County are suspected to be the result of past disposal of copper mining wastes.

The network of rivers flowing from the center of the state to the Great Lakes made easy access between interior forests and markets throughout the world. In fact, the first reported court ruling on water rights involved a dispute between logging companies who used the rivers to float their logs to mills and the owners of the land that bordered those rivers. Commercial logging began in Michigan around 1830 and peaked between 1860 and 1900. In just a few decades, Michigan's great forests were devastated, and the golden age of lumbering in Michigan came to a close.

Areas of groundwater are still contaminated with tannin and resins from waste disposal at pulp mills. In the Manistee area, rural wells have been contaminated with a thick black liquid, which seeped from pulp wastes in lagoons. Lagoon disposal has not been used at this site since 1970, yet the plume of contamination in the groundwater remains, some 17 years later. Seepage from lagoons is one of the many disposal practices that was an accepted method at the time, but it had devastating effects on water quality and is no longer permitted.

During the nineteenth century, the waters of the Great Lakes supported a thriving commercial fishing industry. Although the fishing business flourished on enormous catches of whitefish and lake trout in the late 1800s, overfishing contributed to a steady decline of a prolific commercial fishing industry in Michigan. Another major factor was the invasion of the parasitic sea lamprey, which migrated to the Great Lakes via the Erie and Welland canals between 1920 and 1950, and all but eradicated deep water fish such as lake trout and whitefish in the lower lakes. A control program using a chemical that killed larval lampreys began in 1960 and resulted in a substantial decline in the lamprey population. This, in turn, contributed to an improved survival rate of lake trout and other game species and helped make possible the establishment of Michigan's salmon sport fishery.

In the wake of the logging boom, thousands of pioneers migrated here in search of fertile, agricultural lands to buy or homestead. During this period, many of Michigan's wetlands were drained and put into agricultural production. While the fertile soils in the southern part of the state and the prime weather conditions along Lake Michigan supported successful agriculture, much of the clear cut land in the north was not well adapted to crops and became reforested.

By the turn of the century, the Michigan economy was shifting from trapping, mining, logging, fishing, and farming to manufacturing. By 1910, more than half the population resided in urban rather than rural areas, and Michigan was the undisputed automobile capital of the world.

Today, land use and land cover in Michigan reflect both the impact of natural resources on human activity and a human influence on the environment (Figure 1-6). Land use is still primarily urban in much of southeastern Michigan and in such cities as Flint, Bay City, Saginaw, Lansing, Grand Rapids, Kalamazoo, Battle Creek, and Muskegon. Outside of these areas, land use is primarily rural. While the automobile industry continues to be of primary economic importance, agriculture and related products hold second place. Agriculture dominates the southern part of the state, while northern Michigan is primarily forests and wetlands.

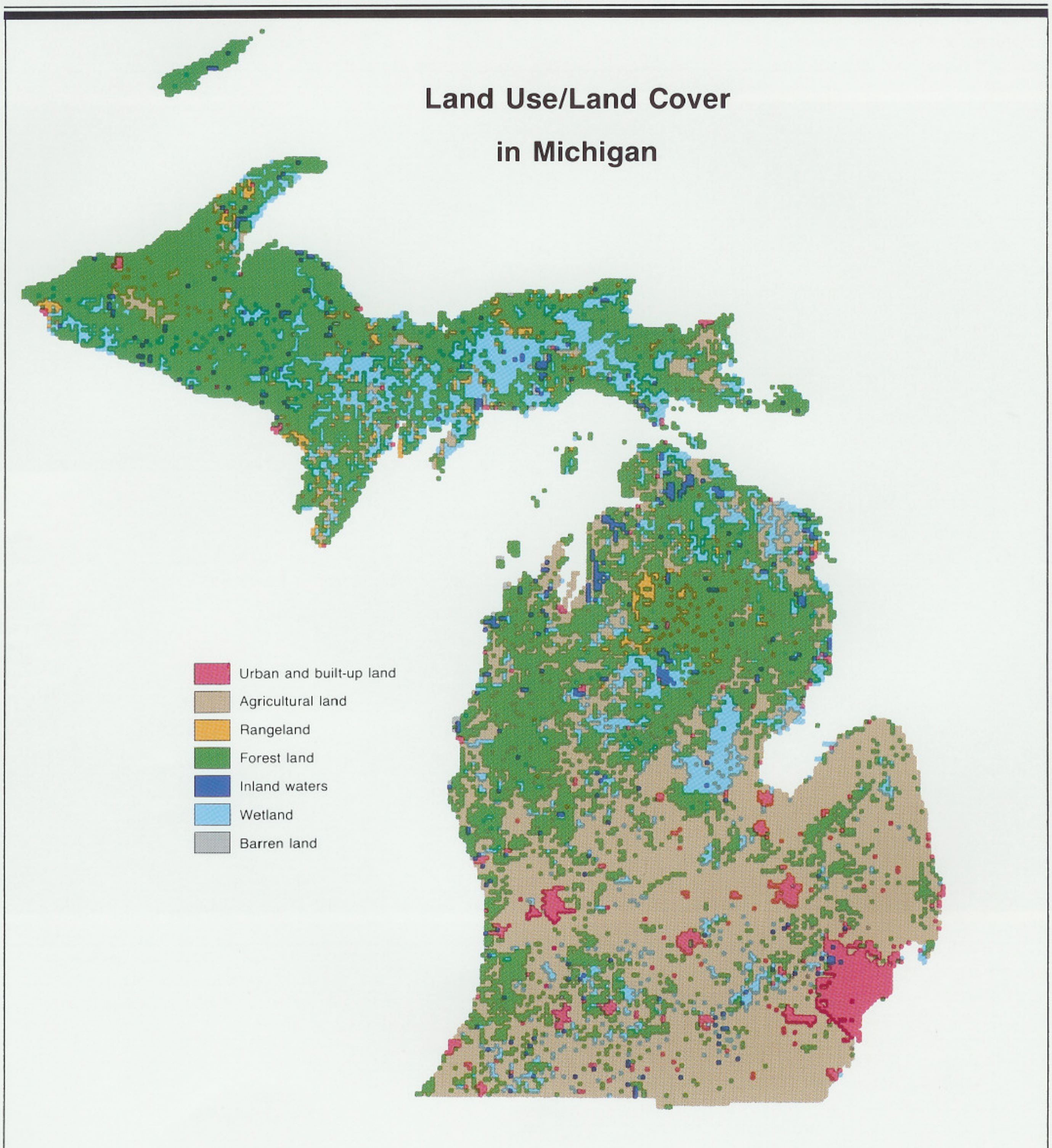
The land use map (Figure 1-6) does not indicate the increasing importance and growth of the recreation and tourism industry which is third in economic importance in the state. Tourism relies heavily on water oriented activities. Michigan has more licensed anglers than any other state and ranks first in the number of boats registered. Sport fishing, boating, lake cottages, and resorts are major income producers and are important to the economy of the state.

Efforts are being made to encourage new businesses such as pharmaceuticals, electronics, food processing, and others which require high quality water for their products. In addition, expanded use of irrigation could greatly increase agricultural productivity. The success of business, industry, and agriculture in Michigan will depend on a continued adequate supply of clean water.

In addition, it is likely that the decision to locate or remain in Michigan will involve business executives' perceptions of the quality of the environment in which they, their families, and employees will be living and working. The high property values near freshwater lakes reflect the demand for a quality environment. Likewise, plummeting property values near sites of environmental contamination attest to the fact that people have a strong preference for a safe, clean environment.

It would be erroneous to imply that only past land use practices affect water resources or that all land use practices are harmful. In the past, water management issues were presented as a trade-off between economic profit and environmental health. Past mistakes have shown that poor use of resources often means short-term gains with high, long-term costs. While water resource managers are learning from past mistakes, a balance must still be maintained among all users of water. Developmental pressures, consumer demands, employment opportunities, and multiple use conflicts are issues affecting water that must be resolved within the limitations of the resource. The judicious use and management of Michigan's water resources is a challenge that now faces citizens, local government officials, legislators, and business and water resource managers.

FIGURE 1-6. Outside of the urban areas of southern Michigan and other major cities, land use is primarily agricultural. In the northern part of the state, forests predominate. **Source: Center for Remote Sensing, Michigan State University, East Lansing, MI.**



2 Water Availability and Distribution

Michigan's landscape varies greatly as one travels across the state, and so does the quantity of water encountered. Michigan owes its great water heritage to the glaciers that retreated 10,000 years ago leaving a rough and varied terrain which has evolved into a verdant landscape interrupted by cold winter reminders of the area's icy past.

Climate

The Great Lakes dramatically affect Michigan's climate. Although weather in Michigan fluctuates daily, the overall seasonal patterns are moderated by the Great Lakes. Michigan's summers are cooler and winters warmer than the harsh extremes found in states of equal latitude.

Moisture is picked up by air masses passing over the Great Lakes, producing cloudy conditions. That moisture which is released over land is called lake effect precipitation. In Michigan, nearly one day in every three receives precipitation. The greatest annual precipitation falls in southwestern Michigan because it receives moist air from the Gulf of Mexico (Figure 2-1). Less lake effect precipitation and limited summertime atmospheric moisture result in lower annual precipitation for the northeastern portion of the lower peninsula. In the western upper peninsula, moisture from Lake Superior is largely responsible for the production of upwards of 300 inches of snowfall per year. Because snow falls in many forms, from a light powder to heavy and wet, it is melted and reported in inches of equivalent water. Most areas of Michigan receive the highest amounts of precipitation in the spring and summer and the least in fall and winter. By adding moisture to the air, the Great Lakes increase the overall quantity of water in Michigan, producing a landscape rich with lakes and rivers.

Rivers

The Great Lakes divide Michigan into two peninsulas which lie almost entirely within the Great Lakes watershed. Michigan has many rivers and streams, each contained within and replenished by its own watershed, which flow short distances and empty into one of the Great Lakes (Figure 2-2). Only two small areas of land are outside of the large watershed draining to the Great Lakes; they include approximately 48 square miles in the western upper peninsula and a small area along the Indiana border, both of which eventually drain to the Mississippi River.

Although the Grand River watershed covers a major portion of south central Michigan, the Saginaw River watershed with its many large tributaries is actually the largest watershed in the state. In general, the larger the watershed, the greater the flow in the river. Progressing downstream, the river receives water from an increasingly larger land area resulting in a greater volume of water flowing in the river (Figure 2-3). Most of the river flow in the lower peninsula is to the west, draining into Lake Michigan.

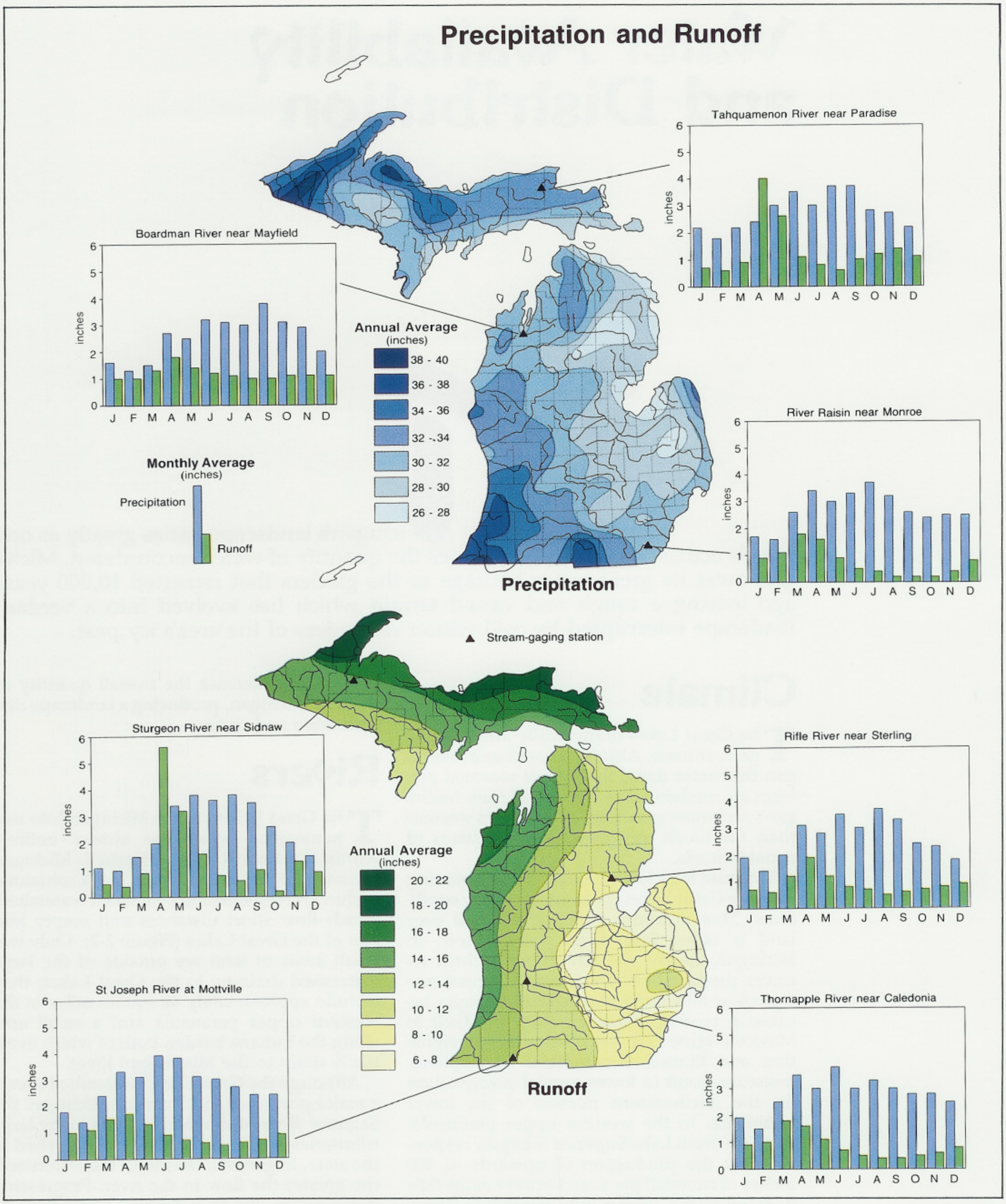


FIGURE 2-1. Annual precipitation in Michigan ranges from 28 to 38 inches. Runoff depends not only on precipitation but on the geology, topography and development, and ranges from 8 to 20 inches. Monthly average values at representative sites indicate the variation in seasonal precipitation and river flow. Adapted from USGS National Water Summary 1985, and F.V. Nurnberger, State Climatologist, Michigan Department of Agriculture.

The amount of water passing a point in the river over a given period of time, or simply the flow, is also referred to as runoff (Figure 2-1). Not to be confused with surface runoff, runoff is all the water in the stream channel and includes water reaching the river through groundwater discharge, surface runoff, and precipitation directly on the water surface. Runoff, when reported in inches, can be equated with inches of precipitation that are not lost from the watershed through evapotranspiration, but reach the river during each year. The western side of the lower peninsula and the northwest portion of the upper peninsula have the highest amounts of runoff. These areas also have high precipitation and lower temperatures, resulting in less evapotranspiration. Records of past stream flows are useful in designing and operating wastewater treatment plants, in building bridges, and in estimating the possibility and extent of future floods.

The flow in Michigan rivers changes throughout the year (Figure 2-1). In general, flow is greater in late winter and early spring when snowmelt and rainfall produce large amounts of surface runoff. During the spring, rivers in the upper peninsula often produce more runoff than the precipitation that falls during the same period of time. This situation is caused by the release of several months of precipitation, during spring melt, which had been stored as snow. Although summer in Michigan is a period of high precipitation, much water is lost to the atmosphere through evapotranspiration due to high solar radiation and temperatures along with lush plant cover. This water is no longer available to the watershed; consequently, the flow in Michigan rivers is lowest in late summer.

Coupled with high summer evapotranspiration, differences in geology and topography cause rivers in southeastern Michigan to show greater variability in seasonal flow patterns than those in the northwestern lower peninsula. In areas where a large portion of the runoff is supplied by groundwater, flow is more uniform throughout the year. Rivers, such as the Boardman near Traverse City, which flow over thick and very permeable surface deposits, tend to have a groundwater supply that sustains the river in summer and reduces variations in flow throughout the year. In contrast, the River Raisin in southeastern Michigan flows over less permeable materials which resist both infiltration and groundwater discharge to the river, resulting in a more significant variation in flow throughout the year and a low flow in late summer.

The quantity of water that each square mile of a watershed contributes through surface runoff and groundwater discharge to the flow in the river is called basin yield. Michigan rivers, with a high basin yield in late summer, have sufficient groundwater discharge to sustain the river flow during dry periods (Figure 2-4). In contrast, a basin with a low yield in late summer has little groundwater supply, and the stream may even dry up.

The contrast in basin yield in late summer statewide is readily apparent. In general, the west side of the state has higher basin yields due to the highly permeable sand and gravel deposits which facilitate groundwater discharge to rivers. The areas of low basin yield in southeast Michigan have low permeability glacial deposits reducing the groundwater discharge to rivers. Low basin yields in the Alpena area are a result of shallow limestone bedrock. This material allows large quantities of water to bypass the river and flow underground directly to Lake Huron.

Although Michigan has an abundant water supply, certain areas experience deficiencies during droughts. The period of least supply occurs during highest demand. For example, irrigation demands are highest during the summer months. During periods of low flow, the impacts of multiple use conflicts and wastewater discharges become even more critical. When the flow in a river drops significantly, so does its ability to support life.

The abundance of water is a benefit to the state; but at times of flooding, the excess water can have devastating effects. During normal flow a stream is contained within its channel. When intense rainfall or snowmelt produces high runoff, the rising stream level overflows its banks and covers the floodplain. The floodplain consists of the low lying areas adjacent to the stream which may become immersed in water during flooding.

Although it is impossible to predict with certainty when floods will occur, statistics are useful for describing the chance that another flood will occur in the future. On the basis of a predicted flood flow, the extent of the floodplain can be determined. Approximately six percent of Michigan's land area is considered to be prone to flooding. Although the flood

FIGURE 2-2. Michigan has been divided into fifty major watersheds. The number of watersheds in the state can vary depending on the detail of the divisions. Many smaller rivers drain directly to the Great Lakes and are unnamed regions on map. **Adapted from Western Michigan University, Hydrogeologic Atlas 1981.**

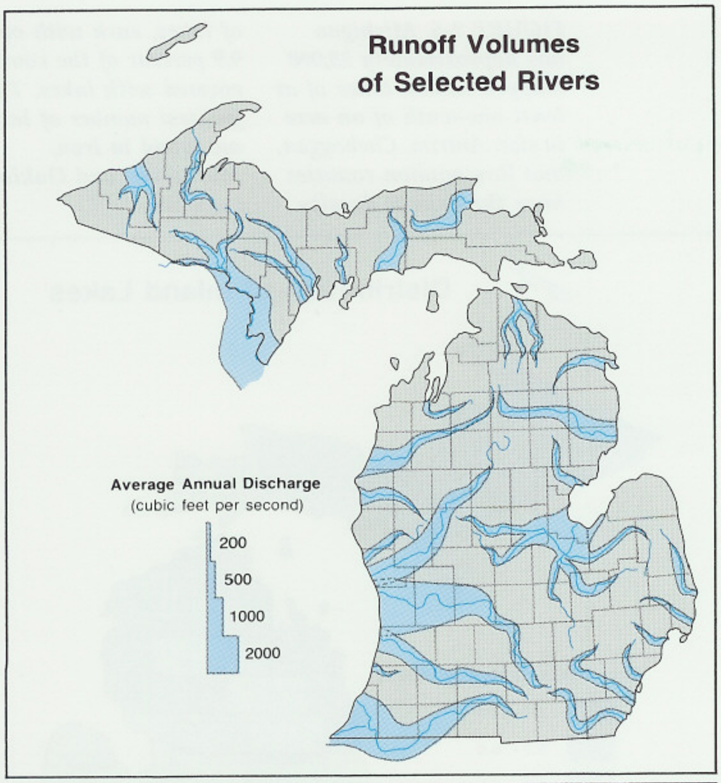


FIGURE 2-3. *Average annual flow volumes are indicated for selected rivers with sufficient flow records. Water volume in the river increases downstream because of a progressively larger land area draining to the river.*

areas are spread throughout the state, frequent flooding occurs in the southern two-thirds of the lower peninsula, especially inland areas along Lake Erie, Lake St. Clair, and the Saginaw Bay of Lake Huron.

Wetlands

In the early 1800s, the first surveyors sent into lower Michigan reported in disappointment that the whole territory was nothing but swamp land. Later surveys determined that Michigan was one-third wetland; by 1955 the wetlands occupied less than one-tenth of the state. During this period of time, wetlands were lost through development of land for agricultural production, highways, parking lots, residential and commercial building sites, industrial plants, marinas, and harbors.

Wetlands can include swamps, marshes, bogs, and hardwood forest bottomlands. Areas with wet and spongy soil are generally considered to be wetlands. They range from areas where soil is visible but saturated with water to submerged land with water too deep for plants to grow. Most wetlands have a direct connection to groundwater.

Wetlands are valuable resources ecologically, recreationally, and aesthetically. Their function and value depend upon the wetland type and location. A wetland can provide wildlife habitat, minimize bank and shoreline erosion along rivers and lakes, improve downstream water quality, provide recreational activities, and act as a water storage area during flooding. Because water is released slowly from wetlands, flood damages are reduced.

Wetlands are located in many areas of the state; those along the shores of the Great Lakes are referred to as coastal wetlands. Some of Michigan's significant wetlands include the Seney Wildlife Refuge in the eastern upper peninsula, the Kawkawlin flood project west of the Saginaw Bay area, and the wetlands along Lake St. Clair.

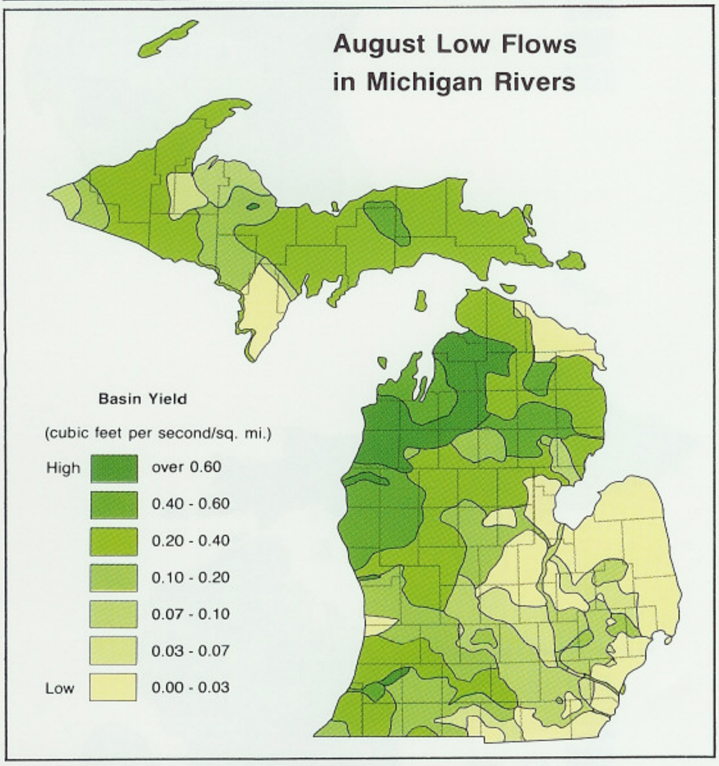


FIGURE 2-4. *Basin yield has been used to characterize drought flows in Michigan rivers. Statistically determined "minimum" flows for the month of August were used. Rivers in the northwestern lower peninsula tend to have high yields, maintaining flow through August, while rivers in southern Michigan have low yields and may even dry up.* **Adapted from Wallace and Annable 1987.**

Inland Lakes

Lakes are formed by many processes, but in Michigan the majority were formed by glaciers. Thousands of years ago, glaciers advanced from Canada, carving out large depressions which later filled with water. During the final retreat of the glaciers, large ice blocks were left to melt and form "kettle lakes." Higgins and Houghton lakes are examples of kettle lakes. Other types of smaller lakes that are less common in Michigan are oxbow lakes, which are formed when river meanders are cut off by the main stream; solution lakes or sink hole lakes, which form when underlying rocks, such as limestone, are dissolved by groundwater; and coastal lakes which result from sand bar deposits along the Great Lakes. Lakes such as reservoirs and impoundments result from damming a river. Gravel pits and other excavations can fill with water from surface runoff and groundwater discharge and form artificial lakes.

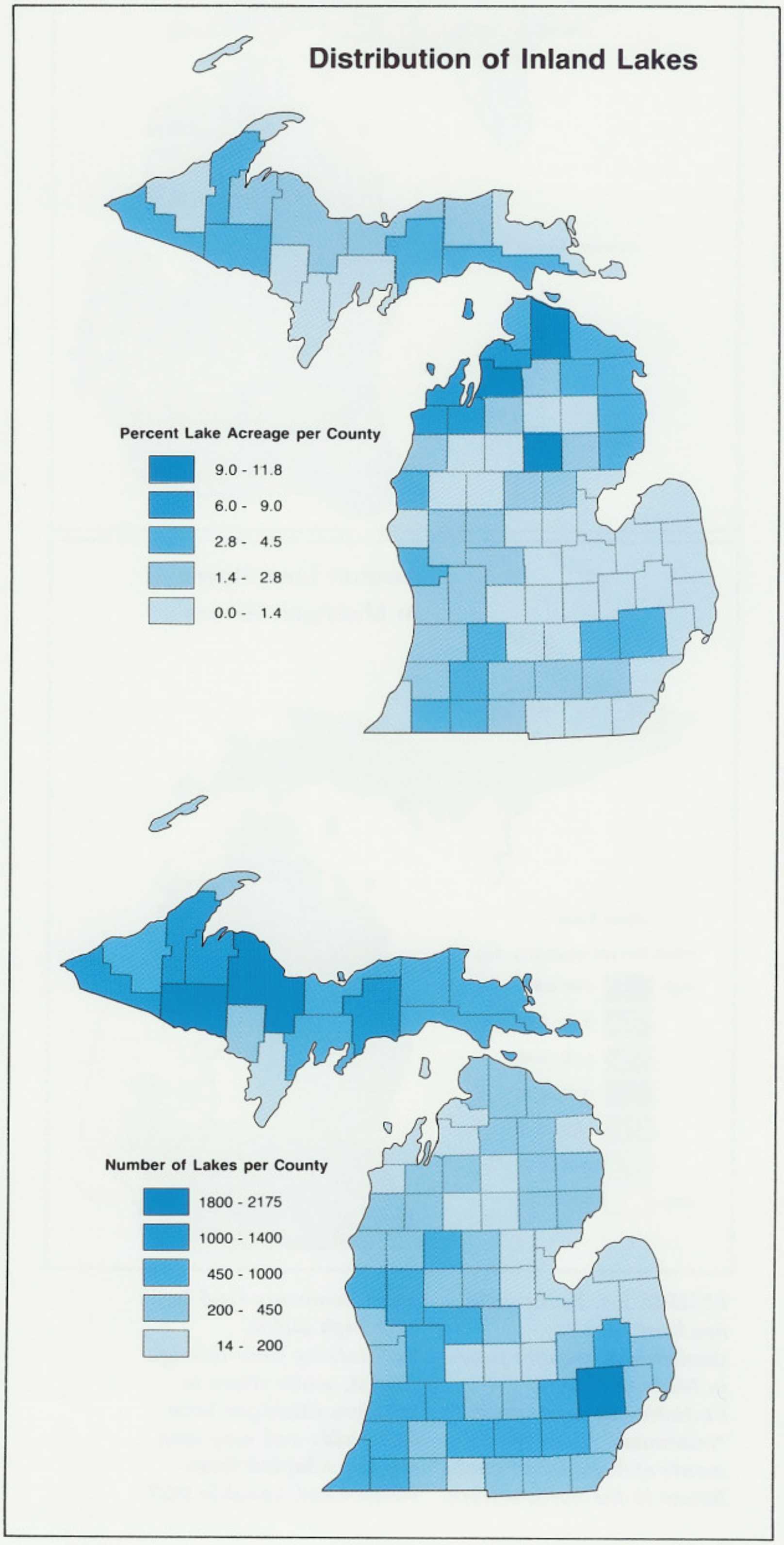
Michigan has approximately 35,000 mapped inland lakes with a surface area of at least one-tenth of an acre or greater (Figure 2-5). Roscommon and Cheboygan counties have the highest density of lakes with over 11 acres of water for every 100 acres of land. Iron County has more lakes than any other county, and Cheboygan County has the greatest total lake acreage. Of the 35,000 lakes, 11,000 are larger than five acres in surface area, and over 2,000 are more than 50 acres.

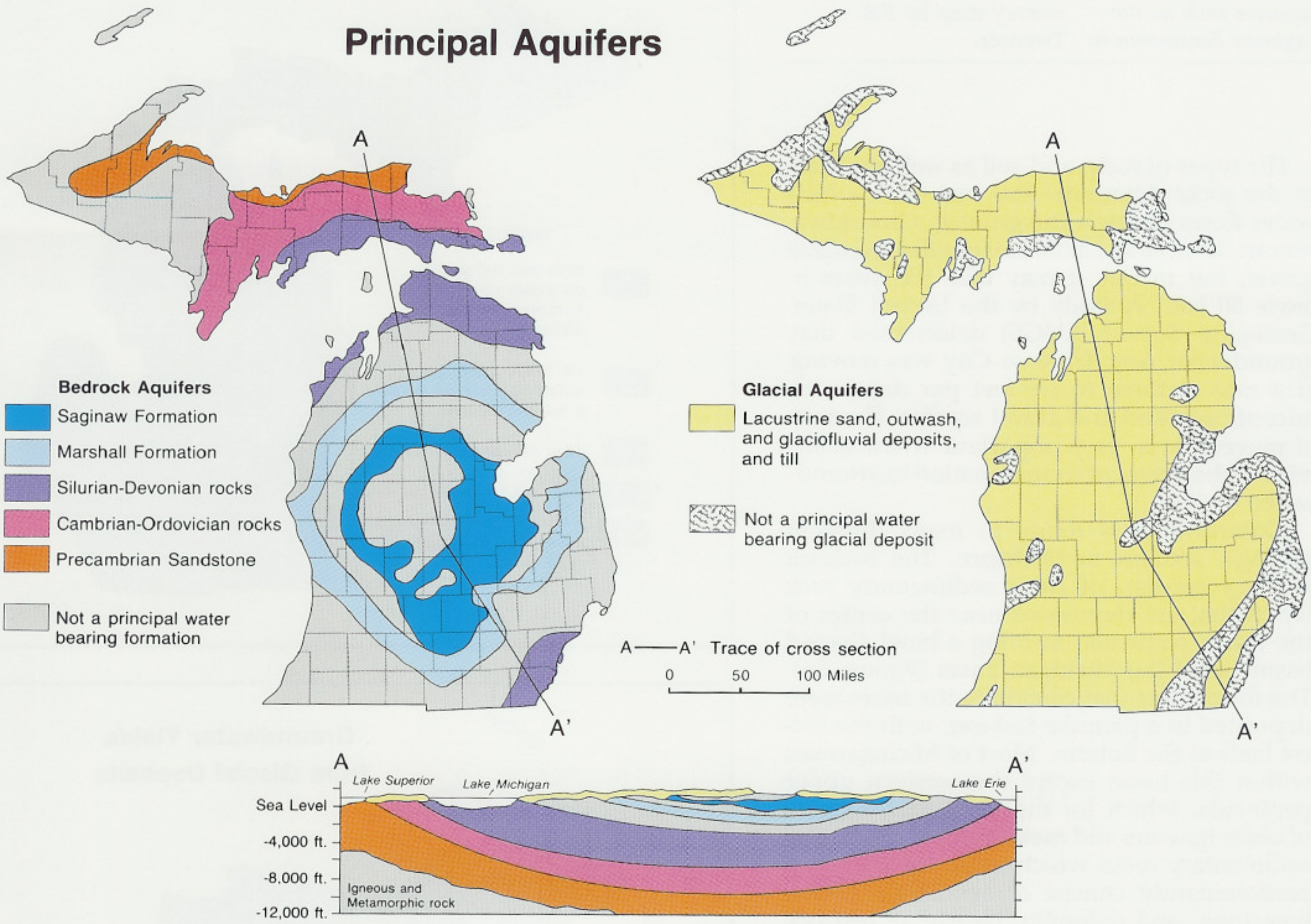
Lakes are sparse in the Saginaw Bay area where the surficial deposits consist of clays laid down at the end of the glacial period. These deposits created a land surface that is very flat, leaving poor conditions for lake formation, and their low permeability limits groundwater supply to the lake. The highest concentration of lakes is in the northwest lower peninsula where glacial processes left hills and valleys suitable for lake formation. The permeable sand and gravel of this area allow groundwater discharges that supply water to the lakes.

Groundwater

Michigan's groundwater supplies are an unseen but vital portion of the state's water resources. Many people in both rural and urban areas rely on groundwater for their sole supply of water. This water receives minimal treatment before use; therefore, its natural background quality is important. Large groundwater withdrawals can lower the water table, possibly leading to lower water levels in surrounding wells. Many Michigan rivers are supplied only by groundwater discharge during dry periods, and a lowered water table can affect stream flow.

FIGURE 2-5. Michigan has approximately 35,000 mapped inland lakes of at least one-tenth of an acre in size. Antrim, Cheboygan, and Roscommon counties have the highest density of lakes, each with over 9.9 percent of the county covered with lakes. The greatest number of lakes are found in Iron, Marquette, and Oakland counties.





Starting in the center of the lower peninsula traveling outward or drilling down through the basin, the formations encountered are:

Glacial Deposits: Found at the surface throughout most of the state, glacial deposits can extend to depths exceeding 400 feet. These deposits consist of outwash sand and gravel, lacustrine sand, silt and clay, along with till made up of clay to boulder-size particles. Deposits with sand and gravel tend to be better aquifers than those with clay.

Jurassic Red Beds: Not a principal aquifer, this first bedrock formation encountered is composed of sandstone, shale, and clay.

Saginaw Formation: This important aquifer for the central lower peninsula consists of sandstone with interbedded shale, limestone, coal, and gypsum. The Saginaw Formation is used for rural wells and municipal supplies both in Lansing and Jackson.

Michigan Formation: Not a principal aquifer, the Michigan Formation is below the Saginaw. Composed largely of shale, it does not allow water to move easily.

Marshall Formation: One of the most productive aquifers in the state, this aquifer is composed of fine to medium grain sandstone and can yield high amounts of water. The Marshall Formation is used for municipal water supplies in cities such as Albion and Battle Creek.

Coldwater Formation: Not a principal aquifer, the Coldwater Formation lies below the Marshall and consists mostly of shale.

Silurian-Devonian: Consisting dominantly of limestone and dolomite, water in these rocks flows primarily through well-connected fractures and can have good yields.

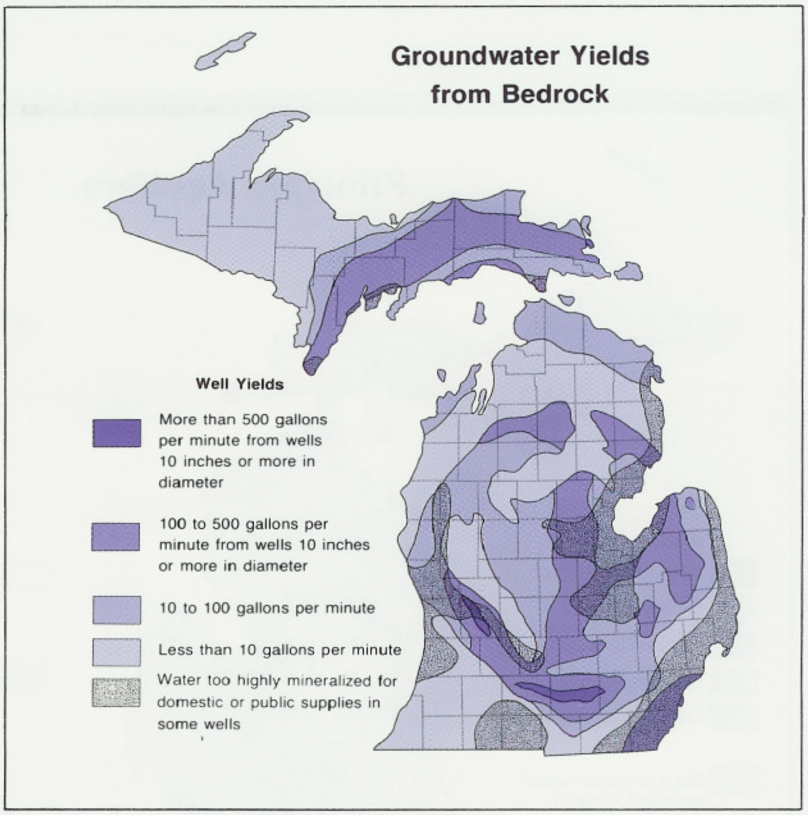
Cambrian-Ordovician: A primary source of water for the eastern upper peninsula, these rocks are composed of sandstone in the lower deposits with limestone and dolomite above.

Precambrian Sandstone: The final aquifer is a sandstone which is well cemented and interbedded with shale. Water travels through these deposits in small fractures which are not well connected.

Precambrian: Not a principal aquifer, Precambrian igneous and metamorphic rocks lie below all the sedimentary rocks.

FIGURE 2-6. A cross-section through the state from the northwest to the southeast shows the underlying bedrock and glacial aquifers. **Adapted from USGS National Water Summary 1984.**

FIGURE 2-7. Water availability from Michigan's bedrock depends on the local formations. Sandstone deposits such as the Saginaw Formation in central Michigan generally yield more water than the less permeable shales such as the Coldwater shale. **Source: U.S. Geological Survey map by F.R. Twenter.**



The types of rocks and soil as well as cracks in the rocks determine the ease with which water flows through the ground. Groundwater can move as fast as 50 feet per day in coarse gravel, but in clay it may take 500 years to move 50 feet. A study by the United States Geological Survey (USGS) determined that groundwater near Traverse City was moving at a rate of three to six feet per day in an unconfined sand and gravel aquifer. The rate of movement is very important when determining the extent of contamination in groundwater.

Groundwater is found in many different geologic settings in Michigan. The bedrock geology consists of thick sedimentary rock layers that are depressed near the center of the lower peninsula forming a bowl shaped basin called the Michigan Basin (Figure 2-6). The formations that constitute the basin were deposited in a pancake fashion, with the oldest beds at the bottom. Most of Michigan lies within this basin except the western upper peninsula, which for the most part consists of older igneous and metamorphic rocks. The sedimentary rocks which make up the basin predominantly consist of sandstone, shale, limestone, and dolomite. Nearly all bedrock in Michigan is overlain by glacial deposits which can also be a source of groundwater (Figure 2-6).

An aquifer can provide water at significantly different rates in various locations. The best way to determine an aquifer's ability to transmit water is to observe past pumping records (Figure 2-7). For example, the Marshall Formation is more productive in the south than in the north. A trend such as this is due to differences in the composition and texture of the aquifer from one area to the next. Water quality also varies within an aquifer, and in some areas water may contain too many minerals for domestic or public use.

Depending on the thickness and composition of the glacial deposits, wells can yield water at very different rates. The highest well yields are in the central to northwestern part of the lower peninsula (Figure 2-8). These areas correspond with the thickest deposits of sand and gravel outwash in the state. The areas of low groundwater yield around Saginaw Bay are due to impermeable clay de-

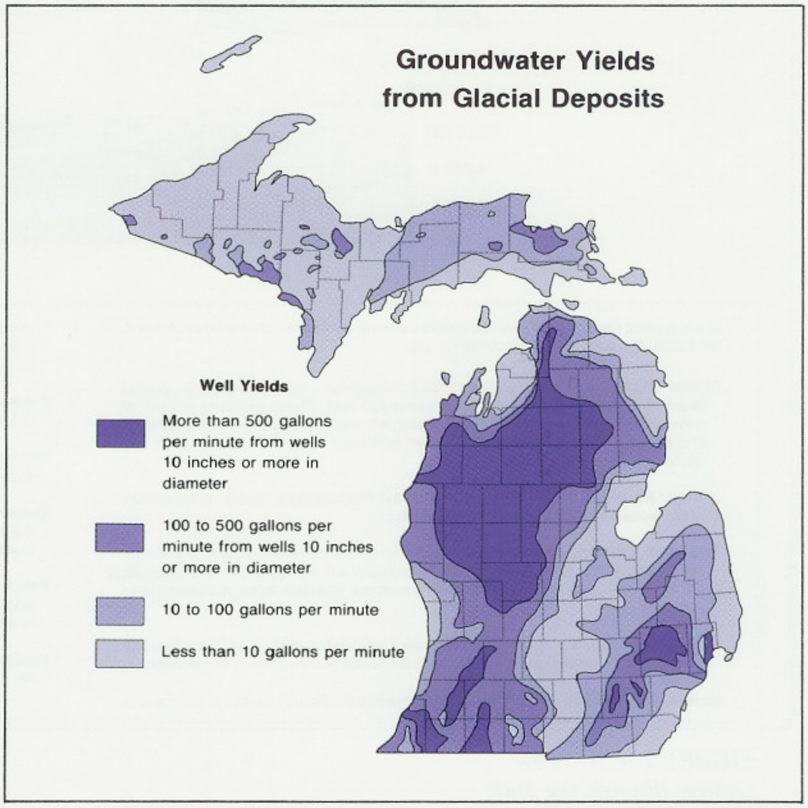


FIGURE 2-8. The availability of groundwater from glacial aquifers depends on the thickness and composition of the glacial deposit. In many areas, the glacial aquifer is the major water supply. Best water supplies are found in the sand and gravel deposits in the northwestern lower peninsula. **Source: U.S. Geological Survey map by F.R. Twenter.**

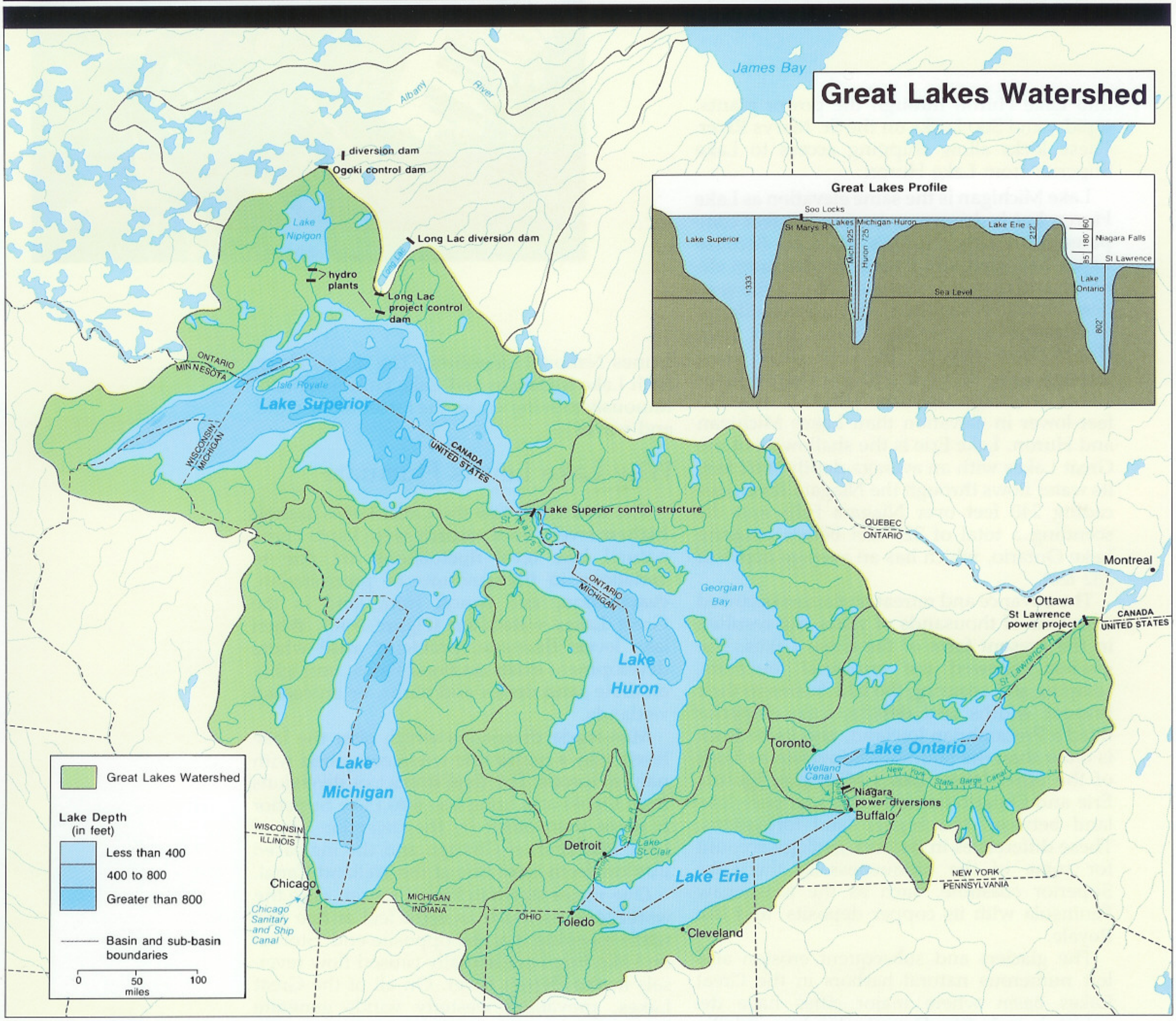


FIGURE 2-9. Great Lakes Watershed

posits, while low yields in the western upper peninsula are caused by thin glacial deposits.

A general rule is that a well must yield 5 to 10 gallons per minute to be a good domestic well. Municipal wells require much higher yields. When wells are located in close proximity, pumping in one can reduce the water level in the other. This can reduce the yield of the latter and may even cause the well to go dry. As more wells draw on Michigan's groundwater, problems between neighboring users are likely to increase.

Great Lakes

The Great Lakes are the largest system of freshwater lakes in the world, containing 95 percent of the surface freshwater in the United States (Figure 2-9). Lake Superior alone holds more than half of all the water in the Great Lakes. Lake Superior, the deepest of the Great Lakes, averages 489 feet and has a maximum depth of 1333 feet. Because it is higher in elevation, Lake Superior waters flow

into Lake Huron through the power plants, rapids, and Soo Locks on the St. Marys River. These locks allow shipping access to Lake Superior from Lake Huron.

Lake Michigan is the same elevation as Lake Huron but is deeper, averaging 279 feet compared with Lake Huron's 194 feet. Because Lakes Michigan and Huron are the same elevation and are connected naturally by the very deep Straits of Mackinac, they are considered to function as one lake. Water from Lake Huron flows into the St. Clair River, then through Lake St. Clair into the Detroit River before entering Lake Erie, which is only ten feet lower in elevation than Lakes Michigan and Huron. Lake Erie is the shallowest of the Great Lakes with an average depth of 62 feet; its water flows through the Niagara River, cascading 240 feet over Niagara Falls and descending a total of 325 feet before entering Lake Ontario, which has an average depth of 282 feet.

The advance and retreat of glaciers occurred over tens of thousands of years and resulted in the present form of the Great Lakes. The glaciers followed the terrestrial lowlands, scraping and scouring the lake basins to their present widths and depths. Lake Superior filled a Precambrian lowland, and its bedrock is older than the Silurian-Ordovician bedrock of the other lakes. Lakes Michigan, Huron, Erie and Ontario occupy what was once lowland between two higher land formations. These differences in bedrock geology account for some of the uniqueness of the Lake Superior coastline, such as the Keweenaw Peninsula with its copper deposits, and Isle Royale.

The glaciers and subsequent erosion also left numerous natural harbors in the Great Lakes basin where major cities have developed, including Detroit, Windsor, Toledo, Cleveland, Buffalo, Erie, Chicago, Milwaukee, and Duluth. Michigan's natural harbors provide a host of recreational opportunities, making Michigan one of the most popular areas in the nation for recreational boating.

The glaciers also left large deposits of sand and gravel that have been transported and shaped by water and wind into the unique dunes of Lake Michigan's eastern shore. These dunes provide recreation areas such as the Warren Dunes, the Nordhouse Dunes, the Silver Lake Dunes, and the Sleeping Bear Dunes National Lakeshore. The dunes along both Lake Michigan and Lake Huron are continuously moving under the forces of the wind and waves.

Why Lake Levels Fluctuate

The mid 1980s saw the Great Lakes at their highest levels since records were kept. These natural lake level fluctuations are due to variations in the amounts of precipitation, evaporation, and runoff from land in the Great Lakes watershed (Figure 2-10). When lake levels fluctuate, problems arise where development exists on floodplains, on highly erodible sand dunes and bluffs, or on coastal wetlands.

Man-made diversions which alter the lake levels play a minor role when compared with natural forces. The total impact of diversions from Ogoki and Long Lac into Lake Superior is more than offset by the diversion out of Lake Michigan at Chicago and the increased outflow from Lake Erie at the Welland Canal.

One major storm in Lake Erie can raise the water level as much as eight feet at one end while lowering it at the opposite end. Storms on Lake Erie have actually caused flow reversals in the Detroit River. On all of the Great Lakes, prevailing westerly winds generate wave actions that undercut bluffs, causing shoreline erosion that results in millions of dollars in property damage.

When years of above average precipitation coincide with cooler, cloudy conditions that cause less evaporation, the lake levels rise. Not only do the lakes receive and retain more rainfall, the runoff from the watershed also increases, contributing to higher lake levels (Figure 2- 11). Recent years have seen high lake levels in the Great Lakes which coincide with above average precipitation. However, Michigan's past has seen much greater fluctuations in lake levels.

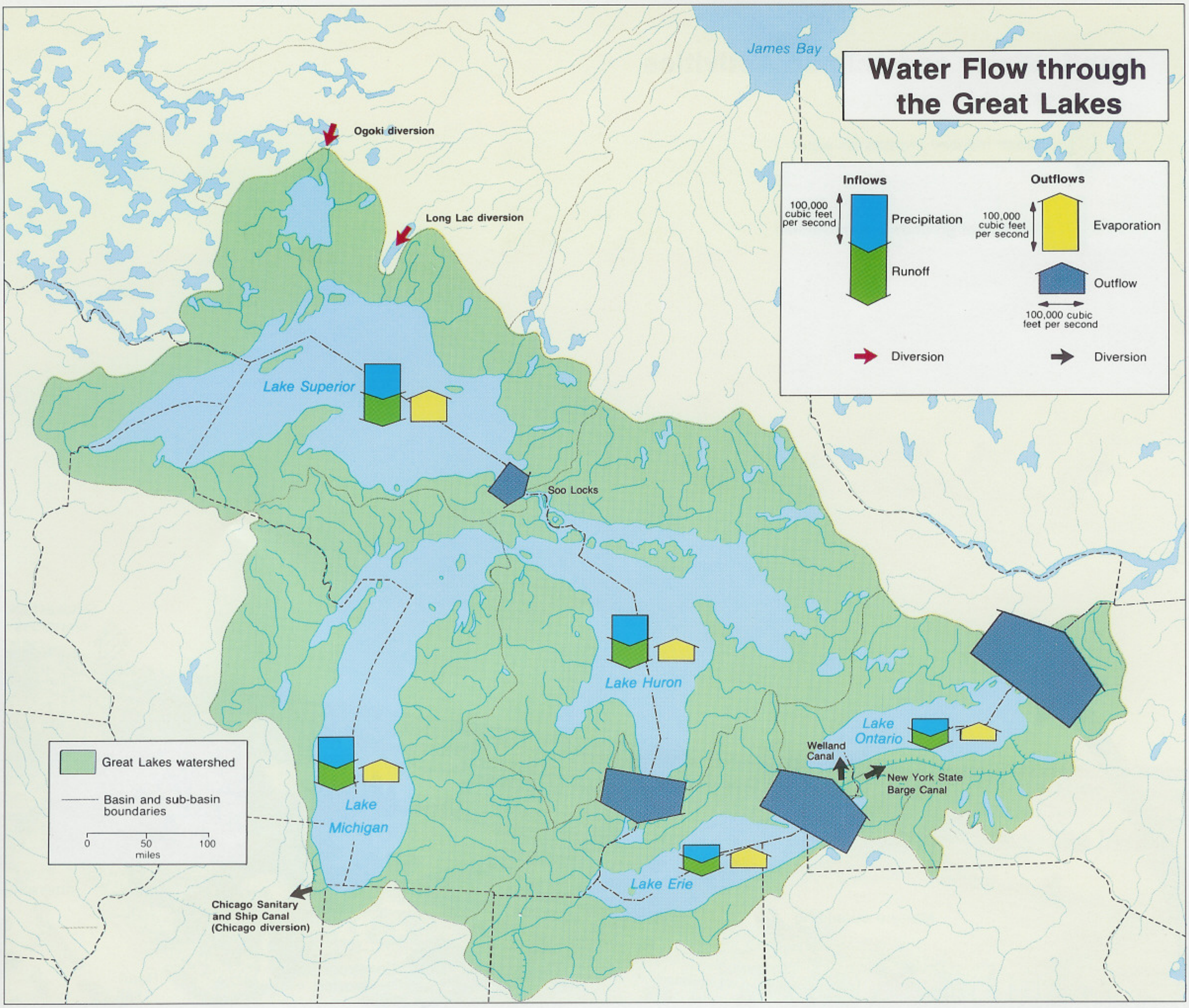


FIGURE 2-10. The inflows and outflows, both natural and artificial, include water gain from runoff and precipitation and water loss from evaporation, diversions and outflows.

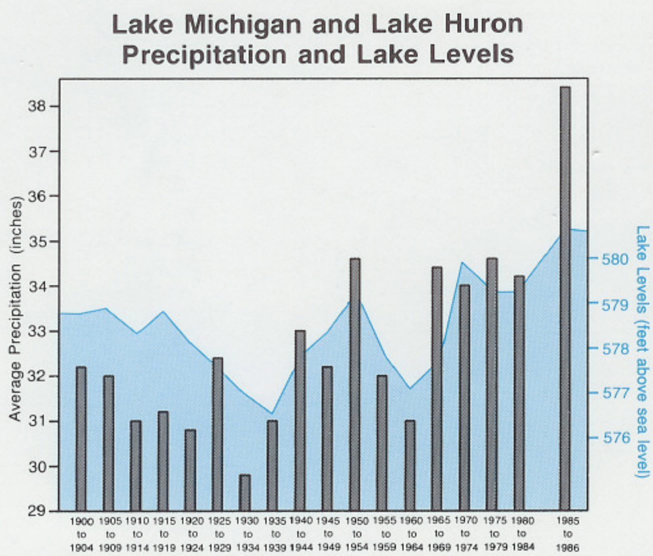
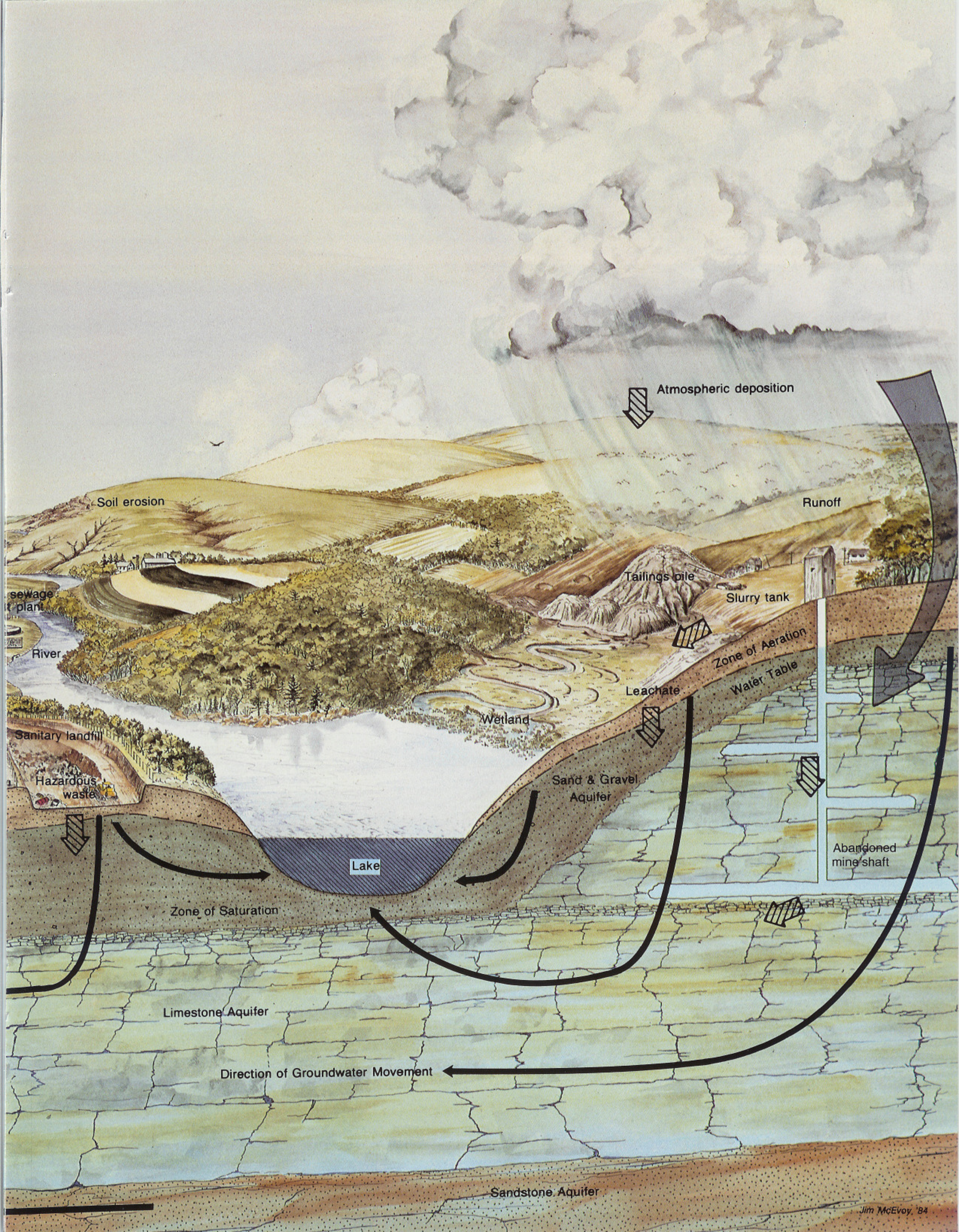


FIGURE 2-11. Comparison of average precipitation from 1900 to 1986 shows the close relationship between periods of higher than average precipitation and high lake levels.
Adapted from National Oceanic and Atmospheric Administration, Ann Arbor, MI.

Land, Water and Human Activities

Figure 3-1


Atmospheric deposition
Runoff
Soil erosion
sewage
t plant
River
Tailings pile
Slurry tank
Zone of Aeration
Water Table
Leachate
Wetland
Sanitary landfill
Hazardous
waste
Sand & Gravel
Aquifer
Lake
Abandoned
mine shaft
Zone of Saturation
Limestone Aquifer
Direction of Groundwater Movement
Sandstone Aquifer
Jim McEvoy '84

3 Water Quality

Water quality is an elusive term because its meaning depends on the water's intended use. For example, dissolved calcium and magnesium compounds produce hard water, which is poor for dishwashing, but these same compounds are necessary to sustain productive fish populations in lakes. Water high in nitrates is excellent for irrigating a cornfield, but may be unsafe to drink, especially for infants. Because most human needs require clean water, water quality can be defined by the amount of harmful or otherwise unwanted substances it contains or its suitability for an intended use. The abundant supply of excellent quality water has allowed a vast array of manufacturing, industrial, and agricultural enterprises to develop in Michigan.

Why Does Water Quality Vary?

Just as the distribution and availability of water varies across the state, so does its quality. Water quality is affected by the many substances water contacts during its movement through the hydrologic cycle. Water dissolves a wide variety of minerals, nutrients, and other substances from soils, rocks, and the atmosphere, and carries them in solution. Lakes, streams, and groundwater accumulate these dissolved substances and reflect the distinctive characteristics of their watershed's soils, geology, and land use.

Human activities also can change the composition of surface runoff and groundwater. Water is vulnerable to contamination at all points in the hydrologic cycle, and all pathways that transport water can also carry pollutants (Figure 3-1). Land use activities and wastewater discharges can degrade water quality. Many practices of the past, especially for waste disposal, which were not known at that time to have serious adverse water quality impacts have left behind long lasting contamination problems. An increasing awareness of and concern for the problems caused by these activities has developed in recent years, and Michigan has made a commitment to cease environmental degradation and clean up the problem areas.

Inland Surface Water

Water quality in Michigan's lakes and streams is generally very good. The inland waters of Michigan's upper peninsula and the northern half of the lower peninsula are of excellent quality, with a few localized exceptions. Coldwater fish populations, such as trout, salmon, and smelt are supported; and the aquatic communities are diverse, indicating a healthy environment. Lakes, rivers, and streams in the southern half of Michigan's lower peninsula typically are of good quality and support warmwater fish populations such as bass, bluegills, walleyes, perch, pike, and catfish. Some rivers and lakes in this area have been affected by municipal and industrial wastewater discharges and by contaminated runoff from agricultural and urban areas.

Approximately 1,000 industrial and 400 publicly owned wastewater treatment facilities discharge effluent, or wastewater, to the surface waters of Michigan. Heavy manufacturing has discharged acids, solvents, oils, hazardous wastes, and heavy metals, such as mercury and lead, into surface water. Paper and pulp mills have discharged organic chemicals such as polychlorinated biphenyls (PCBs) and waste wood fibers. Municipal sewage treatment plants have discharged inadequately treated wastewater into rivers, streams, and lakes. Major efforts have been undertaken to eliminate these pollution sources, and all discharges now require a permit and are monitored. New sewage treatment plants have been built, and a statewide ban on phosphorus containing detergents has resulted in reduced nutrient loading.

Some agricultural and forestry practices have had significant impacts on water quality. Soils denuded of protective vegetation have the potential for rapid erosion. Sediment entering lakes and streams from surface runoff reduces water clarity, thus shading aquatic plants, smothering eggs, or interfering with an animal's ability to catch prey or avoid predators. Nutrients, primarily nitrogen and phosphorus, enter water through surface runoff and stimulate plant growth which may become a nuisance and indirectly contribute to periodic reductions in dissolved oxygen, causing fish kills. Many pesticides and herbicides are extremely toxic to aquatic species and may enter surface waters because of over application, wind drift, or surface runoff. Even when these substances are present in nonlethal quantities, they can interfere with fish reproduction and growth or kill aquatic insects, which are a major food source of many game fish.

Urban areas also contribute pollution through surface runoff and storm sewers. When the land surface is sealed by concrete and asphalt, very little infiltration occurs. During a storm, rainwater washes over the surface, picking up oils, grease, soil, salt, and anything else in its path. The contamination can enter surface waters through direct surface runoff, or through storm sewers. When storm sewers are separate from sanitary or human waste sewers, the stormwater, often untreated, is released directly into surface waters. When storm and sanitary sewers are combined, as is the case in many of Michigan's older urban areas, street runoff and sewage are treated by the wastewater treatment plant prior to discharge. During a storm, the combined sewer often overflows the capacity of the plant, and untreated sewage is released into the river with the contaminated stormwater.

Bottom sediments contaminated with toxic organic compounds and heavy metals present another problem in pollution control. Many toxicants attach to soil and other particles in water and sink to the bottom. While this process removes the contaminants from the water column, toxicants can gradually escape from sediments and reenter the water system. Unlike other pollutants which can be broken down naturally by sunlight and bacteria, some organic chemicals like DDT and PCBs are very difficult to degrade and can persist for long periods of time. The contaminated sediments may continually release pollutants long after the original source of contamination has been removed. This problem is aggravated when a stream channel or lake bed is dredged. Benthic (bottom dwelling) organisms, exposed to contaminated sediments, may be killed by the exposure or may accumulate the toxic material. When fish, birds, and other predators eat these contaminated organisms, they often store the ingested toxicants, especially in fatty tissue. This process of ingesting and accumulating a harmful material is called bioaccumulation. Consumption of these fish by humans is cautioned against because some toxicants are thought to be carcinogenic.

Diffuse sources of contamination such as urban and agricultural surface runoff and discharge of contaminated groundwater are considered to be nonpoint sources of pollution. They are difficult to identify and typically require a change in land use practice to control. Discharges from industrial and municipal wastewater treatment, where effluents enter the surface water from definite physical channels and pipes, are called point source discharges and are easier to identify than nonpoint sources. Point source discharges require a permit and are monitored.

The surface waters of the state have been designated for specific uses with criteria and standards which must be met. For example, a body of water that is designated for full body contact recreational use may not have a fecal coliform (bacteria found in sewage) concentration exceeding 200 organisms per 100 milliliters of water. Standards must also be met for total dissolved solids, chlorides, pH, dissolved oxygen, and temperature for this and other uses. As a minimum, all waters are designated for agriculture, navigation, industrial water supply, public water supply at the point of intake, warmwater fish and other indigenous aquatic life and wildlife, or partial body contact recreation. All waters of the state must

meet the standards for total body contact recreation from May through October, with the exception of certain waters which are immediately downstream from wastewater treatment plants. Of the designated uses for surface water, total body contact and public water supply at the point of intake are the most stringent. If a body of water is not meeting its designated use, it is considered to have a water quality problem.

Where in-depth analyses have been performed, the actual level of certain contaminants may be known for the water, bottom sediments, or fish populations. Those waters containing contaminated fish populations may be under a fish consumption advisory by the Michigan Department of Public Health (MDPH). These advisories are listed in the Michigan Department of Natural Resources (DNR) Fishing Guide, which is issued with every sport fishing license purchased, and also appear in newspapers and fishing updates. A limit is suggested on the number or species of fish that should be eaten from a given body of water, especially in high risk groups such as children under age six and pregnant women. Eight inland lakes and one percent of Michigan's total river miles are included in fish consumption advisories.

Rivers and Streams

Michigan rivers in the Lake Superior drainage basin have very good water quality with minor exceptions. Though most of these streams support coldwater fish, there are localized problems associated with nutrient enrichment downstream of some wastewater treatment plants. New wastewater treatment systems are expected to upgrade treatment capabilities and reduce problems in these areas. Carp Creek and the Carp River have been affected by mercury contamination, but mercury inputs have been stopped and remedial, or cleanup, actions are underway.

Rivers in the Lake Michigan basin north of the Grand River watershed are of good to excellent quality with few exceptions. At least some portions of the streams in this area support coldwater fish. For example, the Pere Marquette River, the Boardman River, and many others are fine trout streams. Localized problems exist on the Menominee, Manistique, White, Muskegon, and Grand rivers. South of the Grand River basin, stream quality varies but is generally best at the source of the stream, the headwater area. Reductions in stream quality are primarily associated with urban areas and result from the combined effects of point source discharges, sewer overflows, urban runoff, and habitat alterations. Pollution control efforts have improved the quality of many of the major rivers in the last few years. For example, the Grand River system is producing a variety of warmwater fish species as well as salmon.

The Kalamazoo River is an example of cleanup efforts made difficult by the persistent nature of water pollution problems. The construction of new sewage treatment facilities has allowed the river to recover from conventional pollution. However, past discharges from paper companies have resulted in PCB-laden bottom sediments which have contaminated the river's fishery. The contamination problem affects the river downstream from Portage Creek in the city of Kalamazoo to the mouth at Saugatuck, where the river discharges toxic contaminants into Lake Michigan. In spite of these problems, some of the best smallmouth bass fishing in the southern lower peninsula can be found in the Kalamazoo River upstream of Battle Creek.

Michigan rivers in the Lake Huron watershed north of Saginaw Bay generally have good water quality. The Au Sable River is one of the finest trout fishing streams east of the Mississippi River, and portions are being considered for protection under the Wild and Scenic Rivers Act. Within the Saginaw River drainage basin, the headwaters of the major tributaries (Tittabawassee, Shiawassee, Flint, and Cass rivers) generally have good water quality, but designated uses are not being met in many downstream reaches. In the thumb area, streams and channels designated as agricultural drains also are not meeting their designated use because of a variety of problems associated with nutrient enrichment from agricultural land runoff, dredging, and the low relief topography of the area. In the mouth of the Saginaw River, phosphorus concentrations have decreased substantially as a result of point source controls and the 1977 statewide ban on phosphorus detergents. Attention is now being focused on reducing nutrient and sediment loads in this basin.

Rivers in the Lake Erie basin are generally of good quality in their headwaters. Localized problems exist primarily because of point source discharges or poor agricultural practices in the downstream reaches. Michigan rivers in the Lake Erie basin are generally more turbid due to natural soil conditions. In the Detroit metropolitan area, stream quality suffers from the combined effects of urban runoff, flow fluctuations, and habitat alterations. The downstream area of the Rouge River, as it flows through Detroit, is heavily contaminated. Bottom sediments are contaminated with metals and other toxic substances, and the accumulation of sludge on the river bottom in the Melvindale area has become so great in recent years that large mats of sludge break loose and float to the surface. These incidents have resulted in unsightly conditions, nuisance odors, and several documented fish kills. An intensive effort is now underway to improve the condition of the Rouge River. At the same time, pollution control efforts in the Detroit River are showing promising results. The reopening of the swimming beach on Belle Isle and the presence of salmon in the channel are indications of improving water quality.

Inland Lakes

Lakes are often characterized by their trophic state, an indication of a lake's biological productivity (Figure 3-2). Lakes with clear waters, few aquatic plants, and sandy or rocky bottoms are called oligotrophic (nutrient-poor); lakes with thick growths of aquatic plants, nuisance blooms of algae, and mucky bottoms are called eutrophic (nutrient-rich). Mesotrophic lakes have characteristics somewhere between oligotrophic and eutrophic lakes. While the crystalline waters of oligotrophic lakes entice swimmers, boaters, divers, and other recreational users, anglers are drawn to eutrophic lakes for their abundant fish populations. However, Houghton Lake is an example of a eutrophic lake that attracts a variety of recreational users.

Lakes undergo a natural eutrophication process where they fill with sediments and organic material. This physical aging is extremely slow, occurring over thousands of years. This process differs from cultural eutrophication, a condition resulting from excessive nutrient input usually associated with the activities of people in the watershed. During cultural eutrophication, shifts in the lake's properties are seen within a relatively short time period. The symptoms of cultural eutrophication include general increases in turbidity, aquatic plants, and organic matter in the sediments, and a change in fish and plankton

Trophic States

Oligotrophic **Mesotrophic** **Eutrophic**

FIGURE 3-2. Lakes are generally classified as oligotrophic, mesotrophic, or eutrophic based on their water clarity, biological productivity, fish species, sediment characteristics, and amount of aquatic vegetation. These characteristics all reflect the nutrient levels in the lake.

populations (Figure 3-2). In severe cases of eutrophication, algal blooms and massive mats of aquatic plants plague the lake, impairing recreation, aesthetics, and contributing to fish kills. These symptoms are responses to nutrient enrichment, particularly phosphorus. Crop fertilization, improper livestock management, forest management, lawn fertilization, septic systems, and municipal treatment plant discharges can all contribute nutrients to lakes.

In 1982, the Michigan DNR surveyed 656 inland lakes and found 12 percent to be oligotrophic, 62 percent mesotrophic, and 26 percent eutrophic. The majority of Michigan's eutrophic lakes are located in the southern part of the lower peninsula where agriculture, urban, and lake shore development are prevalent.

The process of cultural eutrophication can be reversed. The most important step in reclaiming a eutrophic lake is to prevent nutrients from entering it. Recovery can be delayed, however, by in-lake processes, such as turnover in the spring and fall, which remixes nutrients from the bottom water. The long retention times of lakes also prevent the rapid removal of excess nutrients and other contaminants. Retention time is the time required for the volume of water in a lake or stream to be replaced through precipitation, evaporation, inflow, and outflow. The water flowing from a lake or stream carries nutrients and other contaminants, removing them over time. Because streams have greater flow rates and smaller volumes than lakes, their shorter retention times allow them to respond to cleanup efforts more quickly.

The water quality of Michigan's inland lakes is generally good to excellent, with several outstanding lakes, including Torch and Elk lakes in Antrim County, Beaton Lake in Gogebic County, Crystal Lake in Benzie County, Golden Lake in Iron County, and Glen Lake in Leelanau County. Other high quality lakes are Gull Lake in Barry and Kalamazoo counties, and Maceday and Union lakes in Oakland County.

Several lakes have been identified as having specific water quality problems. Manistee Lake is degraded by nutrient enrichment, nuisance algal blooms, and localized bacterial problems due to combined sewer overflows. Pigeon Lake, located west of Grand Rapids, is affected by floating fly ash from a thermoelectric power generation plant. It is also showing symptoms of cultural eutrophication from nutrients discharged from agricultural and food processing sources. Deer Lake in Marquette County is one of the most severely mercury polluted lakes in Michigan. Unregulated discharges from an old sewage treatment plant, laboratories, and unknown sources have produced high mercury concentrations in fish tissue which has prompted the MDPH to issue a fish consumption advisory. Remedial action has been undertaken to reduce the amount of mercury in Deer Lake.

Wetlands

Wetlands play an important role in preserving the quality of rivers and lakes. Wetlands may trap nutrients, sediments, and toxic substances, thereby cleansing water that eventually drains into a stream or lake. In addition, wetlands are important habitats for much of Michigan's wildlife, providing essential breeding, nesting, resting, and feeding grounds for fish and wildlife, including numerous endangered species.

A wetland's shallow waters, abundant emergent vegetation, mucky bottom deposits, and periodic absence of oxygen are eutrophic characteristics in lakes but do not indicate poor water quality in wetlands. Therefore, the quality of a wetland is usually based on the ability of a marsh, bog, or swamp to provide habitat and breeding areas for waterfowl or other wildlife. Because an in-depth analysis of the chemical and physical characteristics of Michigan's wetlands has not been undertaken, an overall evaluation of the quality of the state's wetlands is not possible. One factor known to severely degrade the quality of wetlands, downstream surface waters, and groundwater is the practice of using wetlands as disposal areas. This practice is no longer permitted. Michigan wetlands are now protected under the Wetlands Protection Act of 1979, which provides for the preservation, management, protection, and use of wetlands and establishes penalties for illegal wetland alterations.

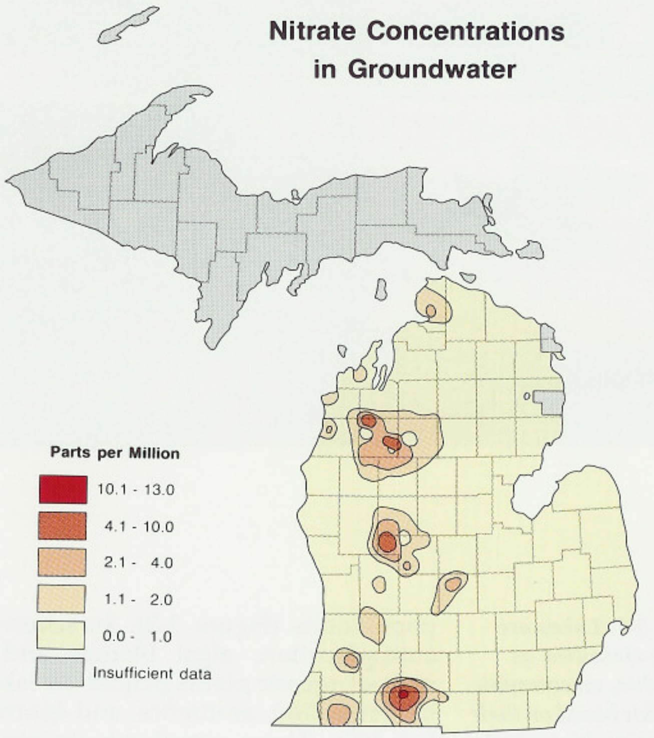


FIGURE 3-3. Well records dating back to the 1930s have been interpolated by a computer model and mapped, locating areas where groundwater nitrate concentrations exceed background levels. Actual nitrate levels may differ from the values on the map. **Source: Kyle Kittleson and Russ Kruska, Institute of Water Research and Center for Remote Sensing, Michigan State University.**

Groundwater

Like surface water, the quality of groundwater varies in Michigan, but most is excellent. A major factor affecting groundwater quality is the geologic composition of the aquifer where it is found. Limestone aquifers characteristically have hard water, while sandstone aquifers can have soft or hard water. A naturally elevated level of lead is contained in some of the groundwater in the northern lower peninsula, and natural background levels of arsenic in the groundwater of the thumb area may exceed the maximum standard limit of 50 parts per billion. Some areas of the Marshall Formation contain natural salt brine.

Even though groundwater is below the surface, human activities can affect it. Disposal practices, both past and present, contaminate groundwater. Landfills have been the source of contaminated groundwater. The variety and concentrations of contaminants and wastes that leach from a poorly sited landfill can be extremely harmful. While these practices are no longer allowed, years of dumping on permeable soils, the use of seepage lagoons, and improper handling of chemicals have taken their toll on groundwater.

Polybrominated biphenyls (PBBs), manufactured as fire retardants, were improperly disposed in the Gratiot County Landfill, located in a populated region near Alma, Michigan. The landfill was poorly constructed in that a clay layer at the surface was removed in several places, allowing waste to come into contact with the aquifer below. PBBs and other contaminants leached out of the landfill and contaminated the groundwater. Wind erosion of the landfill site deposited a plume of PBBs over the downwind area. The intensive cleanup of this landfill is well underway.

Dry cleaning operations have disposed of organic solvents such as trichloroethylene

FIGURE 3-4. Michigan aquifers with highly permeable overlying materials, such as sand and gravel, are more susceptible to surface contamination than aquifers with overlying layers of relatively impermeable materials such as 15 feet or more of clay, or unfractured rock. **Adapted from Western Michigan University, Hydrogeologic Atlas 1981, and Center for Remote Sensing, Michigan State University, 1989.**

(TCE) onto ground surfaces where they can enter surface water and groundwater. Vehicle maintenance facilities with floor drains connected to storm drains and homeowners' improper disposal of used oil can also contaminate groundwater. Petroleum exploration has resulted in the seepage of brine and oil from brine disposal pits. On-site industrial disposal of hazardous waste, leaking barrels, and storage tanks have released a variety of organic and heavy metal contaminants to the groundwater.

Leaking underground storage tanks are another significant source of groundwater pollution. Steel tanks have an underground life expectancy of 15-20 years. As they corrode, they develop leaks which are not easy to detect. Over time, gasoline, fuel oil, and other hydrocarbons stored in leaking tanks seep out and enter groundwater aquifers. A leakage rate of two drops per second can result in the loss of up to 500 gallons of fuel per year and can contaminate up to 500 million gallons of water to the level where odor and taste make it unacceptable for drinking.

Home septic systems also contribute to diminished water quality. Because these systems are underground, they are assumed to be functioning properly as long as they are disposing of sewage. A good septic system must also remove nutrients and pathogens (disease-causing bacteria and viruses) from the wastewater before it enters the groundwater. A septic system that is not adequately treating sewage is a threat to any lake, stream, or well in its vicinity because it can transmit a number of diseases, including hepatitis. Septic systems are not capable of treating most chemicals. Paints, turpentine, strong cleaning solvents, large amounts of bleaches and drain cleaners should not be poured down the drain because they may harm the septic system. Nutrients from leaking home septic systems contribute to the cultural eutrophication of lakes and streams, especially in highly developed areas. To prevent these problems, home septic systems should be inspected by qualified personnel to determine if they are treating wastes effectively.

Nitrate levels in Michigan's groundwater appear to be increasing in some areas (Figure 3-3). These increases are attributed to septic systems, fertilizer application, and animal wastes. Nitrate can infiltrate the soil, enter groundwater aquifers, and contaminate well water. One concern with high levels of nitrate in water is the possibility of infants contracting methemoglobinemia, a respiratory disease caused by the conversion of nitrate to nitrite in the infant's stomach. This disease can and has resulted in death. The maximum allowable concentration of nitrate in drinking water determined by the U.S. Environmental Protection Agency (EPA) is 10 milligrams per liter nitrate-nitrogen (10 mg/l NO_3^--N), equivalent to 45 milligrams per liter nitrate (45 mg/l NO_3^-).

Nitrate is relatively easy and inexpensive to detect in water, and high levels may indicate the presence of more toxic compounds such as pesticides, several of which have been recently detected in Michigan's groundwater. Because no single water test can check for all chemicals, taste, odor, or a nearby contamination source may give some indication of the type of contaminants for which tests should be made. Rural residents are encouraged to have their drinking water supplies tested regularly.

The rate of infiltration of water and contaminants into groundwater depends on the characteristics of the overlying material (Figure 3-4). Relatively impermeable materials such as clay or unfractured rock offer some protection to an aquifer from surface contamination, while permeable materials such as sand or gravel allow quick infiltration of water and contaminants into the groundwater. The sandy soils of western Michigan are so permeable that they provide little or no protection; however, no area is so impermeable that it guarantees protection from surface contamination. An aquifer may also be vulnerable to contamination from the lateral flow of an adjacent, susceptible aquifer.

Groundwater, once contaminated, has a limited capacity for detoxification. Photodegradation, a process where sunlight breaks down complex chemicals in surface water, does not occur in groundwater. The bacterial processes available to break down toxicants in groundwater are extremely slow and cannot be considered as a reliable treatment strategy. Only certain organic contaminants are detoxified by this means, and metals are not affected.

Groundwater contamination is difficult and extremely expensive to correct. A typical remedial action may consist of constructing a slurry wall to isolate the contamination, or a purging system that pumps out and treats the contaminated water. Continuous monitoring of the site is necessary to check for the spread of contamination. Currently, over 500 households in Michigan are restricted to bottled water for drinking purposes. Drinking bottled water is an extreme measure that must be taken when there is no other safe source of drinking water. At one time, 27 of the 30 wells serving the city of Battle Creek were contaminated. Since new wells were drilled, the situation at Battle Creek has been improving.

The Great Lakes

The Great Lakes, with the exception of Lake Erie, are considered to be oligotrophic and have excellent water quality. Pollution problems do exist in some bays, harbors, inlets, and connecting channels where rivers are depositing contaminants. These rivers, such as the Saginaw, receive contaminants in inland areas and transport them to the Great Lakes. Metropolitan and industrial developments along the shores also contribute to local pollution problems in the near shore areas. The amount of contaminants, such as PCBs in fish, often exceeds U.S. Food and Drug Administration standards. Because fish can migrate, all the Great Lakes waters within Michigan's political boundaries as well as the connecting channel areas of the St. Clair River, Lake St. Clair, and the Detroit River are under a fish consumption advisory.

The International Joint Commission (IJC), a United States-Canadian commission created by the Boundary Waters Treaty of 1909, monitors the water quality of the Great Lakes under the terms of the Great Lakes Water Quality Agreements of 1972 and 1978. These international agreements foster intergovernmental cooperation to solve pollution problems. Based on state and provincial recommendations, the IJC has currently designated 43 Areas of Concern where environmental quality is degraded and beneficial uses of the water and biological communities are adversely affected (Figure 3-5). Each state or province is responsible for the preparation of remedial action plans for the Areas of Concern within its borders. Michigan is drafting remedial plans for the 11 Areas of Concern for which it is solely responsible and is involved with three additional Areas of Concern where it shares this responsibility with a neighboring government. Problems in the Areas of Concern include heavy metals, toxic organic substances, and conventional pollutants.

The IJC is also becoming concerned with atmospheric deposition, the process by which many pollutants are carried in the air and fall to land or water. Acid rain, the most well known form of atmospheric deposition, occurs when sulfur and nitrogen oxides are released into the atmosphere through the combustion of fossil fuels in power plants, industry, and automobiles, and from metal smelting. These gases react with water vapor in the atmosphere to form acids. In addition, other substances have also been found in Michigan's rainwater including aluminum, arsenic, barium, boron, cobalt, copper, cyanide, lead, and zinc.

Atmospheric deposition occurs on a global scale and can include organic compounds. Lake trout have been found to be contaminated by PCBs in Siskiwit Lake on Isle Royale and by toxaphene in the Great Lakes. The insecticide toxaphene was used only in very

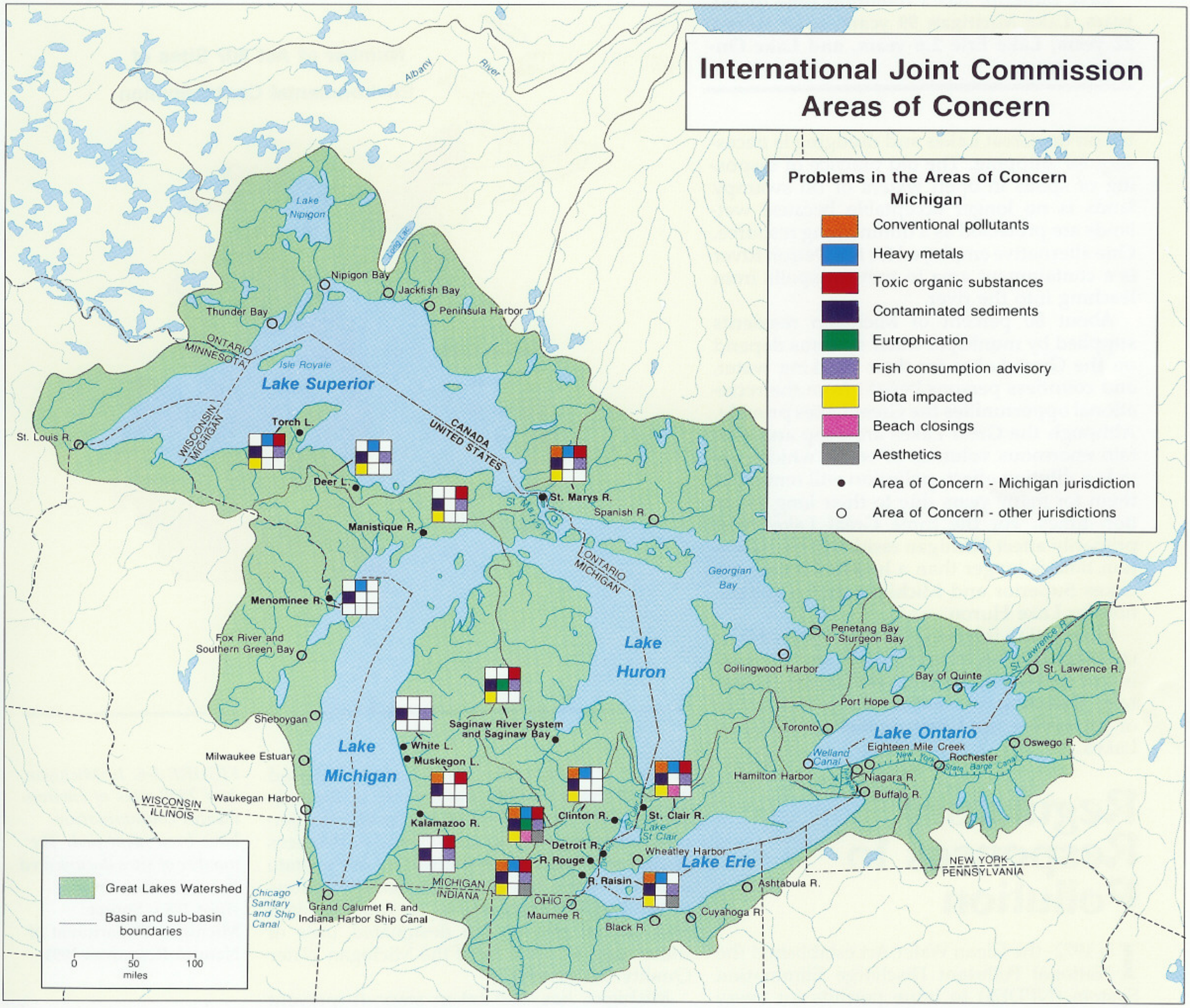


FIGURE 3-5. The problems at the 14 Areas of Concern in Michigan are shown, along with locations of Areas of Concern in other states or provinces. Remedial action plans are being prepared to correct existing problems.

small amounts in the Great Lakes Basin, but many tons were applied in the cotton-growing regions of the southern United States. Further, no known source of PCBs exists on Isle Royale. Therefore, atmospheric deposition is the only plausible explanation for these occurrences and the primary source of many contaminants to the Great Lakes.

Atmospheric deposition poses a significant threat to the quality of the Great Lakes due to their enormous surface area, coupled with the fact that contaminants fall directly on the water with no interception by land cover. Inland lakes and streams, particularly those located in granite or sandstone areas, are also susceptible to the effects of atmospheric deposition.

Another problem in the Areas of Concern is contaminated sediments. Navigational channels naturally fill with sediments, which gradually decrease the depth and require periodic dredging. Where these sediments have been contaminated, their removal can release significant amounts of toxicants. Once the contaminated sediments have been removed, they are called spoils and must be disposed of properly. When spoils piles are eroded, contaminants reenter the water or leach to groundwater. Disposal of spoils confounds regulators because navigation is essen-

Lake Superior has a retention time of 191 years, Lake Michigan 99 years, Lake Huron 22 years, Lake Erie 2.6 years, and Lake Ontario 6 years.

tial on the Great Lakes and dredging is necessary for shipping. The old practice of disposing of spoils in open waters or on swampy lands is no longer acceptable because wetlands are protected as a diminishing resource. One alternative employed for the Detroit River is a containment area to prevent spoils from leaching into the river.

About 80 percent of Michigan residents supplied by municipal water systems depend on the Great Lakes for their drinking water, and countless persons benefit from the recreational opportunities the Great Lakes provide. Although the Great Lakes are deep and contain enormous volumes of water which provide a dilution effect, pollution will remain in them for many years due to their long retention times. For the three Great Lakes that primarily affect Michigan residents, the retention time is longer than a human lifetime for Lakes Superior and Michigan and a generation for Lake Huron.

Information is lacking on the effects of toxic contaminants on human health and the cycling of these contaminants within the ecosystem. Therefore, prevention is the best means of preserving the water quality of the Great Lakes.

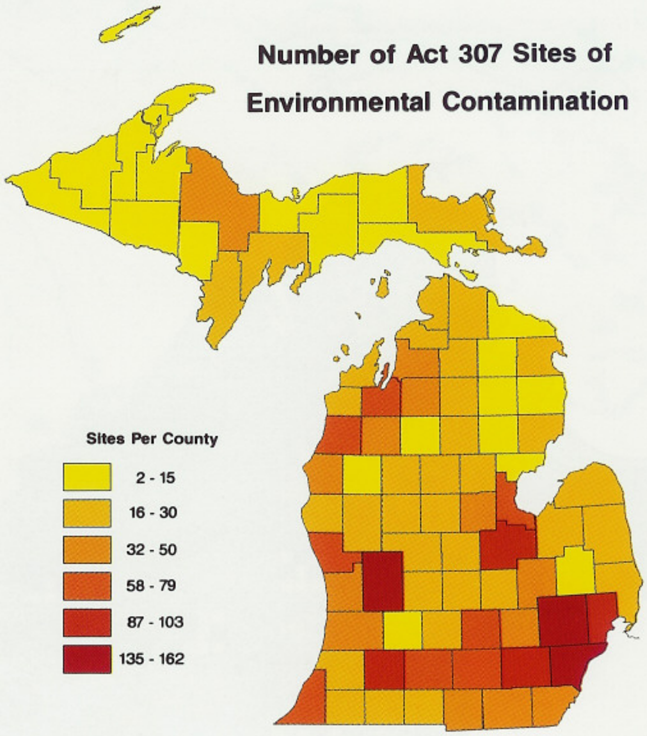


FIGURE 3-6. In Michigan, over 2800 sites of environmental contamination have been identified. The number of sites documented has more than tripled since 1985. **Source: Michigan Department of Natural Resources 1991.**

Regulatory Responses to Pollution

In 1972, the Clean Water Act established the National Pollutant Discharge Elimination System (NPDES) to issue permits for every discharge of wastewater into the waters of the United States. The Michigan Water Resources Commission (WRC) has been delegated the authority by the EPA to implement NPDES permits based on DNR recommendations. Michigan has surface water quality standards which meet or exceed EPA criteria for total dissolved solids, chlorides, pH, phosphorus, fecal coliform, dissolved oxygen, temperature, and toxicants. When application is made for an NPDES permit, the DNR determines the amount of each substance that the applicant can discharge to maintain these standards. Where the water quality is better than minimum standards, further degradation through discharge is not permitted. In the case of toxic materials, discharge levels are based on tests that calculate the toxicity of the substance. Discharges allowed under NPDES permits are designed so that "toxic substances shall not be present in the waters of the state at levels which are or may become injurious to the public health, safety, or welfare; plant and animal life; or the designated uses of those waters" (Rule 57 of the Michigan Water Quality Standards).

Michigan has also taken steps to prevent groundwater pollution. All discharges to groundwater require a permit, and discharge levels are set such that no significant deterioration of groundwater occurs. The Solid Waste Disposal Act and the Hazardous Waste Management Act regulate siting, design, and management of solid and hazardous waste disposal facilities, respectively. In 1982 the Michigan Legislature enacted the Michigan Environmental Response Act, commonly known as Act 307, to identify and clean up sites of environmental contamination. Each year, the DNR publishes a list of these sites (Figure 3-6). The resources affected include air, groundwater, surface water, sediment, residential and municipal wells, and soil.

Manufacturing is the largest single source of contamination on the present list, contributing 23 percent of the sites (Figure 3-7). Landfills are also a significant source of contamination. Other sources include commercial, mining/oil drilling, oil/gasoline storage tanks, and highway maintenance/salt storage. The sources of contamination for 13 percent of the sites on the 1991 list are still not known.

Michigan currently has 79 sites listed on the National Priorities List of the federal Superfund (Federal Comprehensive Environmental Response Compensation and Liability Act of 1980) program. These sites have been determined by the EPA as significant enough to merit federal monies for remedial action. Several of these sites have received funding for site study and development of cleanup plans, and a few are in the cleanup stage. Only two other states have more sites enrolled in the Superfund program.

These statistics are not as bleak as they sound. Michigan has been very active in identifying and cleaning up contamination. Remedial action plans are being prepared or have been implemented for over 20 percent of the Act 307 sites by the parties responsible for the contamination. "Polluter pay" legislation, passed in 1990, assigns financial responsibility for cleanup of contaminated sites to the parties responsible for the problem.

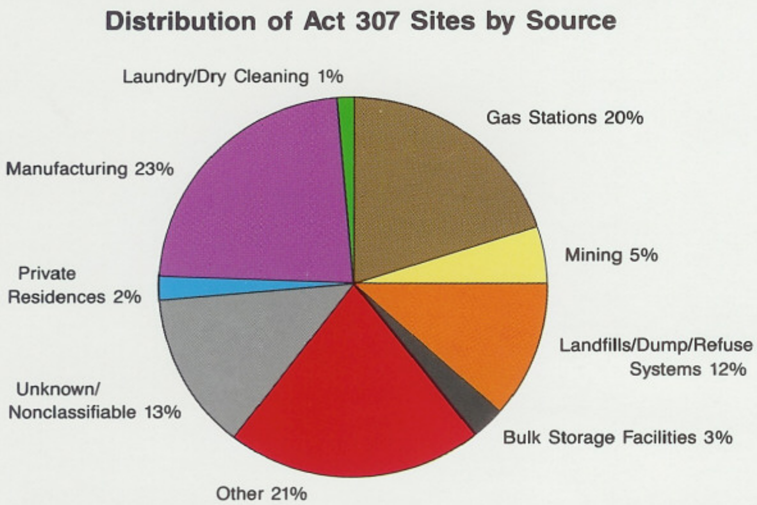


FIGURE 3-7. The over 2800 sites of contamination from the Michigan Sites of Environmental Contamination Priority Lists for Act 307, March 1991 are categorized by source of contamination. **Source: Michigan Department of Natural Resources 1991.**

The Remedial Action Dilemma

The extent to which we can and must clean up the sites of contamination raises difficult and important questions. With the large number of contamination sites and the tremendous expense of cleanup, should every site be restored to background levels, or should a less complete cleanup plan be adopted to address more sites? A remedial action plan may consist of everything from fencing a site or removal of contaminated soils, to a complete purge of contaminated groundwater and cleanup to background levels. Complete cleanup of all sites of environmental contamination may never be possible because of time and budget constraints. This dilemma is best resolved by preventing pollution when possible and proper disposal of unavoidable wastes.

4 Multiple Uses

Michigan's Water Management Challenge

Michigan residents and visitors enjoy an abundance of clean drinking and recreational water. Michigan farmers share the advantages of these same high quality waters for agricultural operations, such as irrigation or raising livestock, while businesses use these waters for industrial processes, such as food processing and pharmaceutical manufacturing. Agricultural products and industrial goods are purchased by consumers, who indirectly become the users of the water incorporated into these products.

Increasingly, multiple uses conflict with one another. Among those competing for Michigan water are instream uses, such as navigation and recreation, and offstream or withdrawal uses, such as public drinking water supply, manufacturing, and irrigation. The goal of multiple use water management is to blend the concerns of the various users into a comprehensive system for compatible and efficient use of water.

The quantity of water in Michigan is often overshadowed by concerns over its quality. However, both availability and quality must be considered for multiple use management. Localized differences in land use, soil type, and geology result in differing concerns about water use across the state. For example, southwest Michigan and the thumb are agricultural areas where the availability of water for irrigation is important, whereas good water quality for manufacturing processes is important in industrialized areas. Recreational and irrigation usage peak during the summer when rivers are at or near low flow periods.

Water use that involves the physical removal of groundwater or surface water from its source is considered a withdrawal water use. When the water is returned to its source, it is a nonconsumptive withdrawal. A consumptive use occurs when water is not returned to its source. Water is considered to be consumed when it is no longer available to the watershed as a result of evaporation, transpiration, incorporation into products or crops, consumption by human beings or livestock, or is otherwise lost to the immediate water environment.

Withdrawal Uses of Water

Withdrawal uses are categorized as *thermoelectric power generation*, *industrial self-supply*, *public supply*, and *irrigation* for record-keeping purposes. In Michigan, water used for mining is included in the industrial self-supply category. These four categories account for over 98 percent of the water withdrawn and used in Michigan. The other two percent is generally classified as rural water use such as rural homeowner wells, drinking water for livestock, and dairy sanitation. Most of this water is self-supplied and cannot be readily monitored for reporting purposes.

Utilities generating thermoelectric power at more than 90 fossil fuel and four nuclear power plants in Michigan withdraw more water than the other three uses combined (Figure 4-1). Power plants use the water for cooling equipment and to produce steam to drive turbines, and then return this water to the lake or river from which it was withdrawn. More than 98 percent of the water withdrawn for thermoelectric power generation is from the Great Lakes and connecting waterways. Only 1.3 percent of all water used in thermoelectric power generation is consumed, primarily through evaporation.

Industrial self-supply is water withdrawn by a user instead of being supplied by a public source. Over 9,000 industries are in this category, using water to manufacture cars, steel, chemicals, and plastics and to make pulp and paper. About 10 percent of the water withdrawn by self-supplied industries is consumed; the remainder is returned to the watershed, often following treatment that removes contaminants or heat.

Public water supply systems provide water to homes, schools, and offices, and to industries and businesses that are not self-supplied. Domestic uses in homes include water for drinking, cooking, bathing, brushing teeth, flushing toilets, watering lawns and washing dishes, clothes, and cars. The average Michigan household uses 75 gallons of water per person per day (Figure 4-2). The average Michigan school uses 15 to 25 gallons of water per student per day.

Municipal water supply systems provide most of the public drinking water in Michigan.

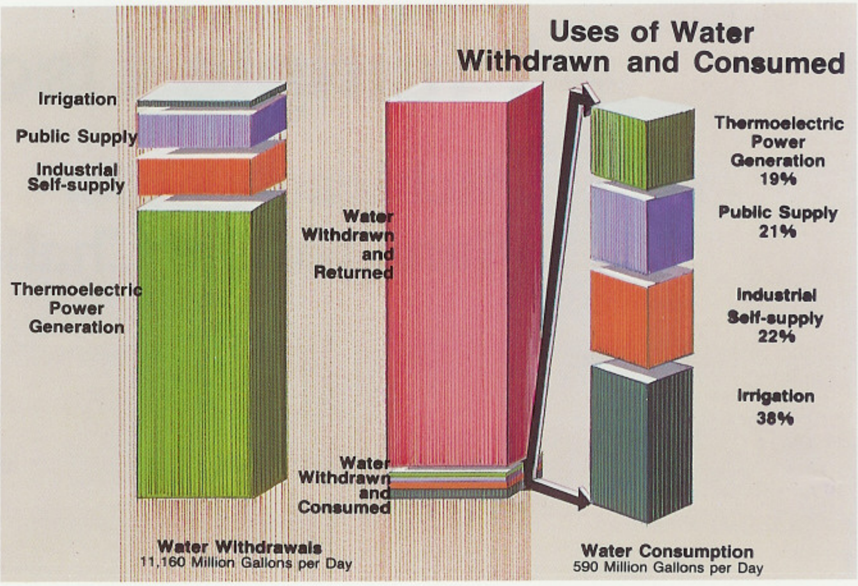


FIGURE 4-1. Irrigation, public supply, industrial self-supply, and power generation withdraw and consume water in different amounts. Overall, less than five percent of the water withdrawn is consumed.

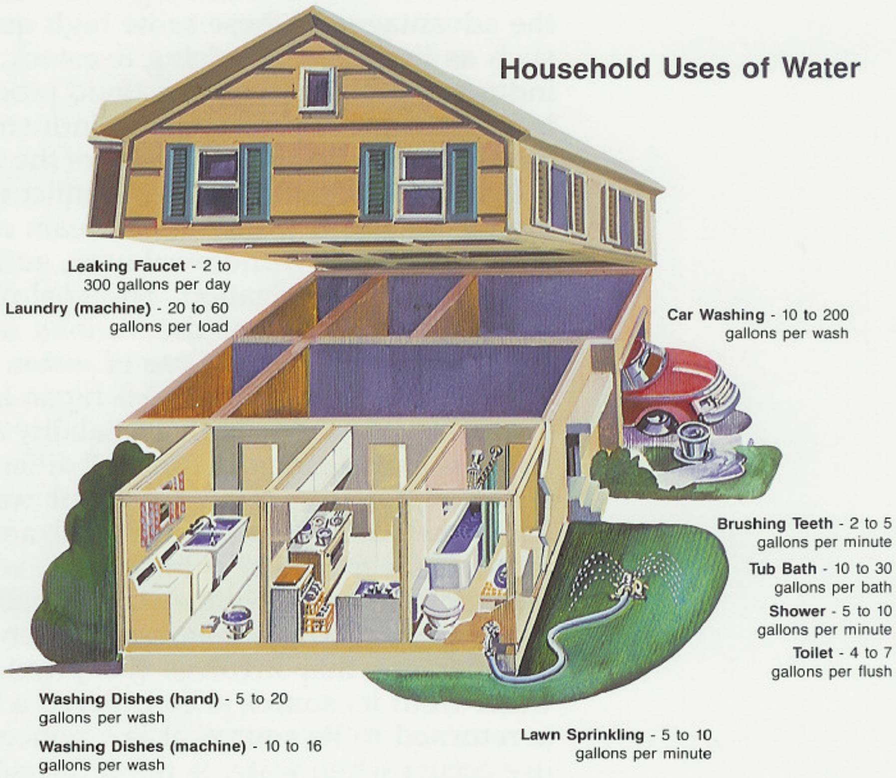


FIGURE 4-2. Household Uses of Water

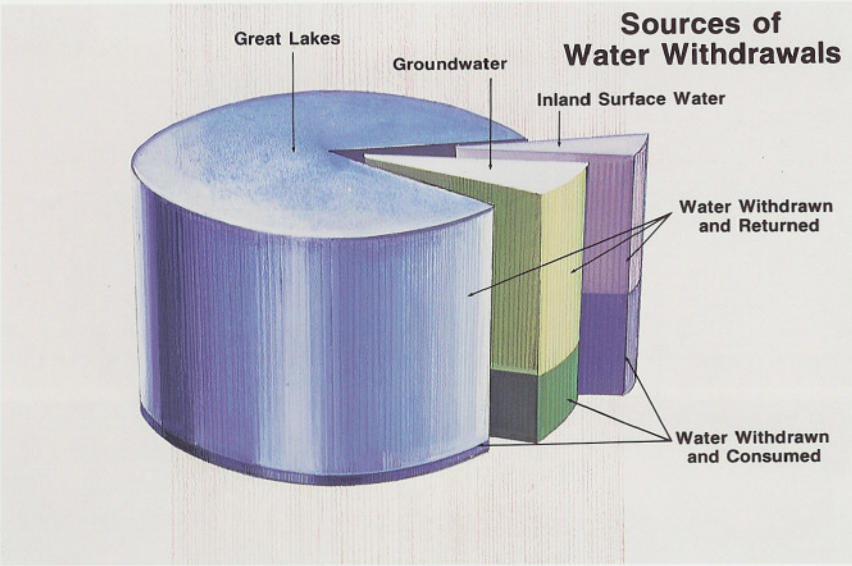


FIGURE 4-3. Quantities of water withdrawn and consumed from Great Lakes, groundwater, and inland surface water sources within Michigan shows the state's dependence on the Great Lakes as a source of supply. Although inland surface waters are the smallest source, almost half of the water withdrawn is consumed.

In rural areas, groundwater from private wells is the source of drinking water for many residents. Municipalities withdraw an estimated 1.2 billion gallons of water per day from the Great Lakes, groundwater or, in rare instances, inland lakes and streams. The Great Lakes and connecting waterways supply about 80 percent of the total withdrawals by municipal systems for public supply.

More than 3,000 irrigators withdraw water for agricultural, recreational, and commercial irrigation. Irrigation occurred in every county in Michigan during 1977, the last year for which data were available, when 2,852,483 acre-inches of water were used to irrigate 324,934 acres. Eighty-five percent of the irrigated acreage was agricultural, including field crops, truck crops, potatoes, tree fruits, hay and pasture, and other. Recreational irrigation used 9.2 percent of the total water, primarily for golf course and park irrigation. Commercial irrigation, accounting for approximately 4.4 percent, includes that for sod and flowers, and nurseries.

HOW ACCURATE ARE WE?

With the exception of public water supply, there is no formal system or legal requirement for reporting or monitoring data on withdrawals or consumption of water in Michigan. To derive information for the National Water Use Information Program, the DNR, which collects the data for Michigan, must rely on several sources of information: U.S. Census Bureau data for industrial self-supply, periodic statewide surveys with an update from the Cooperative Extension Service for agriculture, and individual power plant surveys for power generation. Water use statistics are not always available for uniform time periods across the various use categories, and data must sometimes be estimated from information that is several years old.

Less than five percent of the entire quantity of water withdrawn from all sources is consumed (Figure 4-3). The majority of the water used for irrigation comes from groundwater and inland lakes and streams, accounting for about 70 percent of the water withdrawn from these sources. Through the 1970s, irrigation water use increased at a faster pace than any other category. This was especially true in the southwestern parts of the state where irrigation continues to increase.

Instream Water Uses

Instream uses of water, also called nonwithdrawal uses or in-channel uses, do not involve withdrawing the water from the source. The shipping industry uses the Great Lakes and connecting waters for commercial navigation. More than 75 million short tons of goods passed through Great Lakes ports in Michigan in 1984.

Hydroelectric power plants in Michigan produced over 1.5 million megawatt hours of electricity in 1985, which amounted to 2.25 percent of the total power generated in the state that year. While there is some consumption of water in any hydroelectric project, hydroelectric power generation is generally considered a nonwithdrawal use of water. The Ludington pump storage facility is atypical because it produces hydroelectric power by withdrawing Lake Michigan water during off-peak demand periods, stores the water in an 842 acre reservoir, and generates power during peak demand periods by releasing the stored water.

The tourist and recreation industry uses the water resources of Michigan to attract visitors, generating an estimated $14 billion annually. Michigan's sport fisheries, numerous state parks, forests, and marinas contribute to this revenue. Tourism and recreation emphasize the importance of quality water for both fun and profit. Recreational uses of Michigan's water include power boating, sailing, water-skiing, fishing, canoeing, picnicking, rowing, scuba-diving, swimming, and beach activities. Most Michigan residents live within ten miles of a lake, river or stream, and water activities are frequent pastimes. Recreational opportunities are also provided by wetlands, and include duck hunting, bird watching, and nature hiking.

5 Managing Our Water Resources

Proper management of Michigan's water resources is essential to the state's continued prosperity, as well as to the quality of life. In order to manage water resources efficiently, cooperation and communication among the individual landowners, state, local and federal government agencies, and many environmental and business organizations is necessary. Water management challenges facing Michigan include providing quality drinking water and wastewater treatment, watershed management, water conservation, land use management including floodplain management, and dam inspections.

Drinking Water and Wastewater Treatment

Two important aspects of water management that affect everyone daily are drinking water and wastewater treatment. Public drinking water, which may be supplied by either community or noncommunity systems, is monitored to determine its suitability for use and the treatment needed before it reaches the faucet in the home.

The extent of drinking water treatment depends on the source of the water, its characteristics, and the number of people served. All surface water withdrawals for drinking water purposes require treatment prior to distribution whereas groundwater withdrawals may not require treatment. All drinking water must meet federal and state drinking water standards for basic minerals, coliform bacteria, metals, volatile organic compounds, taste, and odor. To meet these standards drinking water may receive treatment, including filtration and chlorination (Figure 5-1).

Community systems serve more than 25 people for residential uses year round. If necessary, water receives treatment to meet drinking water standards and is monitored regularly by both local and state health departments. Municipal systems are community systems which serve more than 10,000 people, and they almost always receive some form of water treatment. There are more than 11,000 noncommunity systems which are smaller, nonresidential systems, used in rural schools, restaurants, campgrounds, and other facilities. Noncommunity systems almost always use groundwater as their source. This water receives little treatment or monitoring once the well is installed and the source of water is determined to be suitable. Private water supplies are not routinely tested, but a limited number of tests may be arranged through local health departments.

Cities, townships, counties, other local units of government, or sewage disposal districts can all provide waste disposal. Effluent standards are regulated and must be met before a facility discharges effluent to surface

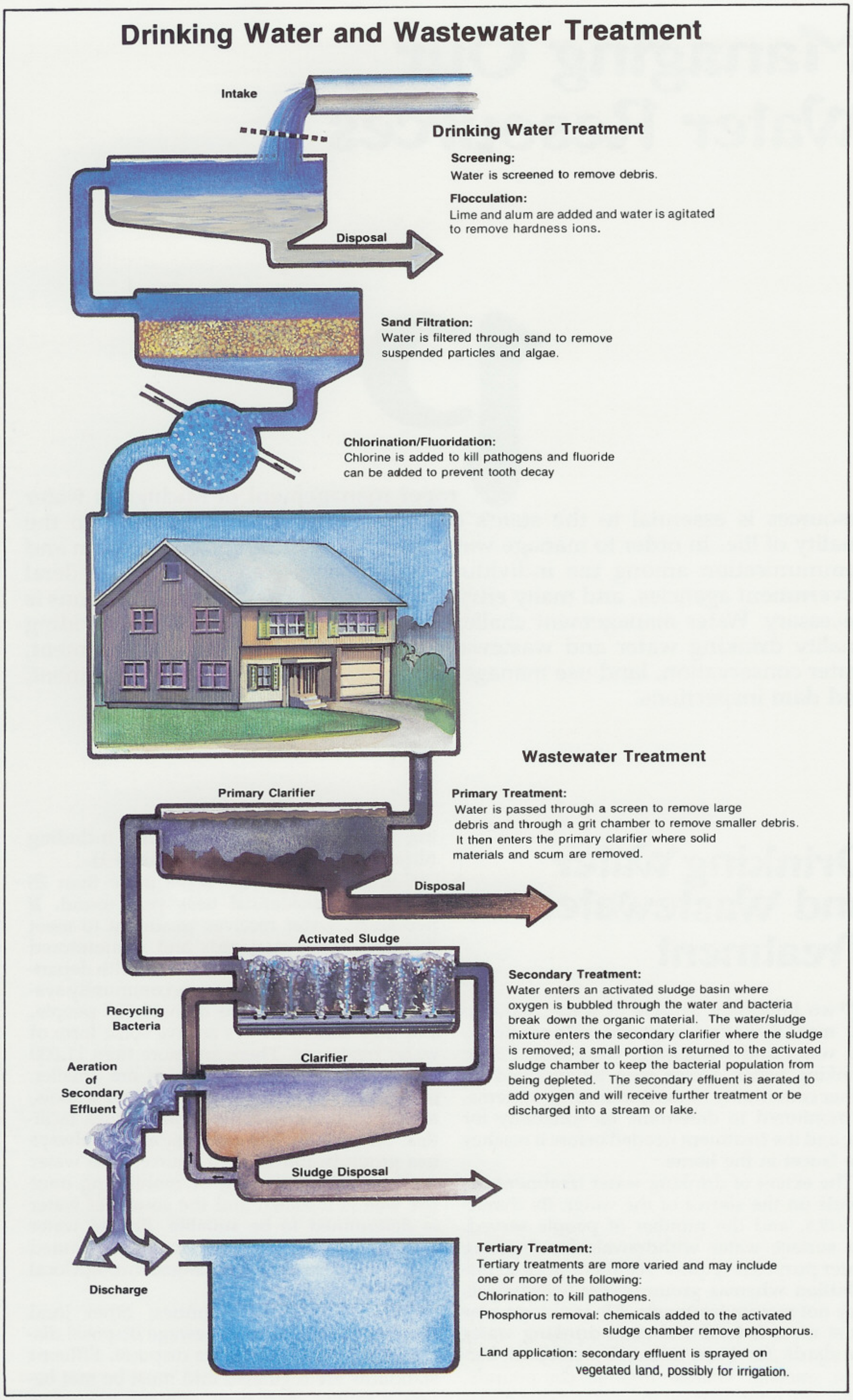


FIGURE 5-1. Drinking Water and Wastewater Treatment

waters. Although individual treatment plant methods may vary, wastewater may receive up to three levels of treatment. Solids are removed in primary treatment. Bacteria digest and degrade organic material in secondary treatment. If the particulate and dissolved organic matter are not removed prior to discharge, bacterial breakdown of this material causes oxygen depletion in the receiving water which can adversely affect aquatic life. Some wastewater requires tertiary treatment to meet effluent standards, especially for phosphorus and pathogens. Presently, most tertiary wastewater treatment processes are not capable of removing heavy metals and toxic organic compounds. Discharging these substances into waterways can have significant adverse effects on plants and animals.

If an industry produces wastewater containing flammable, explosive or hazardous substances, poisons, or toxics, it is required to pretreat the water before discharge to a publicly owned treatment plant.

Implementation of pretreatment varies depending on the type of contaminant, the cost of removal, and the availability of appropriate technology to recover or treat contaminants at their source.

Sewage treatment sludge contains contaminants such as pathogens, nutrients, metals, organics and toxic organic compounds removed from the wastewater. Proper disposal of this sludge is also a problem. The most likely disposal alternatives are incineration, disposal in a secure landfill, or land application.

About 180 treatment plants are licensed by the DNR for land application and are typically systems which only treat domestic sewage and not industrial wastes that require additional treatments. Effluent or sludge is applied to the land where vegetation removes nutrients. Soil acts as a final filter, further removing contaminants and improving water quality. The wastewater must be treated for pathogens, and the levels of contaminants which may remain are very low.

Detroit recently completed over $300 million in improvements to its wastewater treatment facility, which is now in compliance with its NPDES permit. The Detroit facility handles wastes from 73 southeast Michigan communities, 34 percent of the state population. This is only one example of the upgrading and new construction of plants in Michigan, where $2.6 billion in federal and state funds have been spent to improve wastewater treatment and meet NPDES permit requirements.

Management Practices

Watershed boundaries rarely coincide with political boundaries of local units of government which makes management on a watershed basis a challenge. Activities within the watershed, such as manufacturing, farming, providing public drinking water, and treating wastes, result in profound changes in both the land and water. Actions in one locality can result in problems for another. Coordinating the policies and actions among the local governments that share a watershed requires coordinating the roles and responsibilities of the municipal, county, state, and federal levels of government.

In the past, management practices have considered groundwater and surface water separately. However, these two parts of the system are closely linked to one another. For example, both groundwater contamination and withdrawals of groundwater can affect lakes and streams. Effective management on a watershed basis should consider the interrelationship between groundwater and surface water and all of the surface runoff and groundwater discharge that contribute water to the same lake or stream.

Discharges can be permitted on a watershed basis. In granting or renewing NPDES permits, the DNR's goal is to take into account the effect of the applicant's discharge on the receiving body of water, all effluent sources in the watershed, and the flow of the receiving water body. Other areas of management better accomplished on a watershed basis include stormwater management, conflicting water uses, and flood management.

Land Use

Changes in land use in a watershed can have a major impact on water resources. Proper land management techniques can help to control surface runoff, limit groundwater contamination, improve water quality, and reduce flooding and erosion, all of which greatly reduce public expenditures necessary to remedy problems. Water traveling over barren soils

Land Use Effects on Water

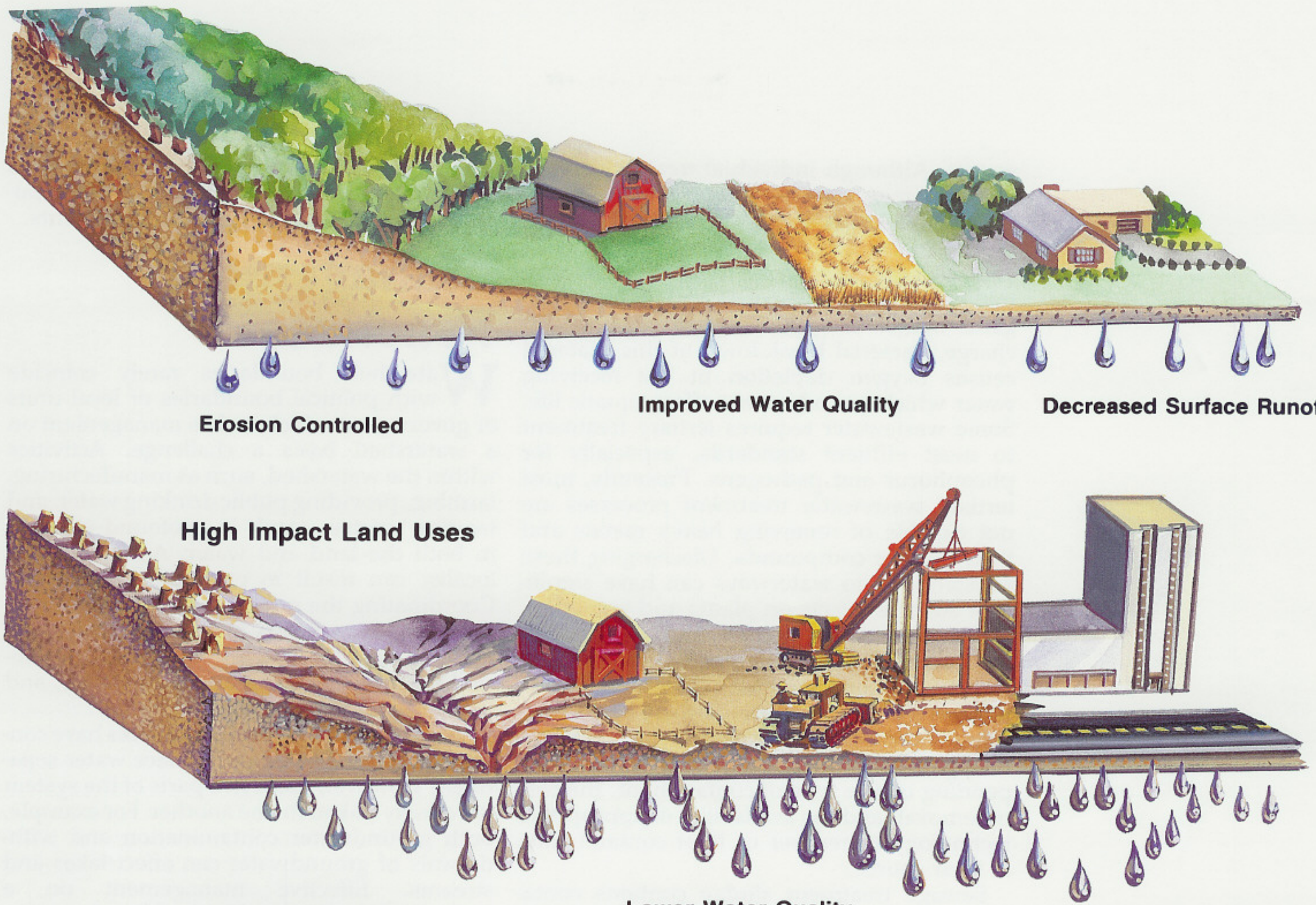


FIGURE 5-2. The condition of the land surface can greatly alter the quantity and quality of surface water runoff. The relative quantity of water running off the land surface is represented by the number of water drops.

exposed by poor construction or farming practices can lead to erosion of soil and carry contaminants to lakes or rivers. Surface runoff is greater on barren soils and can add to flooding problems (Figure 5-2). The impervious surfaces of roads and buildings in urban areas produce high surface runoff which may also contribute to flooding. Proper stormwater management can help reduce the detrimental effects of this runoff.

Local units of government can zone and use subdivision regulations to encourage water quality protection. For instance, drinking water can be protected by zoning ordinances, which might prevent hazardous waste landfills from being located within the recharge zone of an aquifer. Local ordinances may require proper storage practices for hazardous materials and wastes, and secondary containment and emergency response measures in case of hazardous material spills.

Floodplain Management

During periods of high precipitation or snowmelt many rivers overflow their banks onto floodplains, which becomes a problem when a floodplain is improperly developed. Flood damages can be minimized by controlling the flow of water during floods by decreasing runoff from areas upstream in the watershed or by limiting floodplain development to low damage uses such as parks and recreational areas. Water storage in reservoirs or in wetlands are methods to reduce river flows and minimize downstream flooding.

If they are managed properly, floodplains can be a great benefit to an area without being an economic burden (Figure 5-3). Allowing homes, schools, or businesses to be built in a floodplain can cause unnecessary monetary damage and loss of life. Siting of other facilities such as landfills or major industrial complexes in a floodplain can severely contaminate downstream waters during a flood.

stream flooding is a concern. While dams can provide a source of electricity, flood detention, and impoundments supporting recreation and wildlife habitats, they may also prevent fish migration, increase water level fluctuations upstream and downstream, and raise the temperature of the water. The safety of these structures is also a concern, and inspections should be conducted on a regular basis.

Water Management by Individuals

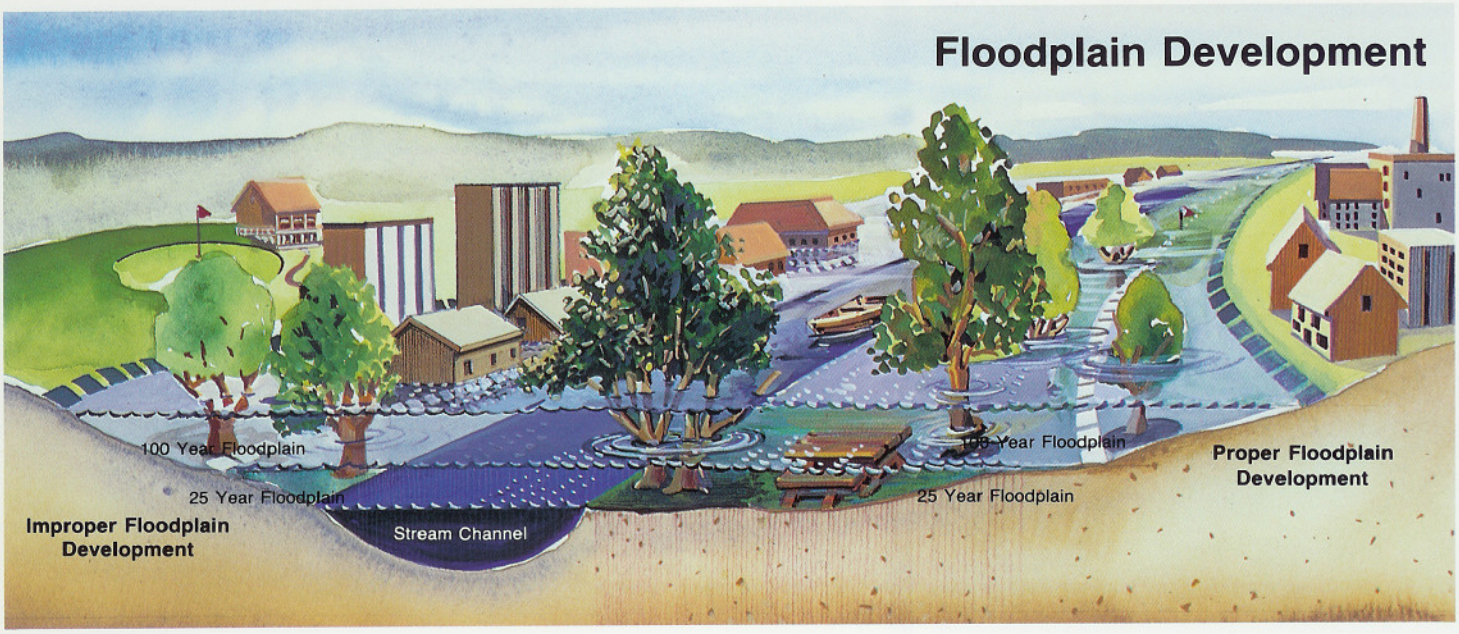
Everyone can assume responsibility for water management by implementing water conservation and environmentally sound practices at home and at work. Simple water-saving measures include installing aerators on faucets and showerheads, buying low volume flush toilets, and using washing machines and dishwashers less frequently by running them only with full loads. Proper recycling of used automotive oils, and responsible use and disposal of household and workplace chemicals help to prevent these materials from reaching the sewage plant or leaching to groundwater. Consumers could choose activities and products which are less detrimental to the environment when these alternatives are available. In addition, attending public hearings to express opinions on water issues will encourage full consideration of all management alternatives.

To aid in proper floodplain development, maps are available from many sources, including the DNR, which show the extent of the 10 year, 25 year, and 100 year floodplain. These areas are expected to flood once in 10, 25, or 100 years, respectively, based on statistical estimates. These maps should be examined prior to construction near rivers or lakes.

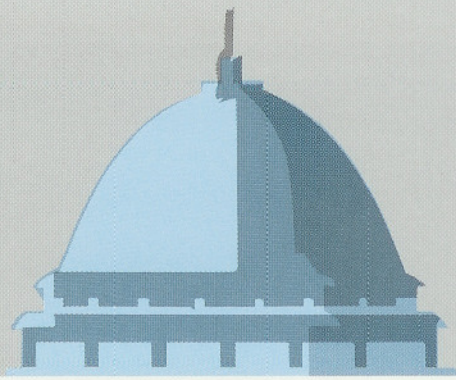
Dams

Currently the state has approximately 2,270 dams used for hydroelectric power generation and to regulate lake level fluctuations throughout the year. Dams are used by some communities to lower lake levels in the winter to reduce shore damage from ice, and to provide storage for spring runoff in areas where down- [continued above]

FIGURE 5-3. Proper floodplain development is necessary to avoid the risks and costs associated with flooding. The left side of the river shows some types of improper development while the right side shows development that will not be significantly damaged by flooding.



The Institutional Maze



International and Multi-State Commissions and Cooperative Arrangements

International Joint Commission
Great Lakes Commission
Great Lakes Fisheries Commission
Council of Great Lakes Governors
Great Lakes Charter
Michigan-Ontario Advisory Board on Transboundary Air Pollution Control

FIGURE 5-4. Levels of government frequently overlap in authority to regulate availability, quality, and uses of water, and land uses affecting waters. This overlap can cause confusion to the public and inefficiency in correcting problems.

Federal Government

Environmental Protection Agency
- Water Pollution Control
- NPDES Permits
- Drinking Water
- Hazardous Waste Disposal
- Toxic Dumpsite Clean-up
- Pesticide Registration
- Training Pesticide and Fungicide Applicators
- Great Lakes Protection
- Air Quality Regulation
- Research

Department of Agriculture
- Soil Stabiliation
- Soil Conservation
- Water Conservation

Department of Justice
- Enforcement

Department of Health and Human Services
- Environmental Health

Department of Housing and Urban Development
- National Flood Insurance Program

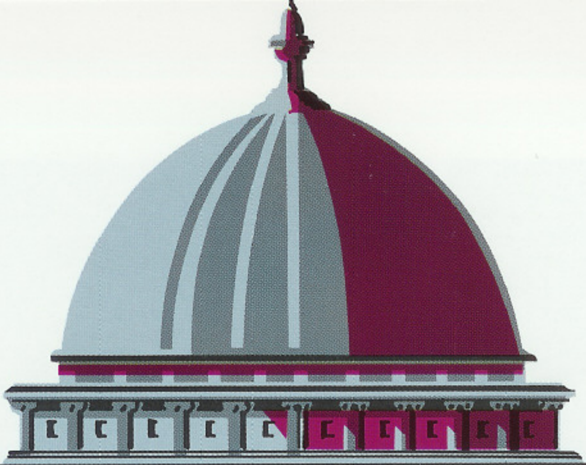
Department of Defense
- Water Resource Development
- Shoreline Erosion Protection
- Navigation Channel Maintenance
- Dredge and Fill Permits-Coasts
- Wetland Regulation
- Flood Control

Department of the Interior
- Fisheries
- Endangered Species
- Geological Survey
- Water Use Information
- Wetlands Permit Review

Department of State
- Treaty Administration

Department of Commerce
- Weather Services
- Flood Warnings
- Storm Warnings
- Ocean and Atmosphere Research
- Great Lakes Water Level Monitoring

Federal Emergency Management Agency
- Disaster Assistance
- Flood Insurance in Flood Prone Areas



State Government

Department of Natural Resources

Water Quality
- Issues NPDES Permits
- Monitors Watercraft Pollution
- Administers Natural Rivers Program
- Permit Enforcement
- Underground Disposal Permits

Inland Water Levels
- Regulates Inland Waters
- Channel Maintenance
- Water Level Data Collection

Lands Affecting Water
- Submerged Lands Regulation
- Sand Dune Protection
- Subdivision Control
- Wetlands Protection
- Erosion Control
- Floodplain Regulation
- Shoreland Protection
- Landfill Monitoring
- Land Inventories
- Leasing State Lands
- Oil and Gas Well Compliance Monitoring
- Mineral Well Compliance Monitoring
- Docks and Harbors
- Public Access Sites

Wastes and Contaminants
- Solid Waste Disposal
- Resource Recovery
- Hazardous Wastes
- Liquid Industrial Wastes
- PCB Disposal
- Oil Spills
- Clean-up of Toxic Contaminated Sites
- Permit Enforcement

Community Assistance

Fish and Wildlife Management

Geologic Survey

Department of the Attorney General
- Enforcement

Michigan Boards and Commissions
- Cabinet Council on Environmental Problems
- Resource Recovery Commission
- Natural Resources Commission
- Water Resources Commission
- Michigan Environmental Review Board
- Toxic Substance Control Commission
- Air Pollution Control Commissoin
- Great Lakes and Water Resources Planning Commission

Department of Transportation
- Water Transportation
- Stormwater Management
- Highway Drain Construction and Maintenance

Department of Public Health

Drinking Water
- Administers Safe Drinking Water Act
- Water Testing
- Regulates Well Siting and Construction

Sewage, Septic Tanks, Cesspools

Environmental Health

Emergency Response

Toxic Information Hotline

Department of Commerce
- Travel and Tourism Promotion and Information
- Assistance to Businesses and Local Government

Department of Agriculture
- Soil and Water Conservation
- Soil Stabilization
- Pesticide Application
- Weather Data
- Removing Dead Animal Bodies
- Agricultural Products Regulation
- Local Government Assistance

Department of State Police (Fire Marshal Division)
- Regulates Underground Storage of Fuels and Chemicals
- Storage of Flammable and Combustible Liquids Monitoring

Local Government

Courts
- Riparian Disputes
- Inland Lake Levels
- Environmental Protection Litigation
- Littering

Local Governments (Counties, Townships, Cities, Villages)

Governing Board or Commissions
- Health, Safety and Welfare Protection

Health
- Drinking Water
- Environmental Health
- Sewage Treatment
- Land Disposal of Wastes
- Trash Disposal
- Public Health
- Landfill Inspection
- Well Construction Review
- Septic System Installation Review

Public Improvements
- Wastewater Treatment
- Drinking Water
- Sewers

Drain Commission
- Drains and Ditches
- Floodplain Regulation
- Storm Sewers
- Hazardous Waste Management

Road Commission
- Road Drains

Fire Department
- Storage Tanks

Planning Commission
- Subdivision Controls
- Zoning
- Wetland Protection
- Floodplain Protection

Agriculture
- Cooperative Extension Agents
- Soil Conservation
- Erosion Control
- Soil Stabilization

Drainage Districts

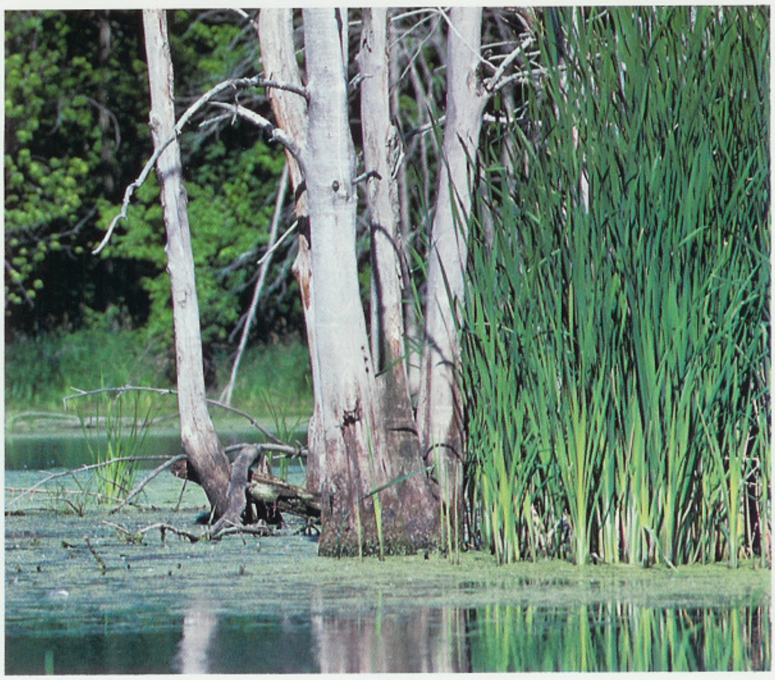
Sewage Disposal Districts

Soil Conservation Districts

Watershed Councils

Regional Planning Agencies

Institutional Considerations



The institutional maze of a multi-tiered government demonstrates the dilemma facing water management problem solvers who must coordinate efforts with one another and with other agencies (Figure 5-4). For example, the DNR is the agency with primary responsibility for the issuance of permits affecting wetlands. At the state level, the DNR must coordinate permit processes for four primary and several secondary laws. On dredge or fill permit decisions affecting wetlands, the state implements federal law. This requires coordination with the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service. State and federal permit processors and the permit applicant also must negotiate with appropriate local government units, which can include officials of the county, township, village, and city. The maze of governmental units illustrates the difficulty involved in identifying the decision-makers necessary to resolve any water issue.

More than one local unit of government may assume jurisdiction and provide water-related services. Drinking water supply and wastewater treatment are examples where a city, township, county, or other local unit of government may take responsibility for the installation of sewers, drains, or highway culverts. The growth of an area can result in overlapping jurisdiction, for example, among city, township, and county.

Superimposed on this regulatory scenario is the ultimate arbiter of disputes, the judicial system. Circuit courts can decide disputes regarding water use, the protection of water resources from misuse, and enforcement of state laws involving water. Under Michigan's system of water laws, property owners whose land is adjacent to a stream or lake are riparian owners. They have the qualified right to use the surface water without "unreasonably" diminishing either its quality or quantity. The courts may also decide disputes between groundwater users when competing uses are causing damage. Groundwater law in Michigan also requires property owners to make only "reasonable use" of groundwater. For instance, if a municipality pumps groundwater at a rate that causes neighboring wells to stop producing or to flow at diminished rates, the landowner may petition the court to determine a remedy fair to both parties because each owner may have a right to use the groundwater.

Historically, landowners have enjoyed the right to take and use water on their land and to dispose of it without permits (common law). Recently federal and Michigan laws have required landowners and other water users to secure a discharge permit before disposing of wastewater (statutory law). As surface water and groundwater conflicts become more frequent, litigation to determine both common law and statutory rights is likely to increase. Consequently, the courts may ultimately establish the standards for water use and priorities between or among users. Who gets the water in a river if an upstream landowner wants to use nearby groundwater for irrigation, which decreases streamflow, but a downstream municipality needs a steady flow to be allowed to discharge effluent? Within a

watershed, groundwater and surface water withdrawals both can decrease the flow in a river. Increased conflicts between water users may require state or local officials to conserve the supply by restricting the quantity of water each user removes or by implementing cost related measures.

Conclusion

Countless persons benefit from the abundant supply of Michigan's freshwater. Over 50 percent of Michigan residents and businesses depend on the Great Lakes for their drinking water, and many rural residents and businesses rely on groundwater for their sole supply of water. To ensure quality water for all uses, Michigan has taken a firm stand to avoid diminution of the quality of the Great Lakes, groundwater, inland lakes, streams, and rivers.

Many citizens remember the decline of the Detroit River and Lake Erie and the publicity about phosphorus from detergents and wastewater accelerating eutrophication. Since then many improvements have been made in monitoring and controlling effluents, but continued vigilance is essential to preserve Michigan's water. Successes, such as the water quality improvement in Lake Erie, will come much slower in correcting groundwater problems. One management practice to safeguard drinking water supplies is to protect valuable aquifers by imposing point and nonpoint source controls for both water and airborne pollutants, monitoring these controls, and enforcing compliance. Groundwater moves very slowly, so adverse effects will remain for many years or will be costly to correct.

Effective enforcement of environmental laws promotes compliance with water quality standards. Therefore, eliminating or reducing pollution becomes the most cost effective option because of the high economic costs of treatment or cleanup. Michigan is active in correcting the problems caused by past practices and is aggressive in encouraging implementation of practices which protect water resources or prevent degradation. Preventing contamination is the best means of preserving the quality of the Michigan's most valuable resource and ensuring a continued abundant supply for the multiple uses Michigan citizens make of water.

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