SURFACE-WATER HYDROLOGY

The surface-water resources of the Maumee River basin include the Maumee, St. Marys, and St. Joseph Rivers; Cedar, Little Cedar, Blue, Fish, and Spy Run Creeks; an extensive network of smaller tributary streams and ditches; two man-made reservoirs; natural lakes; ponds; and scattered remnants of *marshes*, *swamps*, and other wetlands.

These surface-water features comprise a significant part of the hydrologic cycle (figure 2), a continual movement of water between the atmosphere and earth. The hydrology of lakes, streams, and wetlands is closely related not only to precipitation, but also to topographic, *geomorphic*, and hydrogeologic conditions.

The greater Maumee River watershed, which encompasses areas in Indiana, Michigan, and Ohio is the largest watershed in the United States portion of the Great Lakes Basin (figure 4). The Maumee River is Lake Erie's largest tributary (Great Lakes Basin Commission, 1977).

The Maumee River begins at the confluence of the St. Joseph and St. Marys Rivers. From the present-day urban setting of Fort Wayne, the Maumee River flows eastward as a large river for about 134 miles until it discharges into Maumee Bay at Toledo, Ohio. The 15-square mile embayment of western Lake Erie, which forms Maumee Bay, allows more than 100 foreign ships to anchor at Toledo each year. Thus, the inland Maumee River ends as a transit point for ocean cargo. This link to the Great Lakes/St. Lawrence Seaway has played an important role in the development of Fort Wayne and Indiana's Maumee River basin.

The major tributaries of the Maumee River, the St. Joseph River and the St. Marys River, are mature streams in their own right. The St. Joseph River, the larger of the two, originates from a lake region near Hillsdale, Michigan, flows southwest, and enters Indiana from Ohio; whereas, the St. Marys River originates from western Ohio's flat prairies.

HISTORICAL PERSPECTIVE

The present surface-water hydrology of the Maumee River basin is different from the natural drainage conditions that existed prior to permanent settlement of the area.

An historical overview provides a broad perspective for assessing potential constraints and impacts of future water and land development. The most extensive changes which have occurred in the basin include logging, ditching and urbanization.

As ancestral Lake Maumee receded from the basin, the drainage networks developed. The course of the Maumee River generally follows the route of an earlier subglacial channel, but the modern eastbound drainage system did not become established until headward erosion by the river captured the St. Joseph and St. Marys Rivers (for additional information, see **Geology Section** of the **Physical Environment** chapter of this report).

The "Three Rivers" occupied a vast wetland lake plain, and much of the area was covered by dense forests. This forest-covered, water-laden land stretched for more than 120 miles from Fort Wayne to Lake Erie. Early settlers called this area many names including: the Great Black Swamp, Maumee Swamp, The Big Swamp, The Swamps, the Lake Plains, or the Dismal Swamp. The extensive swamp and the hostile Indians prevented early settlement of the Maumee region.

The "Three Rivers" however, were destined to be important trade routes because of an eight-mile portage connecting the Maumee River and the Wabash River. For many years the Maumee River provided the shortest water route between the Quebec and New Orleans colonial centers.

The streams, which nourished the hardwood forests by cycles of flooding and soil deposition, became frontier highways that brought Europeans to Indiana and accelerated settlement of Fort Wayne. Growing towns and cities needed vast quantities of wood; and the streams provided easy transportation of logs to the mills and power for sawmills. The timber industry became the first to harvest natural resources in the Maumee region.

The floodplains were rapidly cleared after the settlers learned that the soils which supported the finest trees would also grow the best corn. Intensive ditching and tiling turned the former swamps into productive farmland.

By 1819, when the last garrison was withdrawn from Fort Wayne, the surrounding village had begun to take on the character of a regional commercial and manufacturing center.

The completion of the Wabash and Erie Canal in 1843 improved the transportation infrastructure. This canal grew to become the continent's longest artificial waterway, and Fort Wayne one of its major ports. Stretching about 464 miles, it connected Toledo, Ohio and Evansville, Indiana. In conjunction with the Miami and Erie Canal in Ohio, the Wabash and Erie Canal allowed boats to travel from Lake Erie at Toledo via Fort Wayne to the Ohio River at Evansville. The emergence of the canal also led to the nickname Summit City as Fort Wayne was the highest point along the canal.

The St. Joseph River played an important role in operation of the Wabash and Erie Canal and in development of Fort Wayne. It supplied water for the central section of the Canal; when streamflow was not adequate to operate the Canal. A feeder canal was excavated and a dam was constructed about 7 miles upstream from Fort Wayne. The dam was constructed on dry land and the St. Joseph River rerouted behind it. The river helped keep the canal operating for nearly 50 years.

Another canal was planned that would have connected Fort Wayne with Coldwater, Michigan, by way of Noble County. Preliminary work on the canal resulted in the creation of Sylvan Lake, which was intended as a reservoir to supply water to the canal. However, a few years later, work on the project was abandoned due to its high cost. Sylvan Lake, located just outside the basin boundary, remains (Maumee River Basin Commission, 1993).

SURFACE-WATER RESOURCES

The larger streams in the basin provide water for withdrawal purposes such as public supply, industrial use, and energy production in northeastern Indiana. The St. Joseph River is the source of public water supply for Fort Wayne. Water for non-withdrawal uses such as instream recreation is provided by St. Joseph, Maumee, and St. Marys Rivers and the other tributary streams. Wetlands and the smaller lakes in the basin are not considered potential water supply sources, but their occurrence and regulation directly affect land use and its associated water-resources development.

Wetlands

Wetlands are an important hydrologic feature in many parts of the Maumee River basin. Generally wetlands occur where the ground-water table is normally at or near the land surface, or where an area is periodically covered by shallow water. Cowardin and others (1979) define wetlands as having one or more of the following three attributes: (1) at least periodically, the land supports predominantly *hydrophytes*, (2) the substrate is predominantly undrained hydric soil, (3) the substrate is *nonsoil* and is saturated with water or covered by shallow water at some time during the growing season of each year.

Wetlands within Indiana can be organized according to the classification scheme used by the U.S. Fish and Wildlife Service and published in 1979 as "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin and others, 1979). This classification involves a hierarchical approach analogous to the taxonomic system used to identify plants and animals. It progresses from the general levels of systems and subsystems, to the more rigorous levels of classes and subclasses. The latter two levels in the hierarchy can be further subdivided according to water regime (duration and frequency of flooding), water chemistry, soil type, and dominant plants or animals.

Wetlands in Indiana belong to three of the five major wetland systems identified by Cowardin and others (1979). **Lacustrine** systems include permanently flooded lakes and reservoirs of at least 20 acres, and smaller impoundments where maximum depth equals or exceeds 6.6 feet at low water. **Riverine** wetlands are contained within natural or artificial channels which continuously or periodically contain moving water, or which connect two bodies of standing water. **Palustrine** wetlands are associated with areas and/or bodies of water which usually are dominated by wetland plants. Palustrine wetlands include not only vegetated wetlands commonly called *marshes, swamps, bogs, sloughs, or fens*, but also isolated catchments, small ponds, islands in lakes or rivers, and parts of river floodplains. Palustrine wetlands also may include farmland that would support hydrophytes if the land were not tilled, planted to crops, or partially drained.

Table 12. Estimated number and area of basin wetlands by primary class

Values were determined from the U.S Fish and Wildlife Service National Wetlands Inventory.
Wetland Classification: Classification follows the system described by Cowardin and others(1979).

System	Primary Class	Frequency	Acreage	Square Miles
Total	All Classes	11,428	32,829.904	51.297
Lacustrine	Total	45	3,243.025	5.067
	aquatic bed	6	282.242	0.441
	emergent	3	13.910	0.022
	Unconsolidated Bottom	36	2,946.873	4.604
Palustrine	Total	11,369	28,155.883	43.994
	Aquatic Bed	142	197.521	0.309
	Emergent	4,942	7,711.331	12.049
	Forested	3,813	16,181.119	25.283
	Scrub Shrub	549	1,175.435	1.837
	Unconsolidated Bottom	1,900	2,846.233	4.447
	Unconsolidated Shore	23	44.244	0.069
Riverine	Total	14	1,430.996	2.236
	Unconsolidated Bottom	14	1,430.996	2.236

History of basin wetlands

The Maumee River basin in Indiana historically contained a section of the ancient Lake Maumee, a predecessor to modern Lake Erie. As the lake receded, it left an area of poorly drained soils which early settlers referred to as the Black Swamp (Homoya and others, 1985). This area extended from Toledo, Ohio to Ft. Wayne, Indiana. The Swamp once covered approximately 134 sq. mi., or 85,760 acres within the Maumee basin. It consisted mainly of swamp forest dominated by American Elm, Swamp White Oak, Pin Oak, and Shagbark Hickory. Because farmers quickly recognized the value of the rich organic soils for farming, the draining of the Black Swamp was the earliest large drainage program undertaken in the United States. By 1890, most of the swamp had been drained (U.S. Geological Survey, 1994).

Other wetland communities that were present in the Maumee basin include: floodplain forests, till plain *flatwoods*, *wet prairies*, marshes, *seeps*, and fens. These and other natural communities are virtually non-existent today with present land use roughly divided into the following three categories: 88 percent agricultural land, 7 percent urban, and 5 percent forested or other classifications.

Inventory of basin wetlands

A comprehensive inventory of Indiana's wetlands was initiated in 1981 by the U.S. Fish and Wildlife Service as part of its National Wetlands Inventory. The inventory process involves identifying and classifying wetlands from high-altitude aerial photographs, defining wetland boundaries using photointerpretation and field reconnaissance, and then transforming the photographs into detailed maps (1:24,000 scale). The location and classification of each wetland is then digitized and electronically stored. This computerized data is now accessible for Indiana and available for analysis through the use of a geographic information system (GIS).

Analysis of the GIS data indicates that the Maumee River basin contains 11,428 wetlands covering approximately 51.3 square miles or 32,830 acres (table 12). This is roughly 4 percent of the basin's land area (figure 23). Palustrine wetlands constitute 99.5 percent of the region's total number of wetlands, and nearly 86 percent of the total wetland area within the basin. Riverine and lacustrine wetland coverage accounts for approximately 4 and 10 percent, respectively (table 12).

As previously discussed, wetland systems are divid-

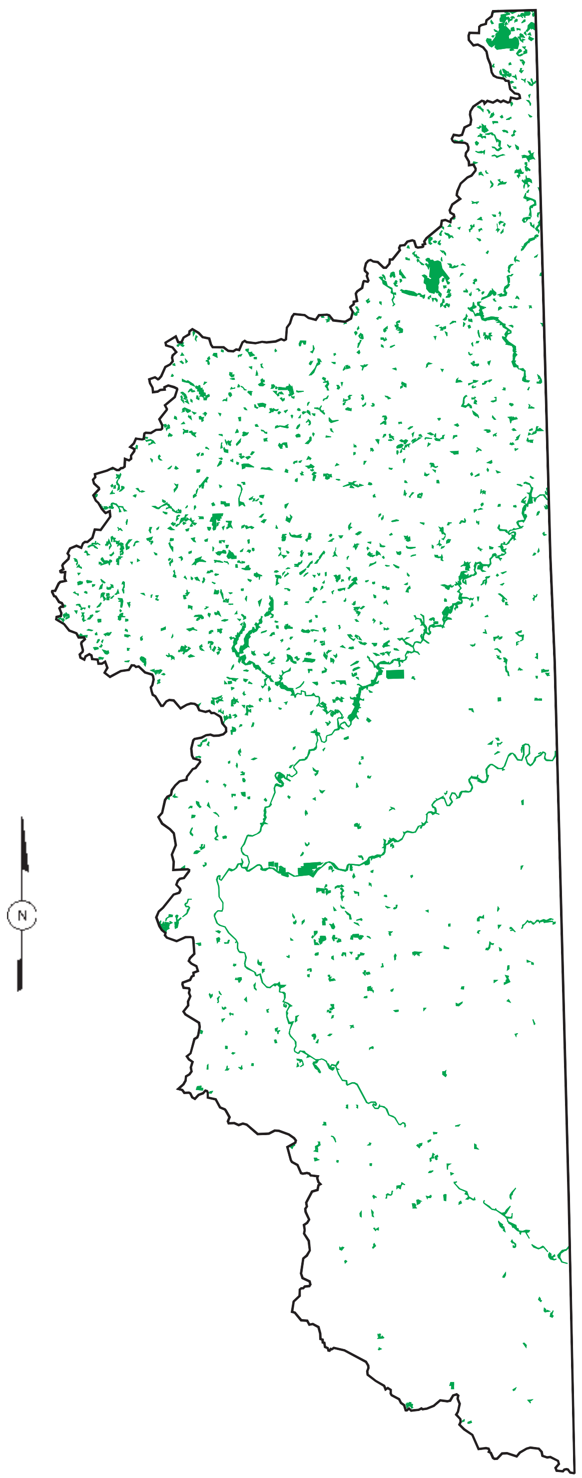


Figure 23. Wetlands of 5 or more acres
(adapted from U.S. Fish and Wildlife Service national wetlands inventory)

ed into several different classes. Palustrine Forested (PFO) and Palustrine Emergent (PEM) are two of the classes which Indiana Department of Natural Resources staff have preliminarily identified as state priority wetland types (Indiana Department of Natural Resources, 1988c). Fifty-seven percent of the Palustrine wetlands in the Maumee basin are classified as forested, and 27 percent are classified as emergent.

Palustrine Forested wetlands are characterized by woody vegetation 6 meters (19.7 feet) high or higher. They are common in the eastern United States and in moist areas of the West, particularly along rivers and in the mountains. Scattered remnants of PFO wetlands are present throughout the Maumee basin, but the majority are found within the northern regions. Major concentrations of PFO wetlands are located along Fish Creek and its west branch, Cedar Creek, Little Cedar Creek, and the St. Joseph River. Forested wetlands play a role in maintaining water quality (Winger, 1986), and the locations of these PFO's correlate well with the high quality surface waters found in these rivers (see discussion under **Surface Water Quality**). There are a few PFOs along the St. Marys River, but they are extremely rare throughout the southern part of the Maumee basin.

Palustrine Emergent wetlands are characterized by erect, rooted herbaceous hydrophilic vegetation (except mosses or lichens). Scattered remnants are located in the northern part of the basin in Steuben, DeKalb, and Noble Counties, but are extremely rare in Allen and Adams counties.

Wetlands in the Maumee River basin can be further characterized by the duration and timing of surface inundation (see sidebar titled **Water regime of wetlands in the Maumee River basin**). Approximately 45 percent are seasonally flooded, 31 percent temporarily flooded, 12 percent semi-permanently flooded or intermittently exposed, and 8 percent are either saturated or permanently flooded. The remaining 4 percent is unclassified (U.S. Fish and Wildlife computerized data base).

In addition, wetlands can be described by comparative size. Size classification is important when evaluating different functions and values of a given wetland. For example, for flood prevention a large wetland would provide increased water storage potential, whereas many species of waterfowl prefer smaller wetland areas for nesting and raising their young. In the Maumee basin, 9 percent of the wetlands are less than one acre in size, 44 percent are from 1 to 10 acres, 26 percent are from 10 to 40 acres, and the remaining 21 percent are greater than 40 acres.

Water regime of wetlands in the Maumee basin

Seasonally flooded wetlands contain surface water for extended periods, especially early in the frost-free growing season, but usually become dry by season's end. When surface water is absent, the ground water table is often near the land surface.

In **temporarily flooded** wetlands, surface water is present for brief periods during the growing season, but the ground water table usually lies well below the land surface for most of the season. Plants that grow both in uplands and wetlands are characteristic of the temporarily flooded regime.

Semi-permanently flooded wetland contain surface water throughout the growing season in most years. When surface water is absent, the ground water table is usually at or near the land surface. The region's semi-permanently flooded wetlands typically are found along river corridors or adjacent to the larger lakes.

In **intermittently exposed** wetlands, surface water is present throughout the year except in times of extreme drought.

In **saturated** wetlands, such as fens, ground water is at the land surface for extended periods during the growing season, but surface water is seldom present.

In **permanently flooded** wetlands, water covers the land surface throughout the year in all years. Riverine and lacustrine systems constitute the majority of permanently flooded wetlands.

Wetland protection programs

Once considered "wastelands", Indiana's wetlands have been ditched, dredged, tiled or filled to allow for agricultural production and other economic development. Although this perception of wetlands as barren or useless land still persists, there is a growing awareness of the valuable functions of wetlands. Wetlands not only play a role in the hydrologic cycle (figure 2), but also provide a wide range of benefits including floodwater retention, water-quality protection, erosion control, fish and wildlife habitat, recreational and aesthetic opportunities, and possibilities for education and research. In addition, wetlands may be significant contributors to certain global chemical cycles (See sidebar titled **Wetland values and benefits**).

In general , these wetland values have largely been overlooked until recent years, when state and federal agencies developed or expanded programs that directly or indirectly afforded some protection for wetlands. These state and federal programs generally are designed to balance the need for wetland protection with developmental and drainage needs. Appendix 6 summarizes programs having good potential for protecting the wetlands of northern Indiana.

Because the number and extent of wetlands protected through regulatory programs are limited, non-regulatory programs involving land acquisition and voluntary measures often are major factors in wetland protection. Many state agencies and private trusts are involved in acquisition of prime wetland habitat for preservation.

Indiana's Wetland Conservation Program is one method by which wetland tracts are being purchased and protected. At present there are 29 specific wetland conservation areas (Indiana Department of Natural Resources, written commun., 1995). Four of these areas lie within Steuben County, however, none are located in the Maumee basin.

Indiana's Dedicated Nature Preserves protect wetlands that are contained within their borders. There are presently eight dedicated nature preserves within the Maumee River basin. Four of these sites incorporate wetlands. One significant site just outside of the basin boundary is the 270 acre Fox Island Nature Preserve located in Allen County. Within this preserve, marshes and swamps border a dune which was created after the recession of the last glacier. The diverse land and water habitats present in this preserve support a wide variety of plant and animal life. A private nonprofit organization is presently working to extend the boundaries of this preserve which would include area within the Maumee basin.

Another important area within the basin is the Albert D. Rodenbeck Nature Preserve. This preserve is dominated by bottomland forest which borders Cedar Creek, a waterway designated as an Outstanding State Resource. (Cedar Creek is discussed further in the section titled **Surface Water Quality**.)

Indiana Wetlands Conservation Plan

In recent years, wetland systems have been recognized as one of the most productive and beneficial ecosystems on earth, yet wetland losses continue. Indiana presently has lost an estimated 87 percent of the wetlands that existed in pre-settlement times

Wetlands values and benefits

Wetlands provide **water storage** functions in river basins by temporarily retaining water in upstream reaches and slowing its release to downstream reaches. During periods of flood, the storage capacity of the low-lying areas characteristic of wetlands helps decrease floodwater velocity and increase the duration of flow thus decreasing flood peaks. During dry periods, stored water may discharge into the main river channel, thereby helping to maintain streamflow. Flooding in the Maumee River basin has been a continuing problem, especially in the Ft. Wayne area. The Maumee basin has experienced flood damages totaling nearly $50 million in recent floods (Maumee River Basin Commission, 1993). Although most of this damage is a result of developments being located within the floodplain, damages may have been reduced if the upstream water storage capacity had not been significantly altered due to wetland destruction.

Under certain conditions, water from wetlands supplements **ground-water recharge**. Rates of recharge depend on wetland soil permeability. Wetlands also function as **ground-water discharge** points. Discharge wetlands typically form where the ground surface intersects the water table. Wetlands are most likely to serve as ground-water discharge points at depressional lakes and along major river systems where regional ground-water flow patterns are toward the main channels.

Wetlands also play an important role in **water-quality maintenance** and improvement by functioning as natural filters to trap sediment, recycle nutrients, and remove or immobilize pollutants, including toxic substances that would otherwise enter adjoining lakes and streams. In the Maumee basin, the U. S. Fish and Wildlife Service is restoring wetlands along Fish Creek. This effort is an attempt to improve water quality to protect the White Cat's Paw Pearlymussel, a federally-endangered species that resides in these waters. Since this program began, two other endangered mussels, the Northern Riffleshell and Clubshell have been found in Fish Creek (Indiana Department of Natural Resources, 1995a). In other areas of the state, wetland creation/restoration is being used for lake enhancement programs, and although natural wetlands in Indiana cannot be used for wastewater treatment, a few artificial wetlands have been created for this purpose.

Wetlands play a role in **erosion control** along lakeshores and streambanks by stabilizing substrates, dissipating wave and current energy, and trapping sediments. Lakeshores frequently subjected to wave action generated by heavy boat traffic can particularly benefit from the stabilizing effect of adjoining wetlands.

The value of wetlands as **fish and wildlife habitat** has long been recognized. Many species of fish and shellfish, and virtually all important game fish rely on wetlands. They are considered wetland-dependant because many species: 1) spawn in aquatic portions of wetlands, 2) use wetlands as nursery grounds, and/or 3) feed in wetlands or upon wetland-based food.

Hundreds of vertebrate species found in Indiana utilize wetlands. Furthermore, species that originally used wetlands in rare circumstances, have come to rely increasingly on these resources due to other habitat destruction. Muskrats, beavers, and river otters are examples of Indiana furbearers that are totally dependent on wetland environments.

Eighty percent of America's breeding bird populations and more than 50 percent of the 800 species of protected migratory birds rely on wetlands (Wharton and others., 1982). Hamilton Lake in Steuben County has historically been an important area for waterfowl and continues to serve this purpose today. In addition, Fox Island Nature Preserve in Allen County contains a variety of wetland habitats, and has provided resources for 190 different species of birds (Indiana Department of Natural Resources, 1995b).

Wetlands provide the natural habitat necessary for the survival of many endangered species. In Indiana more than 120 plant species and 60 animal species considered as either endangered, threatened, rare or of special concern depend on wetlands (Indiana Department of Natural Resources, 1988c). Of these, 17 plant species, and 36 animal species have been documented within the Maumee River basin.

Many **recreational activities** take place in and around wetlands. Because of the aesthetic quality of wetlands, these lands are key features of many public parks and outdoor recreation areas providing opportunities for hiking, picnicking, birdwatching and a variety of other activities. Hunting is another value associated with wetlands. Many small game and big game species have been identified by state game managers as being associated with wetlands. Various furbearers also depend on wetland resources including the mink, beaver, raccoon, and fox. In addition, the popularity of waterfowl hunting relates directly to the importance of wetlands as feeding, nesting, resting, and wintering grounds for waterfowl (appendix 7).

Wetlands have **educational and cultural** significance as well. In education, wetlands are used for field trips, nature study, and teaching a variety of the biological, chemical and physical sciences. Rare and unique plants associated with wetlands are valuable for research and may be vital in the development of future pharmaceutical products. Many wetlands also have cultural relevance as areas that were once refuges for American Indians, scenes of inspiration for artists and writers, or sites of colonial campaigns (Reimold, 1979).

Wetlands may significantly impact **global cycles** of nitrogen, sulfur, methane and carbon dioxide (Mitsch and others, 1993). Many plants and microorganisms within the wetland environment "fix"or transform inorganic forms of nitrogen to organic, ecologically useful forms. Also, because of nutrient loading to wetlands from agricultural runoff, many wetlands may be important in returning excess organic nitrogen to the atmosphere through denitrification.

Sulfates released by the burning of fossil fuels are washed out of the air by rain and can acidify lakes and streams. The anaerobic environment present in wetland systems can alleviate this problem by reducing these sulfates to sulfides. Most of these sulfides then form insoluble complexes with phosphate and metal ions and precipitate out of the water column, thus more or less removing them permanently from circulation.

Carbon dioxide in the atmosphere is increasing due to burning of fossil fuels, destruction of rainforests and other oxidation processes involving organic matter. Draining and oxidation of peat deposits within wetland systems result in a net release of carbon dioxide into the atmosphere. Therefore, wetlands may be shifting from a net sink of carbon to a net source. Carbon is also released from wetlands in the form of methane. Aselmann and others (1989) estimate emissions of methane from natural wetlands at 40-160 x 106 mt/yr.

(Dahl, 1990), and continues to lose this valuable resource at an estimated rate of 1 to 3 percent of existing wetlands annually (Hansen, 1992).

Conservation of wetland habitat is an important part of maintaining the health of the environment. Consequently, the Indiana Department of Natural Resources began in July of 1992 "to review the current programs and activities involving wetlands in the Department of Natural Resources[,] and to provide recommendations on the direction and structure for

Constructed wetlands for wastewater treatment

In recent history, regulations specifying increased wastewater treatment standards and heightened concern over environmental issues and the safety of our water supplies have led to an increased interest in the application of constructed wetlands for wastewater treatment. Wetland systems have been found to be efficient at treating a wide variety of pollutants including excess nutrients, toxic substances and pathogenic organisms. Wetlands act as sinks for these substances through various physical and chemical processes such as sedimentation, nutrient uptake, absorption, adsorption, ion exchange, and the dissimulation of harmful bacteria.

Because of their ability to deal with a wide variety of pollutants, wetlands have been used to treat both point and nonpoint sources of pollution. In southern Indiana, wetlands are being used in the reclamation of streams impacted by acid mine drainage. In other areas of the state, they enhance the quality of downstream lakes by functioning as filters for nonpoint source runoff from agricultural areas. In addition to these nonpoint source applications, wetlands are increasingly being used to treat sewage from a variety of sources.

Organic matter is one of the major components of wastewater from human activities. Wetland plants use this organic matter as an energy and nutrient source, thereby removing excess nutrients and other materials from the water column. These plants also provide sites for microorganisms which aid in the purification process.

There are two basic types of constructed wetlands, surface flow and subsurface flow systems. Surface flow systems have a shallow bed or channel with water exposed to the atmosphere, and contain the appropriate emergent and/or submergent aquatic vegetation. A subsurface flow wetland consists of a foot or more of permeable media (rock, gravel, sand, or soil) which supports the root systems for emergent vegetation. The water level is kept below the ground surface. Which ever type is used, it is recommended that at least *primary treatment* precede the use of a wetland for wastewater treatment.

One relatively new application in Indiana is the use of wetlands for single family residence septic systems. These systems have been designed as subsurface systems for several reasons: odor and mosquito problems are avoided, freezing weather has less impact on this type of wetland, and subsurface systems require less area than surface flow systems to treat a given amount of wastewater. Several of these wetland septic systems have been installed throughout northern Indiana, including the Maumee River basin.

These systems generally consist of three stages. First a septic tank is used for primary settling. This results in removal of the majority of the solids. Second, the effluent flows from the septic tank into the constructed wetland. To help comply with State Board of Health regulations and recommendations, the wetland portion of the system is lined with an impermeable membrane to avoid potential ground-water contamination. From the wetland, treated water enters a small leach field. This leach field provides treatment while the wetland plants are being established and serves as an area for further treatment once the wetland is fully functioning.

To achieve proper wastewater treatment during the winter, wetlands in temperate zones need to be roughly twice the size of systems in warmer climates. A conservative estimate for Indiana is to allow one square foot area of wetland for each gallon treated per day. A single family residence typically uses 500 to 600 gallons of water per day. Therefore, 600 square feet of wetland (an area 30' X 20') would be appropriate. As more is learned from careful monitoring and evaluation of these systems, the area considered to supply adequate treatment will probably be reduced.

Monitoring indicates that these low maintenance systems are performing well in Indiana. Effluent from the wetland portion of the system often meets Indiana water-quality standards for recreational use (table 19). E. coli. bacteria (an indicator for pathogenic organisms) have been reduced by as much as 99.9 percent. Removal rates are also very good for total suspended solids and biological oxygen demand. They do, however, have difficulty removing ammonia, especially in winter (Ditzler, written commun., 1995). These systems have great potential for areas where soil conditions are not suitable for conventional septic systems.

managing Indiana's wetland resources during the next decade" (Hansen, 1992).

Recognizing the value of wetlands and the need to protect them, IDNR is in the process of developing the Indiana Wetland Conservation Plan (IWCP). The plan development is being accomplished through the input of two key groups; a Technical Advisory Team comprised of specialists from state and federal programs directly related to wetland protection and management, and a Wetlands Advisory Group which includes representatives of major interest groups such as developers and environmental agencies. As drafts of the plan are updated, they are sent out to additional reviewers representing various interests throughout the state. In addition, drafts are available for public comment.

The goal of the plan to date is to "conserve Indiana's remaining wetland resources, as defined by acreage, type, and function, and to restore and create wetlands where opportunities exist to increase the quality and quantity of wetland resources". This goal does not imply a "hands off" policy, as fairness and a recognition of private property rights is inherent in the plan.

One of the major undertakings has been the prioritization of wetlands, a step that has not been accomplished by any other state in their conservation plans (Case, oral commun., 1995). This prioritization is being generated so that limited money and resources can be spent in the most efficient and beneficial ways. Prioritization is being developed in two distinct areas: the **physical/chemical** benefits of wetlands such as flood protection and water-quality enhancement, and the **biological** benefits including biodiversity and wildlife habitat. In addition, inherent in the conservation of any wetland system for the above reasons are the **recreational** and **educational** benefits derived from these unique ecosystems.

At the heart of the Indiana Wetlands Conservation Plan is the Hoosier Wetlands Conservation Initiative. This initiative focuses on several strategic components for conserving wetlands that have broad support among interests throughout the state. These components are as follows: 1) developing "focus areas" or pilot projects where conservation efforts can be built around partnerships which utilize strategies developed in the IWCP, 2) increasing scientific information on wetland resources to better guide conservation efforts, 3) providing positive incentives for wetland conservation and restoration, 4) educating technical staff, farmers, school children, and others on our wetland resources, 5) targeting wetlands for permanent acquisition from willing owners, 6) continuing the work of the Technical Advisory Team and Wetlands Advisory Group to address additional issues such as creating a clearly-defined mitigation program that addresses mitigation banking, and improving coordination, efficiency and consistency of local, state, and federal regulations.

Upon its completion, it is hoped that the Indiana Wetlands Conservation Plan will be the guiding document for wetland conservation in Indiana, and that open interaction of the state with interested public and private parties will be inherent in all future conservation projects.

Lakes

The physiographic features within the Maumee River basin create the unique distribution of natural freshwater lakes. The Steuben Morainal Lake Area (figure 15) at the northern extreme of the study area contains many of the basin's natural lakes. Hummocky ridges and uplands with thick, unconsolidated glacial deposits differentiate this area from the southern regions. Most of the natural lakes within this area probably formed in depressions left by the irregular deposition of glacial drift. Other lakes, known as kettle-hole lakes, were created by the melting of isolated masses of buried glacial ice. Clear Lake, having a maximum depth of 107 feet, is an example of a deep kettle-hole lake located in northeastern Steuben County.

In contrast to the morainal area, the southern section of the Maumee basin consists mainly of very low-relief regions with thin deposits of glacial till. These tills, which overlie karstic limestone bedrock, make up the Maumee Lacustrine Plain and Tipton Till Plain (figure 15). Within these regions some small, shallow *oxbow* lakes remain scattered along the lengths of the St. Marys, St. Joseph and Maumee Rivers. Because most oxbow lakes are only temporarily, seasonally, or semi-permanently flooded, the U.S. Fish and Wildlife Service and the Division of Fish and Wildlife of the Indiana Department of Natural Resources typically classify these lakes as palustrine wetlands. In one sense, the remnant lakes (wetlands) are artificial because they were formed when the rivers were dredged and straightened. In another sense, they are considered natural because oxbow lakes commonly form along meandering rivers. Altogether, shallow remnant oxbows probably account for the majority of small lakes remaining in the lower Maumee River basin.

An unknown number of lakes in the basin may have disappeared due to natural cataclysmic events. Some lakes gradually filled in because of natural or cultural eutrophication, and others were destroyed or greatly diminished by artificial or natural drainage.

Ancestral Lake Maumee

In the relatively flat expanse of the Maumee Lacustrine Plain lies the remains of ancestral Lake Maumee. Lake Maumee, the most recent stage of ancestral Lake Erie (a predecessor to modern Lake Erie), formed between the retreating Erie Ice Lobe and the Fort Wayne Moraine. The lake's former power remains evident in the widely scattered sand bars, spits, and wave-scoured terraces near the ancient shorelines. On the lakeward side of the Fort Wayne Moraine, a complex of prominent *beach ridges* was deposited atop till *benches*.

An event of debated origin destroyed ancestral Lake Maumee. When the Fort Wayne Moraine was breached, the rapidly draining waters scoured the Wabash-Erie Channel and drained Lake Maumee (for more information see the **Geology** section of **Physical Environment**).

Eutrophication

"A lake of small size, like those in Indiana, begins to die the moment it is born." This quote by W. S. Blatchley (1901) refers to a lake's natural processes of aging or *eutrophication*. This normally slow accumulation of sediments decreases lake depth. Eventually, a lake may become a wetland and finally may convert to land that can support terrestrial vegetation.

A young lake typically contains low nutrient levels and numbers of organisms, but a wide variety of species. The dissolved oxygen content of the *hypolimnion* remains relatively constant throughout the year. Lakes with low nutrient levels, high biodiversity, and a stable dissolved oxygen content are considered *oligotrophic*. Added nutrients from surface runoff into lakes and streams augment phytoplankton production. As this biomass dies and settles to the lake bottom, decomposition rates increase resulting in a reduced dissolved oxygen content. This reduced oxygen content affects aquatic species composition. The more desirable fish species are replaced by tolerant varieties that thrive in the diminished water-quality conditions of a eutrophic lake (Clark and others, 1977).

Humankind influences this process of lake eutrophication by means of point and non-point sources of pollution. This culturally-induced increase in nutrient levels results in premature degeneration of lakes.

Drainage Projects

Another way in which humans have altered the lakes in the Maumee basin is through dredging, tiling, and drainage. The quest for more arable soil led to the extensive drainage projects of the early nineteenth century. Thirteen special drainage Acts were enacted between 1799 and 1852.

The Federal Swamplands Act of 1850 greatly affected lakes adjacent to swamps. This Act transferred 1,378,000 acres of undrained lands from the federal government to the state. Indiana then spent over one million dollars attempting to create more profitable land. Legislation to promote the drainage activities involved at least 34 laws and six resolutions spanning 54 years. A historic atlas from 1882 lists 65 ditches in Whitley County alone. According to the **History of Indiana Lakes**, it is probable that just as many drainage ditches existed in the adjoining counties of the Maumee River basin. Drainage projects affected nearly all lakes in the basin, and this influence did not diminish until the first lake-level protection law passed in 1905.

Inventory of basin lakes

Table 13 presents information on eight natural and three artificial lakes in the Maumee basin having an area of at least 25 acres. Saddle Lake (24 acres) is included because it borders the size limit, and some data are available. The eight natural lakes tabulated in table 13 occupy a total of about 1980 acres, or just over three square miles. Two lakes in Steuben County, Clear Lake and Hamilton Lake, are 800 and 802 acres, respectively. These two lakes account for approximately 80 percent of the total acreage of the natural lakes listed in table 13.

Clear Lake and Hamilton Lake have the largest capacities of the natural lakes in the basin. These two natural lakes and Hurshtown Reservoir account for about 84 percent of the known total capacity of nearly 18 billion gallons for basin lakes.

At maximum pool level, the three reservoirs in the basin occupy about 703 acres or 1.1 square miles. Fort Wayne Utilities constructed the Cedarville and Hurshtown Reservoirs primarily for water supply, but these water bodies subsequently became recreational areas also. According to the Division of Fish and Wildlife's **1995 Indiana Fishing Guide**, Hurshtown Reservoir is now the best fishing area for smallmouth bass in Allen County.

The Cedarville Reservoir, also in Allen County, is a shallow 408 acre in-stream impoundment located east and northeast of the city of Cedarville. Constructed on the St. Joseph River, it acts as a supplementary water supply for the greater Fort Wayne area. Additional information about the Cedarville and Hurshtown Reservoirs may be found in this chapter under the heading of **Reservoirs**.

The St. Joseph Reservoir is a widening of the St. Joseph River upstream from a flood control structure within the Fort Wayne city limits. It is included in this report because of its public use and the amount of information available. The public boat launch at Johnny Appleseed Park provides access to this 30-acre body of water known for its good carp, channel cat, and sucker fishing.

Lake-level fluctuations

Since 1942, the U.S. Geological Survey, through a cooperative agreement with the Indiana Department of Natural Resources (IDNR), has collected records of

Table 13. Selected data for major lakes

Surface area: Acreage at established level; only lakes having a surface area of at least 25 acres are tabulated (Indiana Department of Natural Resources, 1993a).

Maximum depth: (Indiana Department of Natural Resources, 1993a)

Established level: Average normal water level, area determined by local courts; expressed in feet above mean sea level (fmsl).

Period of record: Refers to lake-level data collected by the USGS under cooperative agreement with the IDNR, Division of Water.

Management group and trophic class: Data from Indiana Department of Environmental Management, 1986a and 305(b) report, [1995].

Lake Name	Drainage Area (sq. mi.)	Surface Area (acres)	Maximum Depth (ft)	Established Level (fmsl)	Period of Record	Management Group [1]	Trophic Class [2]
Adams Co.							
Saddle	—	24	10	none	—	VII C	2
Allen Co.							
Cedarville Res.	764.00	408	22	none	—	VI A	2
Hurshtown Res.	0.40	265	35	836.00	—	—	—
St. Joseph Res.	—	30	—	—	—	—	—
DeKalb Co.							
Cedar	23.40	40	16	896.76	1943-56	VII C	3
Indian	3.76	56	52	none	1957	VII C	2
Steuben Co.							
Ball	11.60	87	66	894.76	1961-	II C	1
Clear	6.86	800	90	1037.38	1943-	II B	1
Hamilton	16.50	802	70	898.83	1943-	VI C	2
Long	2.80	154	36	1039.70	1961-63	VII C	2
Round	7.25	30	25	1037.38	1943-	VII A	1

[1] Groups of similar lake types were derived from cluster analysis based on lake morphometry and trophic state. Groups applicable to lake size are summarized as follows:

Group	Surface Area	Mean Depth	Eutrophy Points
II B	40-1034	31.2-45.0	3-25
II C	37-388	32.7-40.5	18-41
VI A	25-421	15.0-27.0	13-39
VI C	802	20.7	31
VII A	25-828	5.0-13.2	18-37
VII C	25-424	5.5-14.4	33-46

[2] Class 1 – high-quality lakes assigned a total of 0-25 eutrophy points; class 2 – intermediate-quality lakes assigned a total of 26-50 eutrophy points; class 3 – poor-quality lakes assigned a total of 51-75 eutrophy points; class 4 – remnant lakes and oxbow lakes.

Lake regulations

Because water-level fluctuation in lakes can restrict their usefulness for recreation, residential development, flood control and water supply purposes, state and local organizations have attempted to maintain average water levels on many lakes. In accordance with a state law passed in 1947 (I.C. 13-2-11.1) and recodified in 1995 (I.C. 14-26-2), the Indiana Department of Natural Resources (formerly the Indiana Department of Conservation) is authorized to have normal lake levels established by appropriate legal action. The Department also has the authority to initiate and supervise the installation of dams, spillways, or other control structures needed to maintain the established levels.

Established lake levels typically represent the average water-surface elevation that has prevailed for several years. Once an average normal water level is established by a local circuit court, the average lake level is to be maintained at that elevation. Temporary lowering of a lake level below its designated level requires prior approval from the Department of Natural Resources. Such approval typically is granted only for shoreline improvements or lake restoration procedures.

A related lake law (I.C. 14-26-2) enacted in 1947, with major amendments in 1982 and 1995, requires prior approval from the Department of Natural Resources for any alteration of the bed or shoreline of a public freshwater lake of natural origin. Permits are required not only for large projects such as channel or lakebed dredging, boat-ramp construction, and boat-well construction, but also for minor projects such as the construction of seawalls or sand beaches. In addition, a permit is required to pump water from a public freshwater lake.

Under a law passed in 1947 and amended in 1987 (I.C. 14-26-5), a permit is required for the construction, reconstruction, repair or recleaning of a ditch or drain that has a bottom elevation lower than the normal average water level of a freshwater lake of 10 acres or more, and that is located within half mile of the lake.

the water-surface elevations of many Indiana lakes. Lake stations generally are equipped with a staff gage that is read once daily by a local observer. Automatic digital water-stage recorders have been installed at a few lake stations in the Maumee River basin (table 13).

Today lake-level data are used primarily to monitor maximum and minimum levels, determine the location of shoreline contours for lakeshore construction projects, and to investigate water-quality and flooding problems. Gage records are also used to establish normal water-surface elevations, as described in Indiana law (I.C. 14-26-2). At present, legal levels have been established at six of the eight natural lakes in the basin. Although Indian Lake has a gage, no legal level has been established; Saddle Lake has neither a gage nor a legal level (table 13).

Between 1954 and 1968, the U.S. Geological Survey in cooperation with the IDNR mapped more than 200 natural and artificial lakes in Indiana, including seven lakes in the Maumee River basin. Although originally intended for use in the establishment of normal water-surface elevations, these depth contour maps have since been used for many purposes, including fisheries studies, water-quality analysis, and recreational planning. Depth contour maps of Ball, Cedar, Clear, Hamilton, Indian, Long, and Round lakes are available from the IDNR Division of Water. In addition, a hydrographic survey of Cedarville Reservoir was completed in 1988 by the Surveying and Mapping Section of the Division of Water, IDNR.

The historic drainage projects conducted throughout the Maumee River basin since the 1800s have greatly affected the basin's natural lakes. Ditching near a lake may intercept or divert surface drainage that normally enters the lake basin, thus reducing the drainage area contributing to the lake. A ditch constructed down gradient of a lake may induce ground-water leakage from the lake to the ditch. Moreover, lowering the local water table by surface or subsurface drainage or ground-water pumping may reduce the amount of ground-water inflow to lakes.

State laws enacted since the 1940s protect public freshwater lakes of natural origin from detrimental development and excessive water-level fluctuations (see sidebar **Lake Regulations**).

Streams

The Maumee River basin in Indiana consists of the drainage basins of the St. Joseph River, the Upper Maumee River, the St. Marys River, and the Auglaize River which drains into Ohio before entering the Maumee River.

The principal drainage network in the Maumee River basin is formed by the "Three Rivers": the St. Joseph River, the St. Marys River, and the Maumee River. The St. Joseph River originates near Hillsdale, Michigan, and enters Indiana from Ohio, northeast of Fort Wayne. The St. Marys River originates near New Bremen, Ohio and flows northwest to Fort Wayne. At Fort Wayne, these two rivers join to form the Maumee River. The Maumee then travels approximately 134 miles to Maumee Bay, a 15 square mile embayment of western Lake Erie.

Other streams in the Maumee River basin in Indiana, listed in order of decreasing drainage areas include Cedar Creek, Blue Creek, Little Cedar Creek, Flat Rock Creek, Hoffman Creek, Fish Creek, Holthouse Ditch, Nickelsen Creek, Bear Creek, Harber Ditch, Willow Creek, Big Run, Houk Ditch, Spy Run Creek, and Dibbling Ditch.

Sources of stream-flow data

Stream gages in the Maumee River basin monitor the spatial and temporal variations in stream flow in the major watercourses of the basin. Hydrologic parameters derived from stream-flow records can be used to evaluate the water-supply potential of streams.

The U. S. Geological Survey (USGS), in cooperation with other government agencies has maintained daily records of stream flow in the Maumee River basin since 1930. Cooperators that participate in the program include the U.S. Army Corps of Engineers (USACE), and the Indiana Department of Natural Resources.

Presently, records of daily *mean* discharge are collected at 8 *continuous-record stations* in the basin (figure 24 and table 14). Of the eight stations, four are located on the St. Joseph River and its tributaries, three on the St. Marys River mainstem and its tributary Spy Run, and one on the Maumee River.

Data from most stations in the Maumee River basin are used primarily for flood hydrology and river forecasting. Three of the gaging stations, one each on the St. Marys, St. Joseph, and the Maumee, are equipped with telemetering devices for automatic reporting of current river stages (table 14). The telemetered stations are part of an "Early Warning System" for flooding near the city of Fort Wayne.

Table 14 also lists active, discontinued, and *partial-record stations*. The partial-record station at Cecil Metcalf Ditch near Auburn has served as a *crest-stage station.* A crest-stage gage registers the peak stream stage occurring between inspections of the gage. Stage readings can later be converted to discharge values, and flood frequency characteristics can be determined. Table 14 lists the only partial-record station in the basin for which flood frequency data have been reported by Glatfelter (1984).

The other partial-record sites are low-flow stations. A series of low-flow discharge measurements collected at a partial-record site can be correlated with simul-

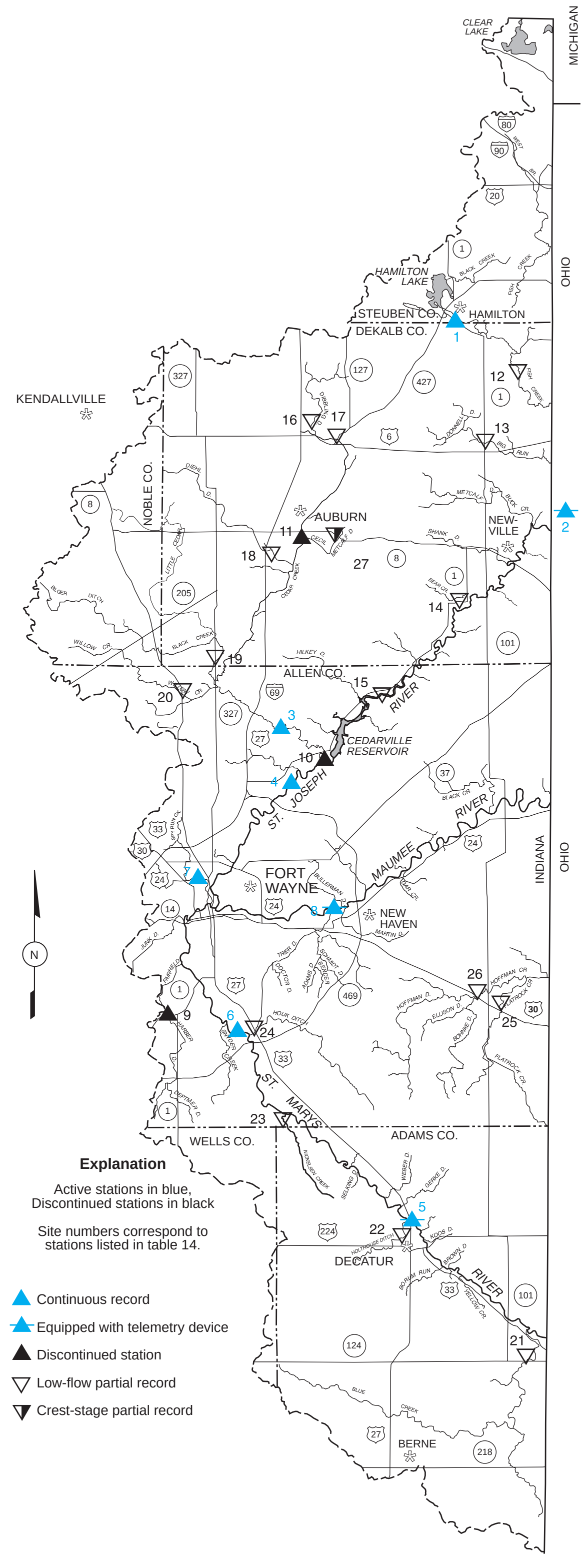


Figure 24. Location of stream gaging stations

Table 14. Stream gaging stations

Map number: Station locations are shown in figure 24.

Station number: Numbers are U.S. Geological Survey downstream-order identification numbers; Letter abbreviation T: Refers to telemetered station or data collection platform.

Contributing drainage area: Portion of watershed that contributes directly to surface runoff; Period of record: Refers to calender year, whether or not data encompasses entire year.

Map no.	Station no.	Station name	Contributing drainage area (sq.mi.)	Period of Record Dates
Active[1]				
1	04177720	Fish Creek at Hamilton	37.5	1969-
2	04178000T	St. Joseph River near Newville*	610	1946-
3	04180000	Cedar Creek near Cedarville	270	1946-
4	04180500	St. Joseph River near Fort Wayne	1060	1983-[2]
5	04181500T	St. Marys River at Decatur	621	1946-
6	04182000	St. Marys River near Fort Wayne	762	1930-
7	04182810	Spy Run Creek at Fort Wayne	14	1983-
8	04183000T	Maumee River at New Haven	1967	1946-[3]
Discontinued				
9	04182590	Harber Ditch at Fort Wayne	21.9	1964-1991[4]
10	04179000	St. Joseph River at Cedarville	763	1955-1981[5]
11	04179500	Cedar Creek at Auburn	87.3	1943-1973[6]
Low-flow partial-record stations[7]				
12	04177800	Fish Creek near Artic	96.8	
13	04177900	Big Run at Butler	16.7	
14	04178400	Bear Creek near Saint Joe	23.9	
15	04178500	St. Joe River near Hursh	734	Daily values 1950-54
16	04179308	Dibbling Ditch near Waterloo	12.9	
17	04179310	Cedar Creek near Waterloo	48.8	
18	04179560	John Diehl Ditch at Auburn	37.5	
19	04179800	Little Cedar Creek near Garrett	72.3	
20	04179900	Willow Creek near Huntertown	19	
21	04181100	Blue Creek near Pleasant Mills	78.5	
22	04181600	Holthouse Ditch near Decatur	34	
23	04181800	Nickelsen Creek near Poe	25.6	
24	04181900	Houk Ditch near Hessen Cassel	16.3	
25	04191340	Flatrock Creek near Townley	47.1	
26	04191360	Hoffman Creek at Townley	41.7	
Crest-stage partial-record station[8]				
27	04179510	Cecil Metcalf Ditch near Auburn	0.78	

[1] Information on Active stations is obtained from: Stewart and others, 1994
[2] July 1941 to September 1995 gage located 1.3 miles downstream at Ely Bridge
[3] From December 1946 to September 1956 only high-water records are available
[4] Discharge measurements available from October 1960 to May 1964 and gage heights from January 1961 to May 1964 at site 0.7 miles down stream (Stewart and Deiwert, 1992)
[5] Discharge measurements are also available from 1931 to May 1932 (U.S.Geological Survey, 1982b)
[6] Discontinued as a continuous-record station, converted to a crest-stage and low-flow partial-record station (U.S.Geological Survey, 1974)
[7] Obtained from Kathy Fowler, U.S.Geological Survey (written communication, 1995)
[8] Obtained from Don Arvin, U.S.Geological Survey (personal communication, 1995)
* Located about 600 feet east of Indiana/Ohio State Line

taneous daily mean discharges at a nearby continuous-record gage on a stream draining a nearby basin of similar hydrologic characteristics. Using this correlation, low-flow frequency characteristics of the partial record site can be estimated using frequency characteristics of the discharges collected at the continuous-record gage.

Factors affecting stream flow

Stream flow varies in response to available precipitation, topographic features, soil conditions, land cover, hydrogeologic characteristics, and channel geometry. Changes in land use, drainage patterns, stream geometry, and ground-water levels also produce variations in stream flow.

Time variation in stream flow and its relation to temperature and precipitation can be illustrated by a graph of mean monthly values (figure 25). The difference between precipitation and runoff, which varies considerably during the year, can be attributed primarily to the seasonal differences in evapotranspiration rates, although soil and ground-water conditions can also play an important role.

Differences in precipitation and runoff are greatest during late summer and early fall when warm temperatures cause high evapotranspiration rates. Hence, most of the precipitation that would otherwise be available to streams is lost to the atmosphere. Moreover, ground-water levels are at or near their seasonal low, and base flow may be limited.

Small differences between precipitation and runoff indicate low evapotranspiration rates, which occur in late winter and early spring when temperatures are cool and plants are dormant or very young. In addition, the ground often is either frozen or saturated, and may be covered by melting snow. As a result of these factors, more of the total precipitation is available to streams in the form of overland flow and base flow.

The geographic variation in stream flow within a drainage basin can be illustrated by comparing runoff characteristics along the same stream and among different streams. Of the many stream-flow parameters that can be used to compare runoff characteristics, flow-duration analysis offers the advantage of not being influenced by the chronological sequence of daily flows.

Flow-duration curves of daily mean discharges, as presented in figure 26, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. For example, daily

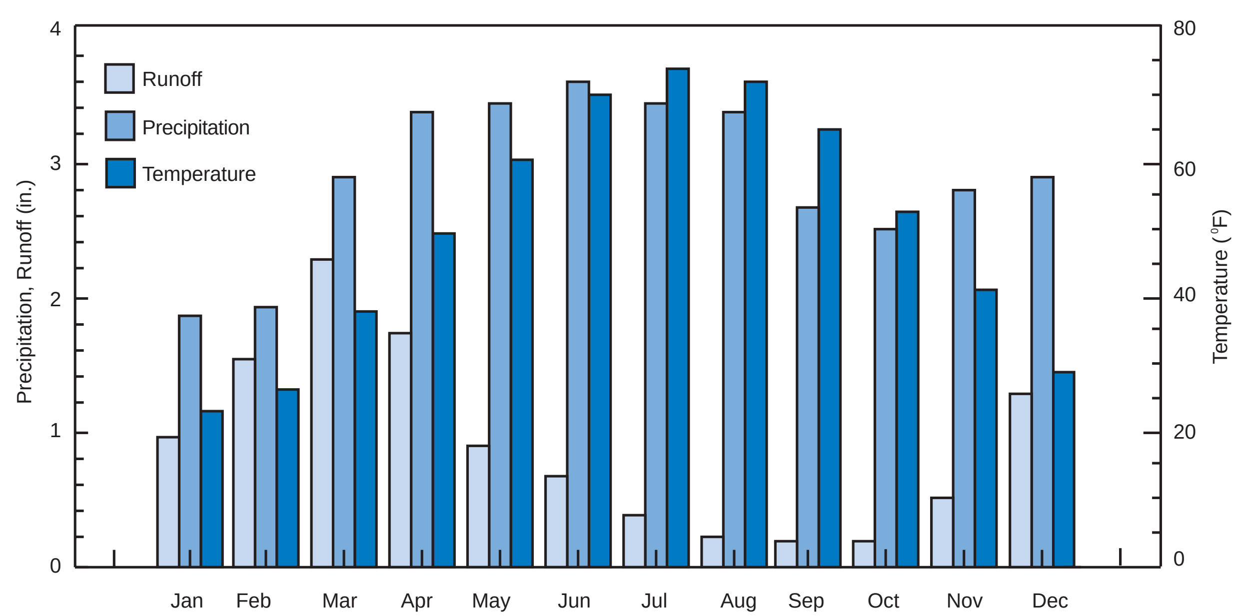


Figure 25. Variation of mean monthly runoff, precipitation, and temperature

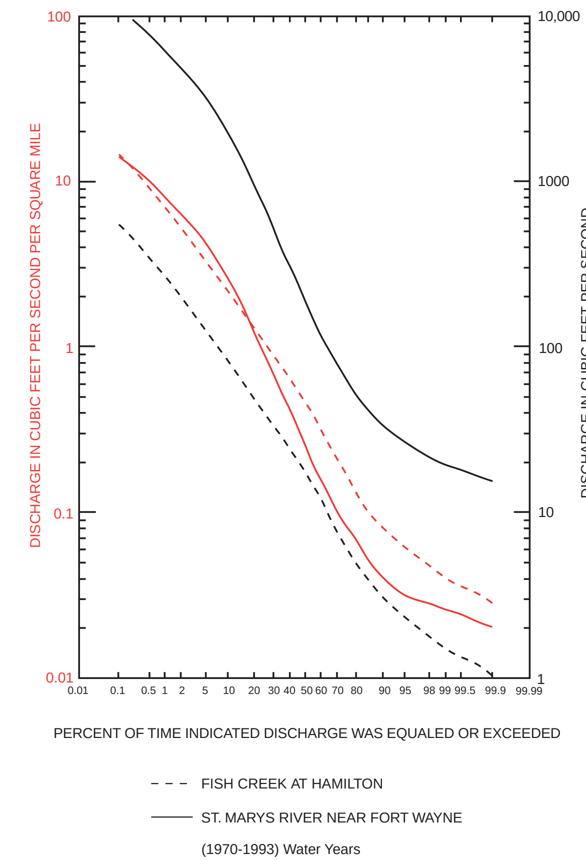


Figure 26. Duration curves of daily mean stream flow for Fish Creek at Hamilton and the St. Marys River near Fort Wayne

mean flows of the St. Marys River near Fort Wayne were at least 26.1 cfs (cubic feet per second) on 95 percent of the days during the period 1970-1993 (figure 26, in black). Daily flows for this period exceeded 3250 cfs five percent of the time.

The overall slope and shape of the duration curve are related to the storage characteristics of the drainage basin, which in turn are related to the topography and hydrogeology of the basin.

A duration curve that is gently sloping indicates a stream draining an area with substantial surface and/or subsurface storage. Flood peaks on this type of stream are attenuated because much of the excess precipitation is stored in surface depressions, permeable soils, or surficial geologic deposits. During dry periods, stream flow is sustained by the slow release of water from these surface and/or underground sources.

A steeply sloping flow-duration curve indicates a stream draining a basin with little surface and/or subsurface storage. Flood peaks on this type of stream are high and rapid because most excess precipitation runs off the land surface and enters the stream. During dry periods when overland flow has ceased, this type of stream may cease flowing because the amount of base flow is negligible.

Duration curves for the St. Marys River and Fish Creek illustrate the effect of topography and geology on stream-flow characteristics (figure 26). A common period of record was used for the duration analysis to minimize flow differences that may be attributed to differences in local precipitation from short-term events. Flow duration curves were also analyzed on a per-square-mile basis, known as *unit discharge*, to minimize the effect of unequal basin sizes on stream-flow characteristics (figure 26, in red).

The duration curve for the St. Marys River is fairly steep in relation to the Fish Creek curve. The higher unit discharges on the St. Marys River at durations less than 17 percent (high flows) indicate a higher runoff rate per square mile of drainage basin during periods of heavy rainfall. The *runoff coefficient* or the fraction of total precipitation that runs off the land surface in the St. Marys watershed is 0.8, which is double the runoff in Fish Creek (0.4) (Glatfelter, 1984).

The higher unit flows on the St. Marys River primarily reflect a limited amount of floodplain storage. The river is confined to a relatively narrow channel and most of its drainage network is developed on fine-grained tills. The steep lower end of the unit duration curve for the St. Marys indicates a limited amount of base flow, hence ground water contribution is minimal.

Whereas, in Fish Creek significant storage is provided by valley deposits of permeable sands and gravels and by upstream lakes. The high base flow at Fish Creek is evident in figure 26, by the sustained unit low flows at durations greater than 85 percent.

SURFACE-WATER DEVELOPMENT POTENTIAL

The development potential of the surface-water systems for water supply purposes can have a great impact on several economic activities. The Maumee River basin will continue to utilize surface water for most of its water use. Further development of streams for potential water supply may be possible in some cases. Other surface-water systems such as ponds, lakes, and wetlands, however, are not considered as significant water supply sources because of their limited storage capacity, water-quality considerations, and in some cases regulatory and environmental constraints.

Lakes

Despite the large storage capacity of some public freshwater lakes in the Maumee River basin, few are used as water supply sources. Both direct and indirect pumping from natural lakes may have detrimental effects on local ecosystems, and may be cause for concern among local residents. Existing state laws effectively preclude significant pumping from natural lakes. Most notably, I.C. 14-26-2 requires that lakes having a legally established water level are to be maintained at that level. In accordance with this law, six of the eight natural lakes within the basin have established levels. Even temporary changes in lake levels from their designated elevation requires prior approval from a local circuit court and the Natural Resources Commission. The authorities typically grant approval only for shoreline improvements or lake restoration.

Even if state laws were amended to allow lowering of lakes levels for water-supply purposes, treatment and distribution costs probably would limit uses to irrigation, livestock watering, or fire protection. Lowering water levels can have harmful affects on water-quality, fisheries habitat, and adjacent wetlands. Moreover, even minor alterations of lake levels would be objectionable to most lakeside property owners.

Amending current laws to increase lake storage has drawbacks beyond the possible public nuisance. New control structures at potential sites might need to be constructed, and existing structures would potentially need modification. Few lake-level control structures are designed to store water at elevations above the legal level. The actual cost of either option might exceed feasible benefits.

Streams

The water supply potential of streams can be evaluated on the basis of selected stream-flow characteristics, which are defined as statistical or mathematical parameters derived from stream-flow records. In this report, average and low-flow characteristics were defined at gaged sites using flow-duration curves, frequency analysis, and hydrograph separation techniques. These methods, which are described below, also can be used in other applications, including the design and operation of water-supply facilities, waste-treatment plants, reservoirs, and hydroelectric power plants; water-quality studies; waste-discharge regulation; and management of fish and wildlife habitat.

Methods of analysis

Average flow

Average flow is the arithmetic mean of individual daily mean discharges for a selected time period, such as a week, month, season, year, or period of several years. However, average flow is commonly used to refer to the long-term mean annual discharge, which is the arithmetic mean of the annual mean discharges for the period of data record.

Recently, the U. S. Geological Survey replaced the term average flow with **annual mean**. However, in this report the term average flow is used because its common meaning is widely known.

Because the statistical distribution of stream flows is *skewed*, average discharge usually is greater than the *median* discharge, which is the flow equaled or exceeded 50 percent of the time.

The relation between average flow and drainage area is commonly used in hydrologic applications. Figure 27 illustrates a relation derived from long-term flows for selected continuous-record gages in the Maumee River basin. The mathematical relation shown in figure 27 may be used to estimate average flows at ungaged sites on streams in the Maumee River basin that drain areas of at least 37 square miles.

Because average flow encompasses the amount of water leaving a basin as both surface-water runoff and ground-water discharge to streams, this flow can be considered as the theoretical upper limit of the long-term yield that can be developed from a stream. If it were possible to store, in a single hypothetical reservoir, all the water that flows from a watershed during a specified period and then release the water at a uniform rate over the same period, that rate would be the average flow. **Average runoff** is defined as the depth to which a drainage basin would be covered by water

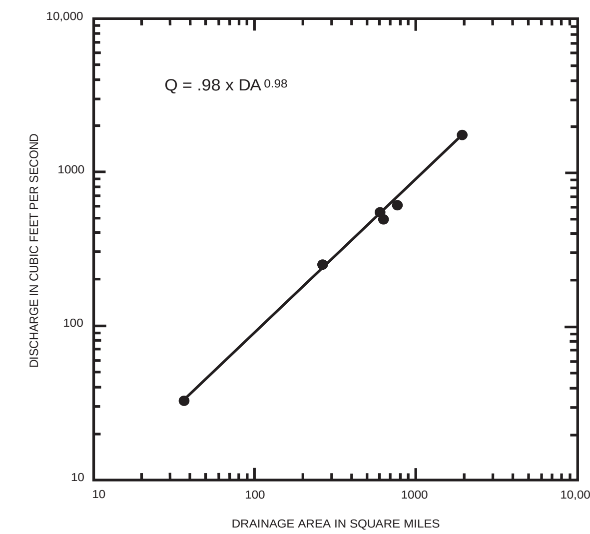


Figure 27. Relation of average discharge at continous-record gaging stations to total drainage area

if the average discharge for a given time period were uniformly distributed upon the land surface of that basin.

Flow duration

Flow-duration curves, as described in a previous section, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. By incorporating the entire range of stream flows, duration curves are useful for indicating overall flow characteristics and identifying differences in stream-flow variability. Duration curves also can be used to estimate the percent of time that a given demand for stream flow can be satisfied, on average, over a long period of time. However, curves cannot be used to determine the sequence, statistical frequency, or duration of either adequate or deficient flows.

Flow ratio is a general term that can apply to many stream-flow parameters. In this report, the maximum-to-minimum ratio of annual mean flows and the ratio of 20-percent-duration to 90-percent-duration flows are used to indicate the variability of stream flow.

The 20-to-90-percent **flow-duration ratio** is a numerical index that represents the slope of the middle portion of the flow-duration curve (figure 26). As described previously, the flow-duration ratio (slope) reflects not only the presence of flood-attenuating factors in a watershed, but also the relative component of stream flow due to base flow.

The St. Marys River near Fort Wayne has a flow-duration ratio of approximately 20, whereas Cedar Creek near Cedarville has a ratio of nearly 10 (Arihood and Glatfelter, 1986). The lower flow-duration ratio of Cedar Creek indicates the higher amount of base flow and the existence of more sustained stream flows during dry weather.

Low flows

Low-flow frequency data can be used to estimate how often, on average, minimum mean flows are expected to be less than selected values. Low-flow characteristics are commonly described by points on low-flow frequency curves prepared from daily discharge records collected at continuous-record gaging stations. At stations where short-term records and/or base-flow measurements are available, correlation techniques can be used to estimate curves, or selected points on curves.

Low-flow frequency curves show the probability of minimum mean flows being equal or less than given values for a specified number of consecutive days. Figures 28 and 29 show the relation of annual minimum mean discharges for 1-day and 7-day periods for Fish Creek at Hamilton, the St. Marys River near Fort Wayne, the St. Marys River at Decatur, Cedar Creek at Cedarville, the Maumee River at New Haven, and the St. Joseph River near Newville.

In this report, the following points on the 1-day and 7-day curves have been selected as indices of low flow: the minimum daily (1-day mean) flow having a 30-year *recurrence interval*, and the annual minimum 7-day mean flow having a 10-year recurrence interval.

The 1-day, 30-year low flow is the annual lowest 1-day mean flow that can be expected to occur once every 30 years, on the average. In other words, it is the annual lowest daily mean flow having a 1-in-30 chance of occurrence in any given year. In this report, the 1-day, 30-year low flow indicates the dependable supply of water without artificial storage in reservoirs or other impoundments. In many cases, the 1-day, 30-year low flow equals or closely approximates the minimum daily discharge of record for streams in the

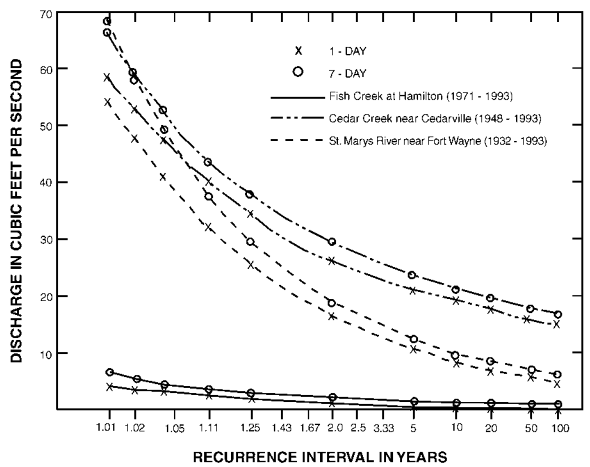


Figure 28. Frequency curves of annual lowest mean discharge for indicated number of consecutive days for Fish Creek at Hamilton, Cedar Creek near Cedarville, and the St. Marys River near Fort Wayne

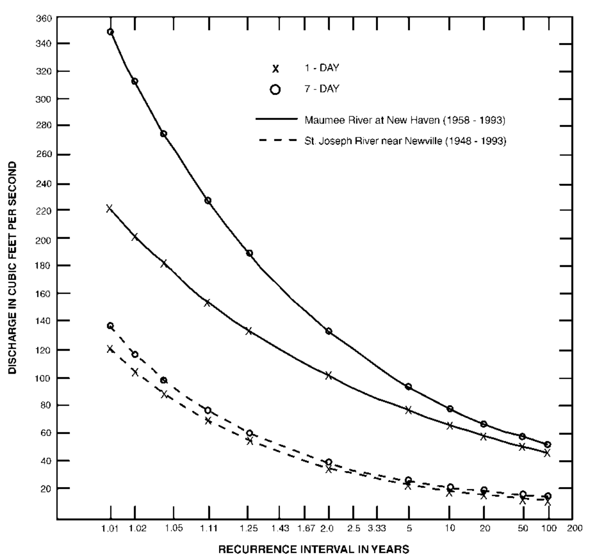


Figure 29. Frequency curves of annual lowest mean discharge for indicated number of consecutive days for the Maumee River at New Haven and the St. Joseph River near Newville

Maumee River basin.

The 7-day, 10-year low flow is the annual lowest mean flow for 7 consecutive days that can be expected to occur, through a long period, on the average of once every 10 years. There is a 1-in-10 chance that the annual minimum 7-day mean flow in any given year will be less than this value.

In Indiana, the 7-day, 10-year low flow (7Q10) is the index for water-quality standards. The flow is used for siting, design, and operation of wastewater treatment plants; for evaluating wastewater discharge applications and assigning wasteload limits to industrial and municipal discharges; and as an aid in setting minimum water-release requirements below impoundments. In the future, the 7Q10 or other low-flow parameters may be used by the Indiana Department of Natural Resources to establish minimum flows of selected streams.

The U.S. Geological Survey has developed a method for estimating the 7Q10 on ungaged streams in Indiana (Arihood and Glatfelter, 1986). Regression analysis was used to derive an equation which is most accurately applied to unregulated streams in northern and central Indiana which drain areas between 10 and 1000 square miles, and have 7Q10s greater than zero. The equation determined by Arihood and Glatfelter (1986) is as follows:

$$7Q10 = 1.66 \times DA^{1.03} \times RATIO^{-1.51}$$

where

DA = the contributing drainage area, in square miles; and

RATIO = The 20-to-90 percent flow duration ratio.

In the Maumee River basin, regionalized flow-duration ratios mapped by Arihood and Glatfelter (1986) for small streams are summarized as follows:

* St. Joseph River basin —5-20 to undefined
* Upper Maumee basin — 20 to undefined
* Auglaize basin — undefined
* St. Marys basin — 25 to undefined

Although 7Q10s estimated from the equation and flow-duration ratios shown above may differ from values based on other regionalization techniques or partial-record data, the estimates are suitable for broad

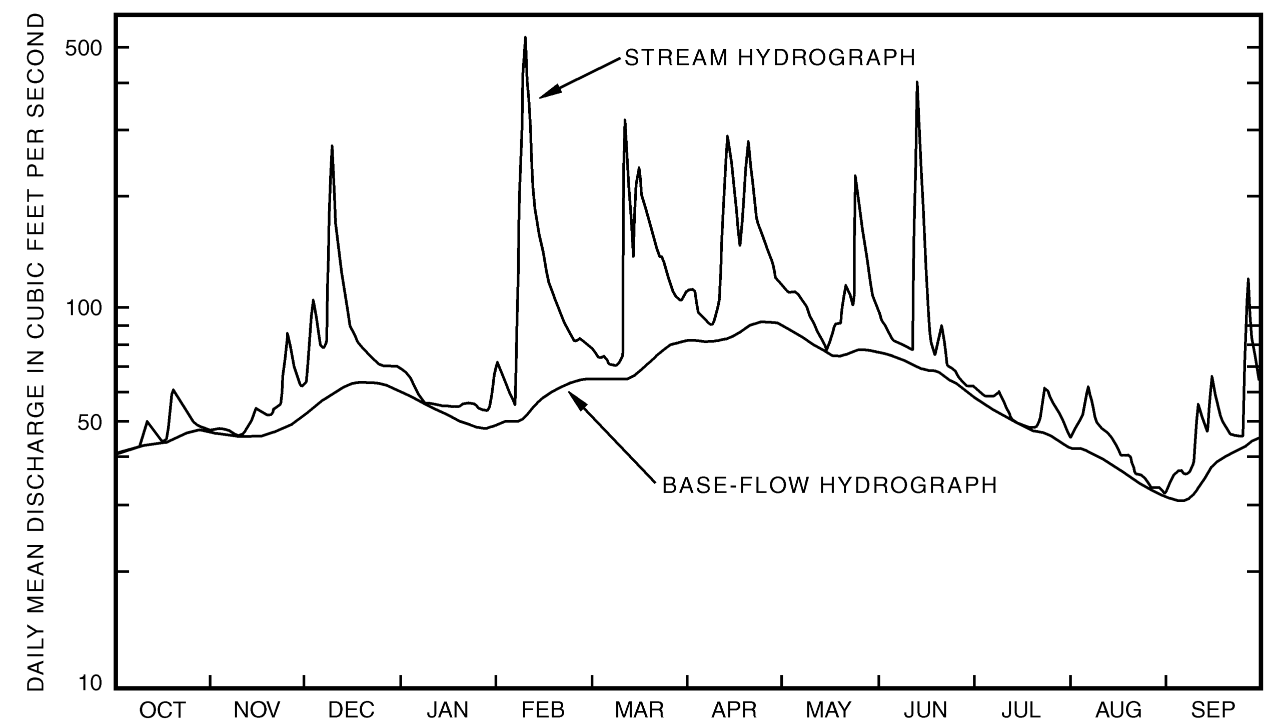


Figure 30. Example of stream-flow hydrographs

planning purposes. Site-specific design flows should be determined according to local watershed conditions and more detailed analyses.

Hydrograph separation

Hydrograph separation is a technique used to divide stream flow (*total runoff*) into its component parts of *surface runoff*, *interflow* and *base flow*. Surface runoff is the combination of precipitation falling directly upon the stream and water flowing over the land surface toward the stream (*overland flow*). Interflow occurs when precipitation that has infiltrated the soil moves laterally through the soil toward the stream. For convenience, interflow and surface runoff can be combined into one category called *direct runoff*. Base flow is the portion of stream flow that is derived largely or entirely from ground-water discharge.

A graphical technique can be used to separate the base-flow hydrograph from a stream-flow hydrograph of daily discharges. As figure 30 shows, the hydrograph of daily stream flows is composed of peaks and valleys which often are quite sharp. The peaks represent the quick response of stream flow to storm runoff received as overland flow and interflow, and occasionally as ground-water flow from hillslopes adjacent to the stream. The base level to which the peaks return represents the base flow which continues to occur after overland flow has ceased. The base-flow hydrograph therefore can be approximated by eliminating the sharp hydrograph peaks and drawing a smooth curve (figure 30).

The volume of total runoff for a given water year is computed by converting each daily discharge to a daily volume, then summing these values over the year in question. The total runoff can then be converted to inches by dividing it by drainage area. A similar technique can be used to compute the total annual base-flow volume.

The ratio of base flow to total runoff is one measure of the degree to which stream flow is sustained by ground-water discharge. This ratio therefore is an indicator of the dependability of a stream for

Table 15. Average monthly runoff of the Maumee River basin

{Values were approximated for a total drainage area of 2097.3 sq. mi. which includes the upstream drainage areas from Michigan and Ohio}

Month	Volume (BG)	Runoff (in)
October	7.3	0.20
November	17.7	0.49
December	41.6	1.14
January	34.2	0.93
February	48.6	1.33
March	77.0	2.10
April	68.6	1.89
May	36.4	1.00
June	28.4	0.78
July	15.8	0.44
August	10.8	0.30
September	9.1	0.25
Total	395.5	10.85

water supply.

Average runoff of Maumee River basin

The total water-supply potential of a basin is the average precipitation that falls on the land surface and is not lost to evapotranspiration or used consumptively, such as incorporation into a manufactured product. The theoretical maximum supply potential of a drainage basin as a whole can be defined as the long term average runoff, which includes both surface runoff and ground-water discharge to streams.

Table 15 shows the mean monthly stream flow leaving the Indiana portion of the Maumee River basin. These values represent a major portion of water leaving the basin as stream flow into Ohio. Discharges were modified to represent flows at the Indiana-Ohio State Line by using drainage-area adjustments. The drainage area at the Indiana-Ohio State Line is 2097.3 sq. mi. The average runoff estimations at the state line were made based upon the data available at the New Haven, Indiana stream gaging station and Antwerp, Ohio stream gaging station. The New Haven station has data from 1957 to present, whereas Antwerp has data from 1957 to 1982. A uniform period of record from 1957-81 was considered in estimating the average runoff. The 1982 data was not used because severe floods had occurred in the basin during 1982 and produced very high flows.

Table 15 shows that water availability in the form of stream flow generally is greatest in spring and least in late summer and early fall. In any given year, however, water availability may vary greatly from the tabulated values. Moreover, future developments which cause increased consumptive use could potentially reduce the amount and temporal distribution of available water.

Supply potential of streams

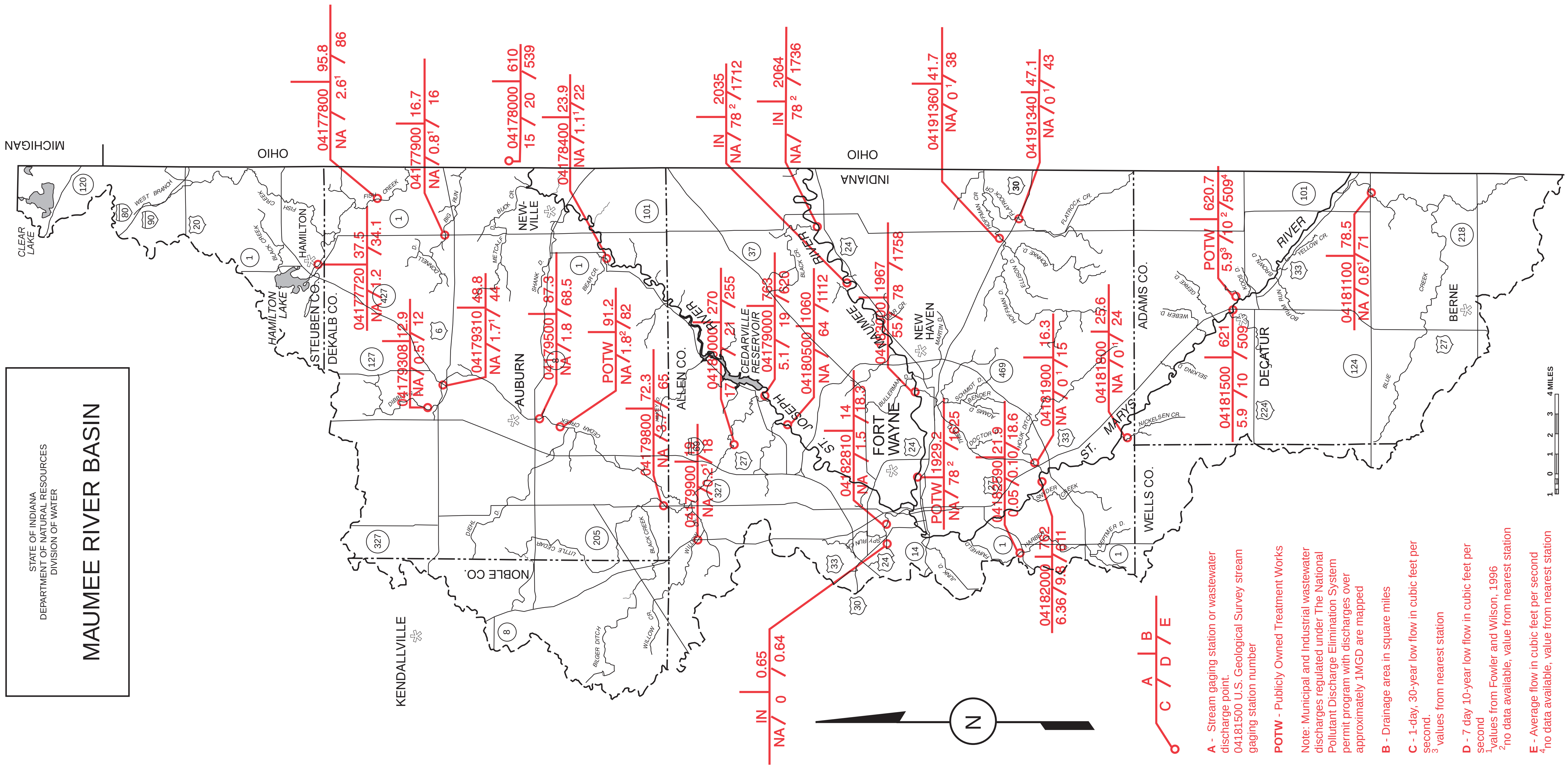
The potential of individual streams in the basin for water-supply development is discussed in the following pages. Water-supply potential is discussed by subbasin including the Auglaize, St. Marys, St. Joseph, and Upper Maumee. It should be emphasized that stream flows are assessed without regard to the potential construction of impounding reservoirs (either in-channel or off-channel) that could greatly improve the water-supply potential of some streams. Variations in stream-flow characteristics are interpreted primarily on the basis of geologic, soil, and topographic differences among and within drainage basins.

Table 16 lists selected stream-flow characteristics for active and inactive continuous-record gaging stations having at least 24 years of data as of water year 1993. Average and low-flow values for these stations and low-flow values for partial-record stations are plotted in figure 31 to facilitate an assessment of the geographic variation in flows.

Streams that have relatively high sustained flows are more reliable than streams of low sustained flows, and thus are preferred for water-supply development.

Auglaize River basin

The Auglaize River basin comprises only 99.8 square miles within Indiana. Its largest tributaries in Indiana include Flatrock Creek and Hoffman Creek which drain into the Auglaize River in Ohio, thence into the Maumee River. Estimated average flow (annual mean) for these two small tributaries is approximately 43 cfs and 38 cfs, respectively (figure 31); 7Q10 is zero.



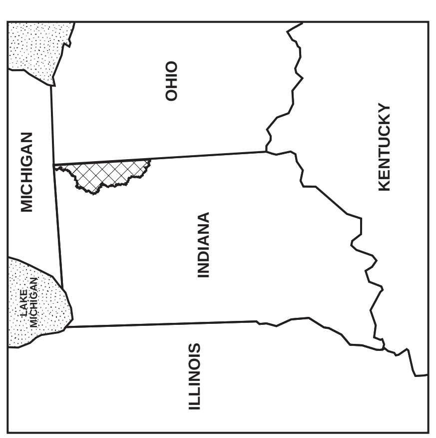


Figure 31. Selected stream flow characteristics

Table 16. Stream-flow characteristics at selected continuous-record gaging stations

(Stations had at least 24 years of data through water year 1993)

Total drainage area, average discharge (annual mean), annual runoff, extremes: From Stewart, A. James & others, (1994)

Extremes: Daily maximum represents maximum daily mean discharge; daily minimum represents minimum daily mean discharge

Low flows: Estimated by USGS using log-Pearson type III distribution method (Fowler and Wilson, 1996)

Ground-water contribution: Estimated by Division of Water using methodology of Pettyjohn and Henning, 1979, for hydrograph separation. Values are for water year 1975

Station name	Total drainage area(sq.mi.)	Annual Mean(cfs)	Annual runoff(in)	Extremes (cfs)				Low flows			Base flow (percent of total runoff)
				Annual mean		Daily		1Q30	7Q10		
				Max	Min	Max	Min	(cfs)	(cfs)	(cfsm)	
St. MARYS RIVER											
at Decatur	621	509	11.15	879	140	10600	5.4	5.9	10	0.02	30
near Fort Wayne	762	611	10.9	1093	174	13000	3.4	6.3	9.8	0.01	29
FISH CREEK											
at Hamilton	37.5	34.1	12.34	54.7	17.8	716	0.52	NA	1.2	0.03	52
MAUMEE											
at New Haven	1967	1758	12.14	2975	669	26300	48	55	78	0.04	42
CEDAR CREEK											
near Cedarville	270	255	12.82	485	85.3	5220	13	17	21	0.08	48
ST. JOSEPH RIVER											
near Newville	610	539	11.99	1008	132	9450	14	15	20	0.03	51

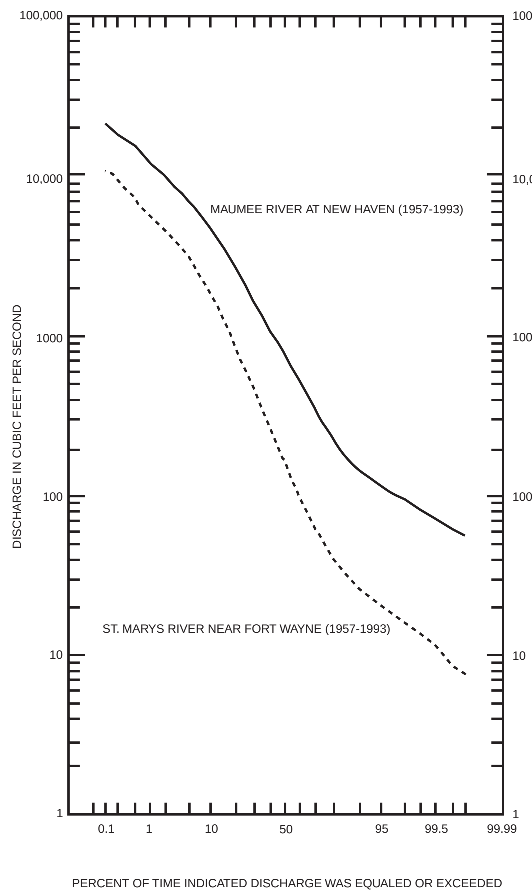


Figure 32. Duration curves of daily mean stream flow for the Maumee River at New Haven and the St. Marys River near Fort Wayne

St. Marys River basin

In the St. Marys River basin, the St. Marys River is the major water resource. A number of sites along the mainstem of St. Marys are analyzed for flow characteristics (figures 31, 32, and table 16). Tributaries which have at least a partial analysis include Blue Creek, Nickelson Creek, Houk Ditch, Harber (Fairfield) Ditch, and Spy Run Creek (figure 34).

Average flow (annual mean) for the St. Marys near Fort Wayne is 611 cfs. The 1Q30 and 7Q10 at Fort Wayne are 6.3 and 9.8 cfs, respectively. Of the major streams in the Maumee River basin in Indiana, the St. Marys River has the lowest percentage (29) of base flow and the steepest flow-duration curve (table 16 and figure 32). The steep flow-duration curve indicates high overland flow and low base flow. The flow-duration ratios of the St. Marys River at Decatur and Fort Wayne are 32 and 33, respectively.

Daily flows on the St. Marys are highly variable, but annual flows are fairly consistent.

St. Joseph River basin

The major sources of water in the St. Joseph River basin are the St. Joseph River, Cedar Creek, Little Cedar Creek, and Fish Creek. Two reservoirs are located in the St. Joseph River basin in Indiana. Cedarville Reservoir, an instream impoundment is located on the St. Joseph River north of Fort Wayne. Hurshtown Reservoir, an off-channel impoundment, is approximately 3 miles northeast of the Cedarville Reservoir.

Flow is analyzed for the mainstem at Newville, Cedarville (figures 31 and 33), and downstream of its confluence with Cedar Creek (figures 31 and 34). The St. Joseph River is affected by storage and regulation downstream from the Cedarville Reservoir. Tributaries analyzed include numerous locations on the Cedar Creek drainage basin and Fish Creek (figures 31, 33 and 34).

Table 16 shows the stream flow characteristics of selected streams in the Maumee River basin. The 1-day, 30 year (1Q30) and 7-day, 10 year (7Q10) low flows in the St. Joseph River at Newville are 15 and 20 cfs. The 1Q30 and 7Q10 for Cedar Creek are 17 and 21 cfs, respectively.

A large amount of base flow is estimated at Newville (about 51 percent of the total runoff). Nearly identical percentages of base flow are obtained from the Cedarville and Hamilton areas, 48 and 52 percent, respectively. High base flow at Newville, Cedarville, and Hamilton, is related to the presence of permeable sandy soils and outwash sand and gravel deposits in that area.

The flow-duration ratio for the St. Joseph River at Newville, Cedar Creek near Cedarville, and Fish Creek at Hamilton are 16, 10, and 16 respectively. The lower flow-duration ratio indicates the higher amount of base flow and also the existence of more sustained stream flows during dry weather.

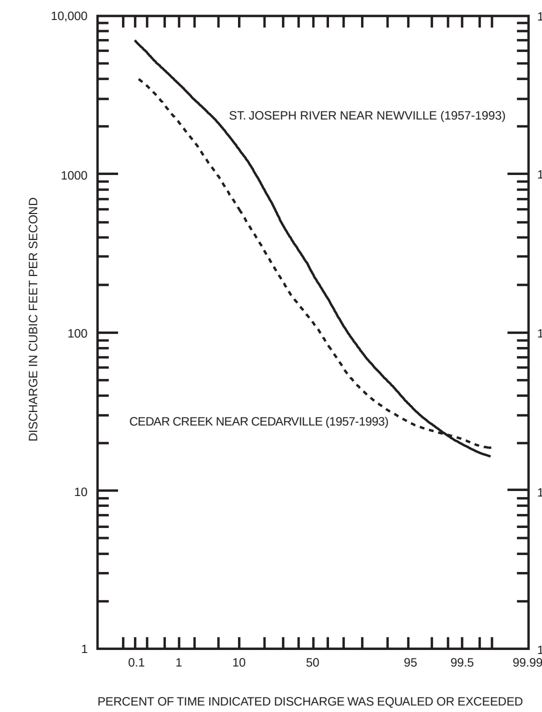


Figure 33. Duration curves of daily mean stream flow for the St. Joseph River near Newville and Cedar Creek near Cedarville

Upper Maumee River basin

The Upper Maumee River basin is the portion of the Maumee River watershed upstream of the New Haven stream gage. Approximately 43 percent of the drainage area is contributed by the St. Marys drainage basin and 55 percent is contributed by the St. Joseph drainage basin.

The flow-duration curve of the Maumee River exhibits characteristics similar to the curves of its major tributaries. At high discharges, the slope of the flow-duration curve of the Maumee River (figure 32), resembles that of the St. Marys River, indicating the predominance of direct runoff during storm events. At low discharges, the Maumee curve is very similar to the St. Joseph River curve indicating similar base flow contribution. However, the overall slope of the Maumee is closer to that of the St. Joseph River.

Of the basin streams, the Maumee River has the most uniform flow characteristics. The small range in flows on the Maumee River is evident in flow ratios.

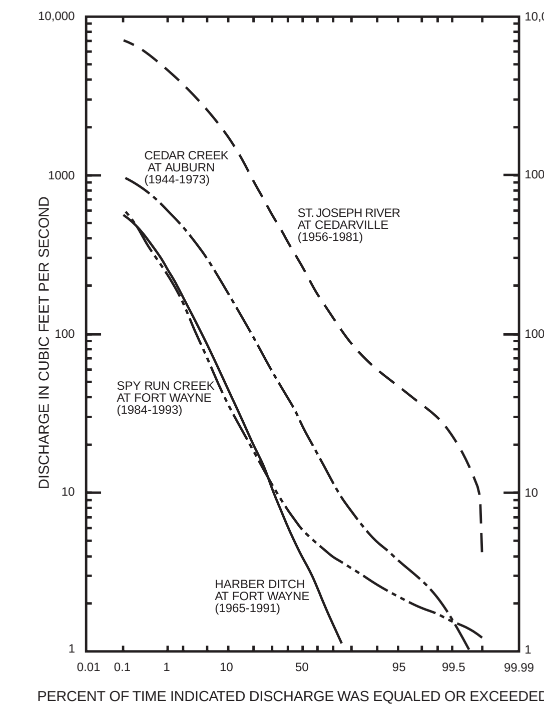


Figure 34. Duration curves of daily mean stream flow on selected streams

The flow-duration ratio of the Maumee River at New Haven is about 18. Maximum annual mean flow at the gage at New Haven is only four times the minimum. Maximum-to-minimum ratios for other major streams in northern and central Indiana range from 4 to 8 (Arvin, 1989).

The 1-day 30 year (1Q30) and the 7-day 10 year (7Q10) low flows in the Maumee River are 55 and 78 cfs, respectively (table 16). The base-flow during a normal year constitute about 42 percent of the total runoff at New Haven.

Reservoirs

Because streamflow varies from season to season, water supplies dependant on streamflow must be designed to meet dry-weather conditions when streamflow may be only a fraction of the normal flow. Demands for water supplied by a stream often exceed the naturally-occurring minimum streamflow; but, substantial increases in water supply can be attained through development of additional storage to hold some of the high flow each year for release during a later period of low flow.

Reservoirs regulate streamflow for beneficial use by storing water for later release. Realizing that the natural inflow to any impoundment area is often highly variable from year to year, season to season, or even day to day, it is obvious that the reservoir function must be that of redistributing this inflow with respect to time so that the projected demands are satisfied.

The design of a storage project should consider the streamflow characteristics, the magnitude and variability of draft (demand), draft requirements imposed by the various types of water use, the physical characteristics of the storage site, the economic consequences for a temporary deficiency in draft, the effect of reservoir evaporation, the probable reduction in reservoir capacity because of sedimentation, the need to serve other purposes as flood control or conservation pool storage, or to permit a restricted range in water level for recreation. In addition, minimum flow needs must be considered for instream uses downstream of the impoundment.

The Maumee River basin has two water-supply reservoirs, the Cedarville and Hurshtown, which store water to supplement Fort Wayne's public water supply. During peak water-demand periods, water is released from the Cedarville Reservoir to augment streamflow at the Fort Wayne public water supply intake on the St. Joseph River. The Hurshtown Reservoir provides a backup supply of water for drought years.

The Cedarville Reservoir, located approximately eight miles northeast of Fort Wayne is a shallow instream impoundment on the St. Joseph River. The reservoir, built in 1952/53, had an original storage capacity of 2130 acre-feet or 694 million gallons at the normal pool elevation of 777.7 feet *NGVD.*

The Hurshtown Reservoir, completed in 1969, is an off-channel structure (see sidebar entitled **Upland reservoirs/side-channel reservoirs**). Separated from the river that supplies it, the reservoir is fed through a system of pipes originating at the St. Joseph River. It maintains 1.885 billion gallons of raw water and has a total pumping capacity of 11 MGD. Because upland reservoirs have little contributing drainage areas, sedimentation does not reduce available storage significantly. Therefore, no analysis was made of change in storage for this facility.

Methods of analysis

To plan for the future use of surface water, the dependability of the supply must be known. The yield of a water supply is the amount of water that is available for use during some period of time, such as a day, a month, or a year. The **safe yield** of a reservoir is defined as the minimum yield during the life of the reservoir (Linsley and others, 1982). Typically, safe yield is determined as the minimum yield during the worst dry period on record.

The concept of safe yield is misleading, however, because there is some probability that a period drier than the worst on record will occur. Even if a reservoir could be built large enough to always supply a guaranteed minimum yield, its cost might be too high.

A better approach to specifying the dependability of a water supply is to specify the probability of supplying the required demand during the life of the reservoir. The dependability of a reservoir of a given capacity decreases as the level of demand increases. For a specified level of dependability, the storage required increases as the level of demand increases.

The storage required to meet a specified demand depends on the average stream flow, stream-flow variability, the magnitude of the demand, and the degree of dependability desired (McMahon and Mein, 1986). The higher the desired level of dependability, the larger the required storage capacity of the reservoir.

Selection of a storage capacity that will satisfy water demands of all users with the highest degree of dependability is not usually warranted. For irrigation requirements, the degree of dependability is usually recommended to be in the range of 75 to 85 percent, while for domestic and industrial water supply the desired dependability is usually in the range of 95 to 98 percent.

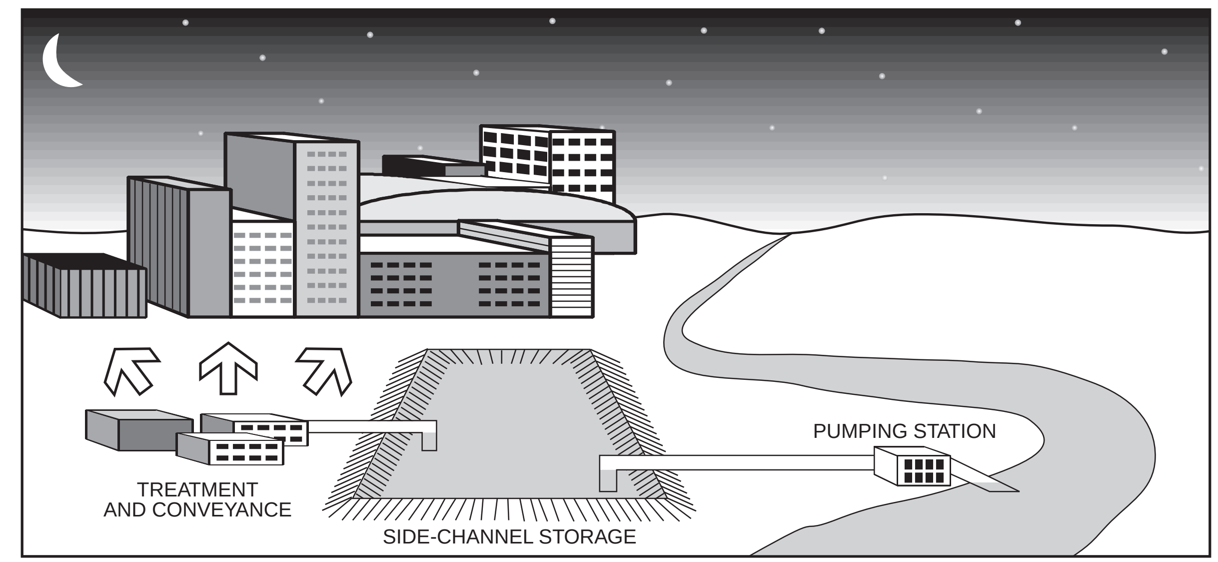
Considering the envisaged purposes of water resources development in the Maumee basin, the dependability level of 98 percent was adopted in the storage yield analyses performed in this study. This level of dependability corresponds to allowing no deficits within a 50-year period of reservoir operation.

One way to determine storage requirement is by using a mass curve or Rippl diagram. The mass curve is a graph of the cumulative volume of inflow to the reservoir versus time and is derived from historical streamflow data. The mass curve can be obtained by cumulating daily, weekly, or monthly streamflow volumes. Monthly values are adequate for most water-

Upland reservoirs/side-channel reservoirs

Upland or side-channel reservoirs are defined as impoundments into which water is pumped from a moderately large stream. They differ from standard reservoirs in that the side-channel reservoirs are generally self-contained, not receiving drainage from the surrounding area. Only the pumped inflow and precipitation account for the reservoir's contents. Side-channel reservoirs can be built using a cut and fill design like Hurshtown (see figure below) taking advantage of naturally-occurring topographic depressions, or utilizing abandoned quarries. The factors affecting the design of side-channel reservoirs include the variability of streamflow, purpose of the water supply, and the volume of demand.

The advantages of constructing a side-channel reservoir over a standard in-stream model are numerous. Even the smallest instream reservoir requires an allowance for the passage of large floods, thus the necessity for constructing a large and usually expensive spillway. Floods generally have little effect upon side-channel reservoirs. The rapid sedimentation found in a standard reservoir is nearly nonexistent in the side-channel versions. Because the pumping system can pump only some of the floodwaters which are carrying a great portion of the stream's annual load of sediment, most of the sediments are avoided. In many situations, the pumping system does not even need to be operating when the streamflow is especially turbid. In addition, while instream reservoirs disrupt the habitat of much of the natural biota, side-channel reservoirs' modification of the stream environment extends only as far as the withdrawal system located on the stream. The environmental effects are completely a function of the management plan, since withdrawal is based upon gross demand. (adapted from Knapp, 1982)



supply storage analyses. The worst dry period on record is usually used to determine storage requirements, but the entire period of record may also be used. The procedure is to select a range of anticipated drafts (levels of demand) and to determine the storage required for each draft. The results can be plotted as a curve which relates storage requirement to draft.

For this report, a computer program YIELD developed by Beik (1986) was used to perform mass-curve analysis to assess dependable yield at the public water-supply intake on the St. Joseph River. The program, allowing no deficits, determines the storage requirement for a given level of demand throughout a given period of record. The underlying concepts of the program are the same as those of the Rippl Diagram, but the digital form provides versatility.

The YIELD program, in addition to accommodating for intake of water at the dam site, incorporates calculations for intake at other downstream locations. Intermediate streamflow between the dam site and the downstream intake point is accounted for. This feature of the program is especially useful for the analysis of the Fort Wayne water supply because the dependable yield relies upon the reservoir storage capabilities and the intermediate streamflow between the reservoir and the river intake.

A series of monthly mean discharges were determined for two sites on the St. Joseph River, the Cedarville Reservoir site and the Fort Wayne public supply intake site. Discharges for the reservoir site were determined from streamflow records for the St. Joseph stream gaging station (located near Newville) using data from 1947 through 1993. Discharge values for the public supply intake site were generated from the data determined at the reservoir site and from recorded data (from 1947 through 1993) for the Cedar Creek stream gaging station located near the town of Cedarville.

Because the useful life of a reservoir can be materially affected by the deposition of sediment, it is necessary to determine how much sedimentation has taken place since the reservoir was constructed. The Division of Water conducted a hydrographic survey of Cedarville Reservoir in 1988, and the information was used to develop depth curves and to calculate storage. Storage at normal pool elevation in 1988 was calculated to be 1715.5 acre-feet (559.1 MG). Therefore, 415 acre-feet or (135 MG) were lost to sedimentation in 36 years of operation. To project future capacity, a *dead storage* volume of 576 acre-feet (188 MG) was set aside for sediment accumulation in the next 50 years of life of the reservoir.

For modeling purposes, reservoir evaporation is assumed to be 2.5 feet per year based on data for Kendallville, Prairie Heights and Fort Wayne (See Chapter entitled **Physical Environment, Climate** section). The draft rates within the model include consideration of evaporation and sedimentation in addition to water-supply requirements.

A number of factors, including population and economic growth, were considered when selecting critical draft rates to model (see the chapter titled **Water Resource Development** for additional discussion). The draft used in the model was the highest recorded annual mean water withdrawal demand at the Fort Wayne intake site. The critical 34.6 MGD or 53.5 cfs draft occurred in 1988, one of the driest years in recent times.

Maximum dependable yield at the intake site is calculated to be 61.5 cfs (39.4 MGD). Although this yield would be adequate to satisfy the critical 1988 demand, it provides no consideration for maintaining any minimum flow downstream of the intake. Because no dependable flow rate would be guaranteed for instream water uses, additional withdrawal uses, or water-quality considerations, such a yield is not desirable.

Although instream flow criteria have not yet been formally adopted in the state, instream flow needs should be considered when addressing augmentation of low-flow by storage release.

However, the dependable yield for public water supply would be reduced to only 6.7 MGD (10.3 cfs) if minimum streamflow were protected to the 7Q10 flow downstream from the intake. This loss in yield, when compared to any enhanced level of protection for downstream flow, is probably not justified because the St. Joseph has such a high 7Q10 flow value.

A more flexible instream flow protection scenario was modeled that provides protection for downstream flow but also permits withdrawal at the intake. In this situation, the 7Q10 flow is selected as the desirable minimum flow to be maintained. However, during times of drought when streamflow is low, any deficit in streamflow below 7Q10 is shared equally between instream and offstream water users. Thus, for every 2 cfs drop in streamflow, both the minimum protected flow and the amount of water available for withdrawal would be reduced by 1 cfs. This type of compromise is only practical on streams like the St. Joseph which have relatively high 7Q10 flows. The dependable yield for this scenario is 21.8 MGD (33.7 cfs).

FLOODING

River flooding occurs when the transport capacity of a river is exceeded and its banks are overflowed. *Overbank* flow is commonly caused by a reduction in either *channel slope* or cross-sectional area, both of which reduce the transporting capacity of a river and lead to higher flood stages. For example, when structures are constructed in a floodway, the cross-sectional area available for flood flow is reduced, backwater levels are elevated, and flood peaks become amplified upstream of the structures.

In developed areas flooding can be caused by storm drainage systems which were built to handle excess runoff generated by the increase in impervious cover. When storm runoff exceeds the capacity of a designed drainage system, water backs up and causes flooding.

The largest and most damaging floods of record typically occur during early spring when saturated or frozen soils, prolonged or widespread rainfall, and snowmelt can combine to produce maximum runoff over large areas. Major floods also can occur in summer, fall and winter under certain combinations of precipitation events and hydrologic conditions. Floods are aggravated by the accumulation of debris, sediment, and ice at bridges and culverts because of *backwater* effects.

The "Three Rivers" of the Maumee River basin which have served as water supply for people and industry and as transportation for commerce have also been agents of disaster and destruction. Flooding on the three rivers has caused damage and loss of property in the basin many times in the past; and during at least one flood event, loss of lives.

Peak annual flooding along the large streams in the basin are principally caused by rains and/or snowmelts occurring in winter or early spring. In small basins, peak runoffs are typically generated by thunderstorm rains occurring during summer months. Flooding in the smaller tributaries of the St. Marys River is primarily due to backwater from the St. Marys mainstem. Floods along the Maumee River are greatest when the St. Joseph and St. Marys Rivers reach peak flow at the same time. In general, the St. Marys River is more likely to flood than the St. Joseph River (Maumee River Basin Commission, 1993).

Figure 35 displays historic and 100-year flood elevations for selected sites within the basin. A brief summary of the history of flooding in the Maumee River, as compiled by the Maumee River Basin Commission, 1993, follows.

The Maumee River basin has experienced major flooding once every three years, on average, since 1907. In most years since then, the Maumee River has crested above the official flood stage of 15 feet.

Of the counties in the basin, flooding has been most disastrous in Allen County because of the high concentration of development in the urban center of Fort Wayne. Fort Wayne is located at the confluence of the St. Joseph and the St. Marys Rivers which forms the headwaters of the Maumee River.

In the spring of 1913, the most severe frontal storm on record in the Midwest led to the worst recorded flood in the Maumee River basin. Rivers and streams spilled over their banks as the Maumee River crested at 26.1 feet, almost 11 feet above flood stage. The floods were approximately equal to the 500-year frequency flood on the St. Joseph, the St. Marys, and the Maumee Rivers (Federal Emergency Management Agency, 1990, Volume 2).

Several neighborhoods in Fort Wayne were under four feet of water. The municipal lighting power plant was flooded; and water had to be rationed and boiled because all three city pumping stations were closed. Six people lost their lives and 5,500 private homes and businesses in the city suffered extensive damage. Approximately 15,000 people were left homeless at the peak of the flood, and water covered about 5,000 acres within the city limits. Total damage in Fort Wayne reached $4,802,000 in 1913 dollars.

At Decatur in Adams County, the St. Marys River crested at 26.5 feet. The city was cut off from the rest of the state because all railroad service except the Chicago & Erie from Chicago had to be halted; and travel by road was suspended as a result of washouts. The interurban bridge north of the city was threatened by rapidly-moving debris in the water, and local residents stationed themselves to remove debris that collected near the structure.

Another notable flood occurred on March 15, 1982 along the St. Marys, St. Joseph, and Maumee Rivers. Snowmelt, having a water equivalent of three to nearly seven inches, combined with above-normal precipitation to keep all three rivers flooded for an extended period of time. The St. Marys and the St. Joseph Rivers near Fort Wayne each reached a peak discharge of about 13,000 cfs, and the Maumee River at New Haven reached a discharge of approximately 26,500 cfs.

The 1982 flooding forced the evacuation of 9,000 Fort Wayne residents and resulted in over 50 million dollars damage to the city. The flood drew the attention of the President, who visited Fort Wayne and declared the area a national disaster area.

Communities in DeKalb County that were hit hardest by the 1982 flooding include Auburn, Waterloo, and Spencerville. There was an estimated damage of about 2 million dollars and at least 30 mobile homes were damaged in the town of Waterloo.

In Adams County, the St. Marys River reached a crest of 24.4 feet, its highest level since 1913. Damage was estimated at about $200,000 to $300,000.

Although there was more major flooding in the basin in the 1910s than in the 1980s, more structures were affected during recent floods because of extensive urban development in flood prone areas this century.

Flood-flow characteristics of the Maumee River basin

Basin characteristics which affect flooding include: drainage area, channel length, channel slope, mean annual precipitation, storage, precipitation intensity, and runoff coefficient.

Some surface and subsurface features within a river basin provide temporary water storage during a flood, thereby retaining the water and slowing its release to downstream reaches. These features decrease floodwater velocities and increase the duration of flow, thereby reducing flood peaks. Storage features include the hydrologic properties of soils, underlying geologic materials, and the percentage of contributing drainage area covered by ponds, lakes, and wetlands.

Other basin features such as soil type and land use affect the amount and velocity of runoff, or runoff coefficient. Soils are classified according to the tendency of the soil to absorb rainfall and, thereby reduce runoff. Most of the soils in the south and central portions of the Maumee River basin have relatively high runoff coefficients (See Chapter entitled **Physical Environment, Soils** for specific information regarding basin soils and their hydrologic characteristics).

Each land use also has a characteristic ability to absorb and/or attenuate surface water runoff and thereby affect the runoff coefficient. For example, increasing urbanization can greatly affect flow characteristics. The imperviousness of the land surface associated with an urban basin is generally greater than that of a nonurban basin, and peak discharge is generally larger for the former than the latter in a basin of similar size.

The "Three Rivers" area once occupied a vast wetland lake plain. The natural hydrology of the Maumee River basin has since been altered by urbanization along the flood plain and by drainage projects beginning in 1885. Some of the man-made changes have resulted in a reduction of overbank storage and an increase in the runoff coefficient, and therefore an increased potential for flooding.

Flood frequency

Although the initial indicator of a flood is the river's water *stage*, the determination of a flood's relative size is related to the peak discharge because ice, debris or vegetation can cause higher water stages than would otherwise occur for a given flow. Peak-discharge data in the Maumee River basin are collected from a network of continuous-record and crest-stage partial-record stream gaging stations operated jointly by the U.S. Geological Survey and IDNR Division of Water (figure 24, table 14).

Deriving peak-flow characteristics from stream gage records is one step in helping mitigate flood damages and in planning for future floods. Discharge-frequency characteristics can be used for 1) the design and construction of roads, bridges, dams, levees and spillways; 2) the regulation of floodplains; 3) the management of water-control works such as dams and spillways; 4) the mapping of flood-prone lands; and 5) flood forecasting.

Table 16 presents maximum daily mean flows recorded at continuous-record gaging stations having at least 24 years of data for the period of record ending in 1993. The maximum daily mean flows on the St. Marys River near Fort Wayne, the Maumee River at New Haven, and the St. Joseph River near Newville are 13,000, 26,300, and 9,450 cfs respectively.

The variability of flood or peak flows, like the variability of low flows, can be statistically described by frequency curves. Flood frequency is generally expressed as the probability, in percent, that a flood of a given magnitude (discharge) will be equaled or exceeded in any one year. The recurrence interval, the reciprocal of the exceedance probability multiplied by 100, is the average number of years between exceedances of a given flood magnitude.

The **100-year flood,** for example, is the peak discharge that is expected to be equaled or exceeded on the average of once in a 100-year period. In other words, there is a 1 percent chance that a peak discharge of at least this magnitude will occur in any given year. Similarly, the 50-year flood has a 2 percent chance of occurring any given year, the 25-year flood has a 4 percent chance, and the 10-year flood has a 10 percent chance in any given year.

It should be noted that the recurrence interval, or frequency, represents the long-term average time period during which a flood exceeding a certain magnitude is expected to occur once. It does not imply a regular periodicity between floods. A peak discharge having a 100-year recurrence interval, for example, could possibly occur in two consecutive years, or even in two consecutive weeks. On the other hand, the 100-year flood may not occur for several hundred years.

Moreover, the discharge-frequency values are only accurate to the extent that the available discharges used in the statistical analysis are representative of the long-term discharge record. In general, a minimum of 30 years of data record is required to yield reliable flood frequency values for large floods.

Since 1976, the Division of Water has coordinated with the U.S. Geological Survey (USGS), United States Soil Conservation Services, and U.S. Army Corps of Engineers to determine peak discharge-frequency values for Indiana streams (Indiana

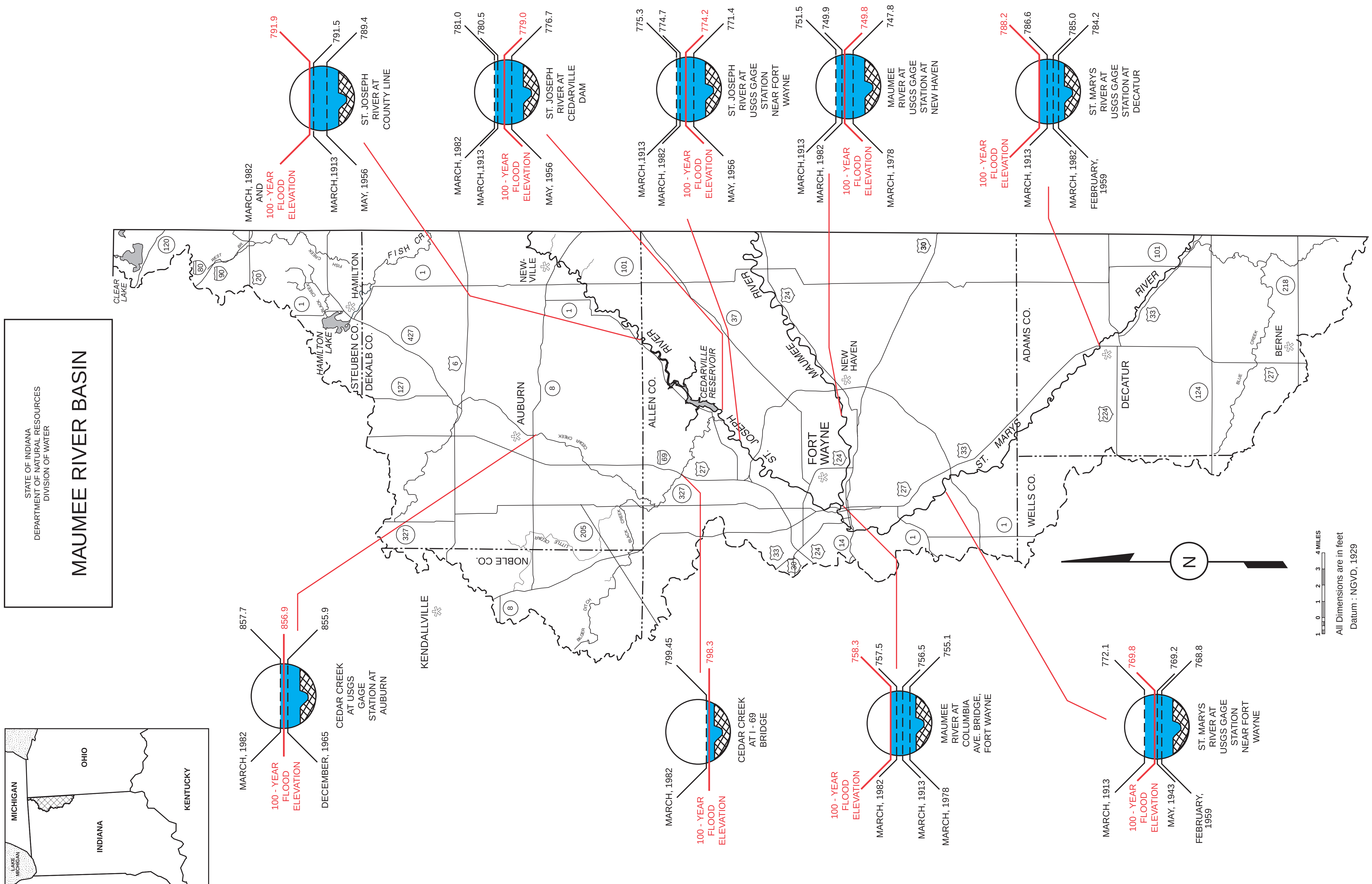


Figure 35. Historic and 100-year flood elevations for selected sites
(Historical, Division of Water files, 1985-1988) • (100-year elevations, FEMA, 1990)

Department of Natural Resources, 1993c). A comparison of computed flood frequency values with maximum recorded discharges on the St. Marys River, the Maumee River, the St. Joseph River, and Cedar Creek reveal that the peak discharges recorded at stream gages (table 17 and figure 36) have recurrence intervals less than 100 years.

For a given flood frequency, a relation between peak discharge and drainage area can be developed to allow the estimation of discharge at ungaged sites within a watershed, or within other watersheds having similar basin characteristics. Figure 37 illustrates the relationship between peak discharge and drainage area for Cedar Creek, the St. Marys, Maumee, and St. Joseph Rivers for the 10-year and 100-year floods.

Higher 10-year and 100-year flood discharges occur in the St. Marys River for a given drainage area when compared to floods in the St. Joseph River. For example, a site on the St. Joseph River with a drainage area of 700 sq. mi. has an estimated 100-year flood discharge of approximately 12,000 cfs. At a comparable site on the St. Marys River, the 100-year flood discharge is about 15,000 cfs.

The St. Marys River valley is underlain by alluvium which does not extend significantly beyond the channel and by hard loam till (figure 17), resulting in very little *bank storage* during floods. In addition, the surrounding clayey or silty soils have high runoff coefficients. These factors promote high surface runoffs and flood discharges in the St. Marys River.

In contrast, the St. Joseph River valley is underlain by thick deposits of sand and gravel which serve as temporary storage features, especially during periods of flooding. The availability of a large amount of bank storage reduces peak runoff and sustains flood duration. In addition, the surrounding soils have moderate runoff coefficients. The lower surface runoffs and attenuated flows lead to lower flood peaks in the St. Joseph River than in the St. Marys.

The curves in figure 37 show that although flows on the St. Marys typically exceed those on the St. Joseph for comparable drainage areas, the curves begin to converge downstream. Two important factors may contribute to this change 1) the St. Marys River near its confluence with the St. Joseph River crosses a relict ice-marginal channel underlain by outwash sand and gravel (Figure 17) which provides an increase in available storage; and 2) the discharge of the St. Joseph River changes abruptly downstream from its confluence with Cedar Creek, which changes

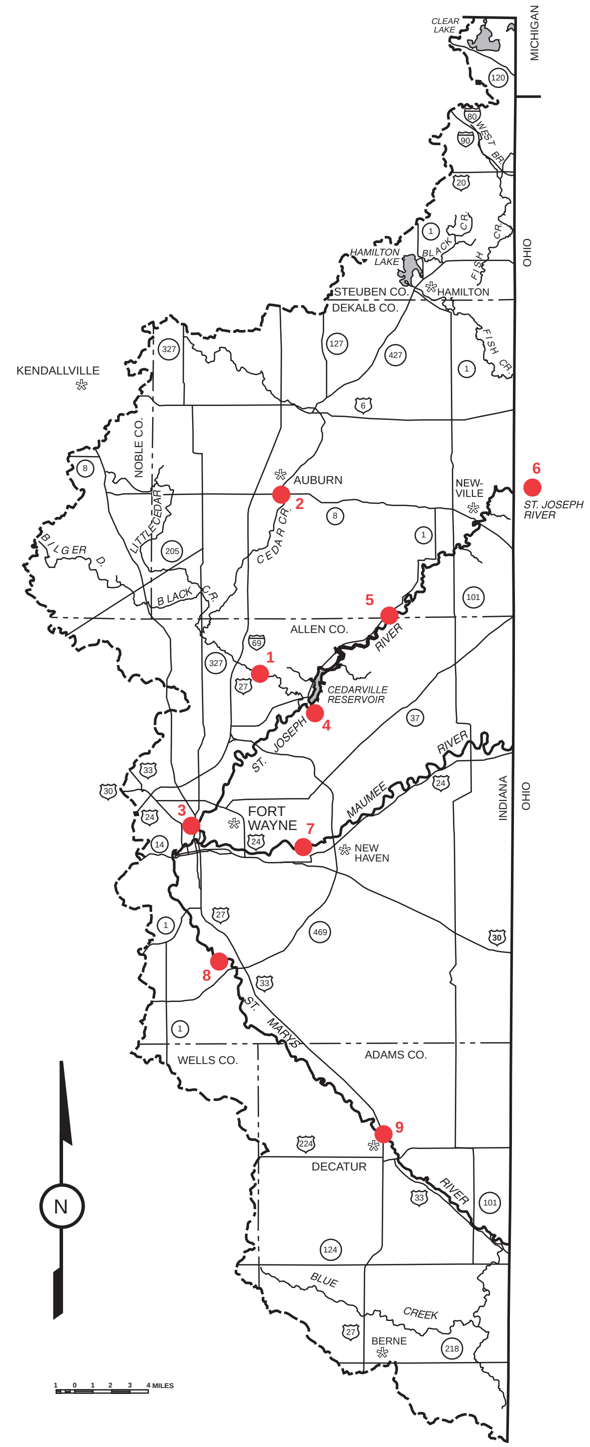


Figure 36. Location of flood discharge points for selected streams

Table 17. Flood discharges for selected streams

{Data from Indiana Department of Natural Resources, Division of Water, 1993c}

Site locations are shown in figure 36.

Map No.	Stream Location	Drainage Area (sq.mi.)	10-Year (cfs)	25-Year (cfs)	50-Year (cfs)	100-Year (cfs)
	CEDAR CREEK					
1.	near Cedarville–USGS gage	270	4700	NA	NA	6200
2.	at Auburn–USGS gage	87.3	1400	NA	NA	2000
	ST. JOSEPH RIVER					
3.	above St. Marys River	1086	11000	13000	14900	17000
4.	at Cedarville Reservoir	763	8400	10300	11900	13000
5.	at Allen-DeKalb County Line	724	8200	10000	11200	12500
6.	near Newville–USGS gage	610	7200	8800	10000	11000
	MAUMEE RIVER					
7.	at New Haven–USGS gage	1967	19000	22500	25000	27500
	ST. MARYS RIVER					
8.	near Fort Wayne–USGS gage	762	10200	12800	14000	16000
9.	at Decatur–USGS gage	621	9300	11300	13000	14500

the discharge to area relationship very rapidly.

Flood control

Flood control options in the Maumee River basin include structural, non-structural, and regulatory methods. Historically, most methods of flood control have involved *channelization*, ditching, dredging, levee construction, and land-treatment measures. Increased emphasis is being placed on floodplain regulation and non-structural alternatives, such as land use regulations, flood insurance, floodproofing, flood warning, and flood damage relief.

The following paragraphs summarize a few of the basin flood control measures identified by the Maumee River Basin Commission (1993).

Flood control measures in Adams County are limited to a few individually-constructed floodwalls and levees. In Decatur, some floodgates have been installed to prevent backwater flooding from the St. Marys River. The Adams County Civil Defense Department has identified areas likely to flood throughout the county and inspects these areas during periods of high water.

DeKalb County flood control measures have been limited primarily to the city of Auburn. Within the city's corporate boundary, floodgates have been installed along most of the pipes having outlets into Cedar Creek. In the mid-1980s two lift stations were installed in Auburn to prevent storm water backup into residential and commercial basements by pumping water from the storm sewer into Cedar Creek during high water events.

In response to the flood of 1982, the city of Fort Wayne developed a work program which addressed specific measures to mitigate flood damages. The program included such items as a floodproofing program, an early warning system, and various structural measures. A supplement to the program was prepared in 1991. A 1991 analysis of the effectiveness of the flood control improvements made in 1982 estimated that flood damages were reduced in the 1990-91 flood from a potential of $61 million to the nearly $5 million that actually incurred (Maumee River Basin Commission, 1993).

In 1983, Allen County and the City of Fort Wayne received money from the State of Indiana for flood control work in Fort Wayne. A large number of floodgates were installed on outlet pipes to prevent reverse

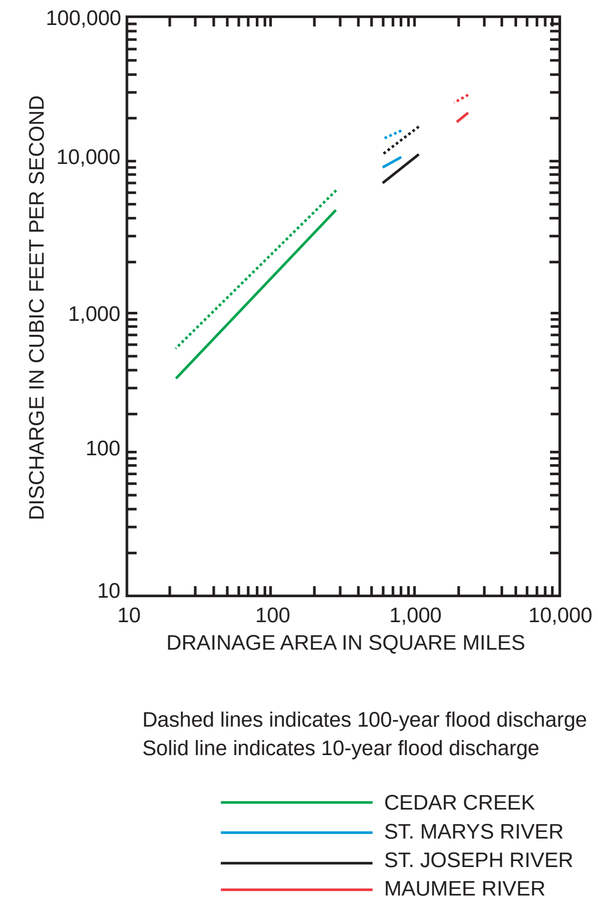


Figure 37. Relationship between drainage area and 10-year and 100-year flood discharge for major streams in the Maumee River basin

flows to the various neighborhoods.

A total of 52,000 feet of levees and floodwalls are reported to exist in the Fort Wayne area. Some of the structures were in place prior to the 1913 flood and many levees were constructed in response to that and subsequent floods.

Work has begun on a U. S. Army Corps of Engineers (USACE) proposal for a diking project that would install or improve approximately 53,000 linear feet of levees, floodwalls, and dikes along the three rivers in Fort Wayne. A flood protection level above the 100-year flood elevation is to be provided for approximately 40 percent of the Fort Wayne residents in the floodplain.

In addition, approximately four miles of the Maumee river, east of Fort Wayne's downtown, were widened to provide additional bank storage. The U.S. Army Corps of Engineers estimates that the widening will reduce the 100-year flood levels in Fort Wayne by approximately one foot.

A three-phase alternative land use plan is in progress to develop a 200-acre Headwaters Park to be constructed near the confluence of the three rivers in Fort Wayne. This area has been inundated many times by flood waters. Phase one has been completed and is open to the public, and phase two is underway.

The City of Fort Wayne also has a program designed to protect flood-prone areas during high-water events. Eighteen areas are designated as 'mitigation areas' which are assigned to a team of city employees who know the flooding characteristics of the areas and provide flood-fighting techniques during high-water events.

In addition to these flood control activities, the Maumee River Basin Commission (MRBC) is involved in a major planning effort to develop, by consensus of stakeholders, a Master Plan for Indiana's Maumee River basin. The MRBC was created in 1986 by the Indiana General Assembly primarily to help northeast Indiana communities minimize the threat of flooding.

The Commission's "Resources and Trends" report of 1993, from which much of the above summary on flood control measures was taken, is the first inventory phase of the Master Plan.

The primary objective of the Master Plan is to prevent or mitigate the 100-year (5-year in agricultural areas) flood damages in the basin's flood hazard areas using a combination of structural and non-structural solutions.

A detailed flood damage inventory of the basin was completed in 1994, and a report was published in 1995. The report, which includes alternative solutions and an implementation plan, was published in 1995.

Major recommendations in the Flood Control Master Plan include: 1) adopting uniform floodplain, stormwater, and erosion control ordinances in the basin; 2) buyout or floodproofing of more than 1,250 residential and non-residential structures; 3) protecting two stream reaches by means of levees and floodwalls; and 4) converting several acres of flooded agricultural lands from agricultural land use to woodland, wetland, and park corridors (Christopher B. Burke Engineering, Ltd., 1995).

The Maumee River Basin Flood Control Master

Plan report was approved by the Commission in 1995 and is currently in the implementation phase.

Floodplain management

Detailed floodplain management reports and flood insurance studies are available for all counties in the basin. Most of these reports have been prepared by cooperative efforts of the U.S. Department of Agriculture (Soil Conservation Services), the Federal Emergency Management Agency, the Indiana Department of Natural Resources, Soil and Conservation Districts, Planning Commissions and other local agencies.

Figure 38 shows the status of flood insurance studies available for the highlighted areas. Flood Insurance Studies (FIS) provide the 100-year base flood elevation and show delineations of the floodway and floodway fringe along the streams and lakes (see sidebar titled **Construction in a floodplain**). The Maumee River Basin Commission is in the process of updating the flood insurance studies on several of the streams shown in figure 38.

Existing floodplain management regulations in Indiana are governed by a combination of statutory laws at both the state and federal levels. In brief, the state establishes minimum standards governing the delineation and regulation of flood hazard areas. Moreover, the 1945 Indiana Flood Control Act (I. C. 14-28-1) prohibits construction, excavation or the placement of fill in a floodway without prior approval from the Department of Natural Resources.

The Indiana Department of Natural Resources, Division of Water administers the flood control law, and also acts as the state coordinator of the National Flood Insurance Program (NFIP) which helps to regulate the development of flood-prone lands. According to requirements of the program, new construction in a flood hazard area must be located and built in such a way that the potential for damages and loss of life is minimized.

Under this program, which is administered by the Federal Insurance Administration of the Federal Emergency Management Agency (FEMA), property owners are eligible to purchase federal flood insurance if their flood-prone community adopts and enforces adequate floodplain management regulations.

Initially, a community may enter the **emergency phase** of the flood insurance program. To qualify, the community must adopt preliminary floodplain management regulations which will guide new construction in flood-prone areas. Boundaries for mapped flood hazard areas are approximate.

The community can enter the **regular phase** of the program after the following criteria have been met: 1) a detailed flood insurance rate map is issued following a flood insurance study, and 2) local officials enact comprehensive regulations that require all new or substantially improved structures to be built in accordance with federal floodplain management criteria. Under the regular program, the full limits of flood insurance coverage become available.

Table 18 shows the communities in the Maumee River basin that participation in the National Flood Insurance Program. The term “community” refers to both unincorporated and incorporated areas which have a government authority capable of adopting and enforcing floodplain management regulations. By

Table 18. Communities participating in the National Flood Insurance Program in the Maumee River basin

(all communities in regular phase of National Flood Insurance Program as of February, 1995)

County	Community
Adams	Berne Decatur
Allen	Fort Wayne Grabill Huntertown Monroeville New Haven Woodburn
DeKalb	Altona Auburn Butler Garrett St. Joe Waterloo
Steuben	Clear Lake Hamilton

Note: The unincorporated areas of Adams, Allen, DeKalb, Noble, Steuben, and Wells counties participate in the National Flood Insurance Program under their respective counties.

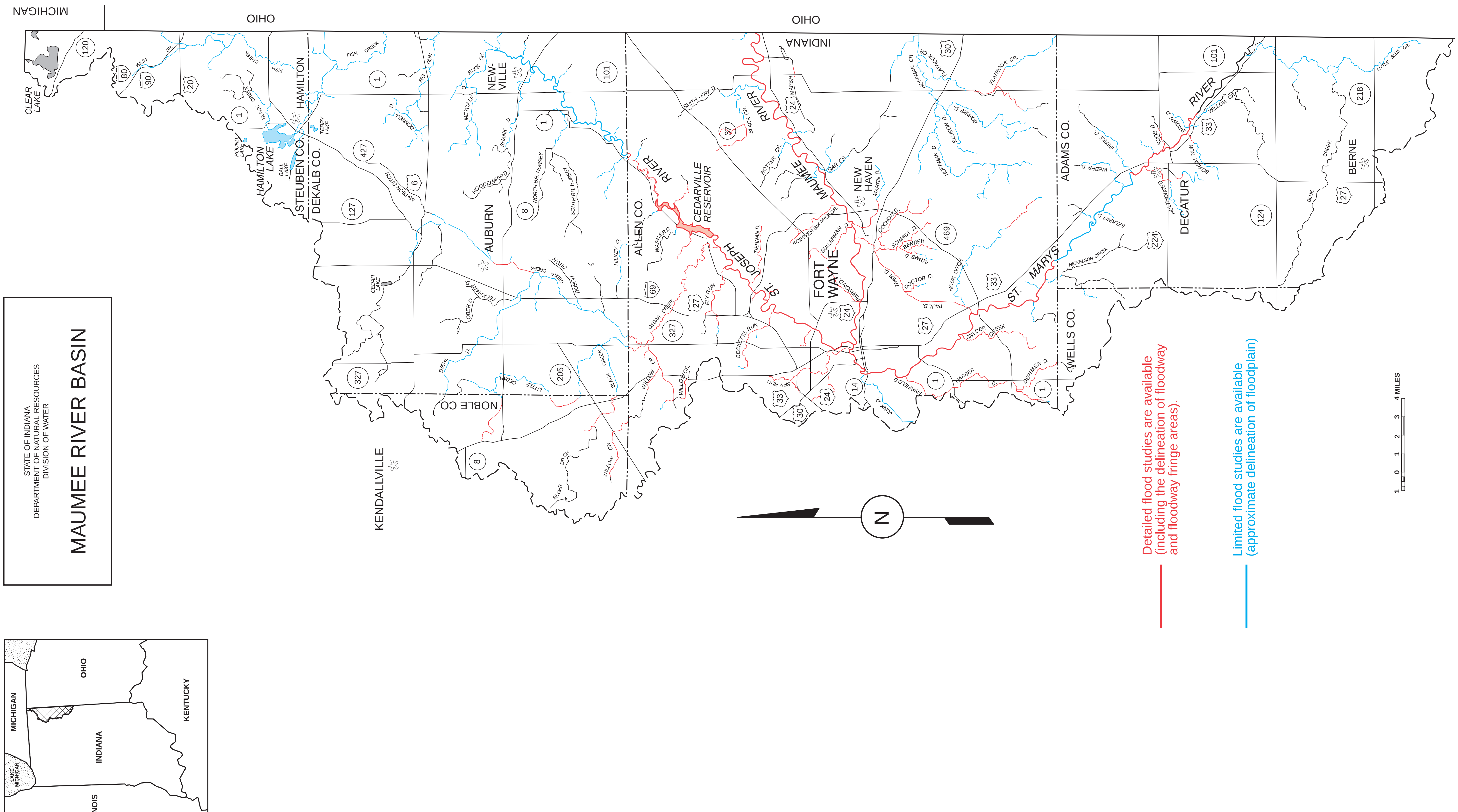


Figure 38. Flood Studies by Federal Emergency Management Agency for selected streams.

Construction in a floodplain

The Division of Water, Department of Natural Resources, offers a **floodplain recommendation service** to the public **free of cost**. The public is encouraged to use the services provided during initial stages of project planning.

A request letter enclosed with a copy of the legal description of the property, site plan, proposed project plan, plat map if available or any other relevant information on tract description is to be provided to the Division of Water to determine whether or not the proposed building site is located in a 100-year floodplain or Special Flood Hazard Area (SFHA). A letter of recommendation will be sent to the applicants providing the available flood information and state requirements that must be met for the site. The Hydrology and Hydraulics Section of the Division of Water handles these requests. Requests usually take from 3 to 8 weeks to process, depending on the availability of information and volume of requests.

More information about the Floodplain Regulatory Program or Floodplain Management services can be obtained by calling (317) 232-4164 or visiting the office of Division of Water in Indianapolis.

Floodplain information is also available at the local planning commission.

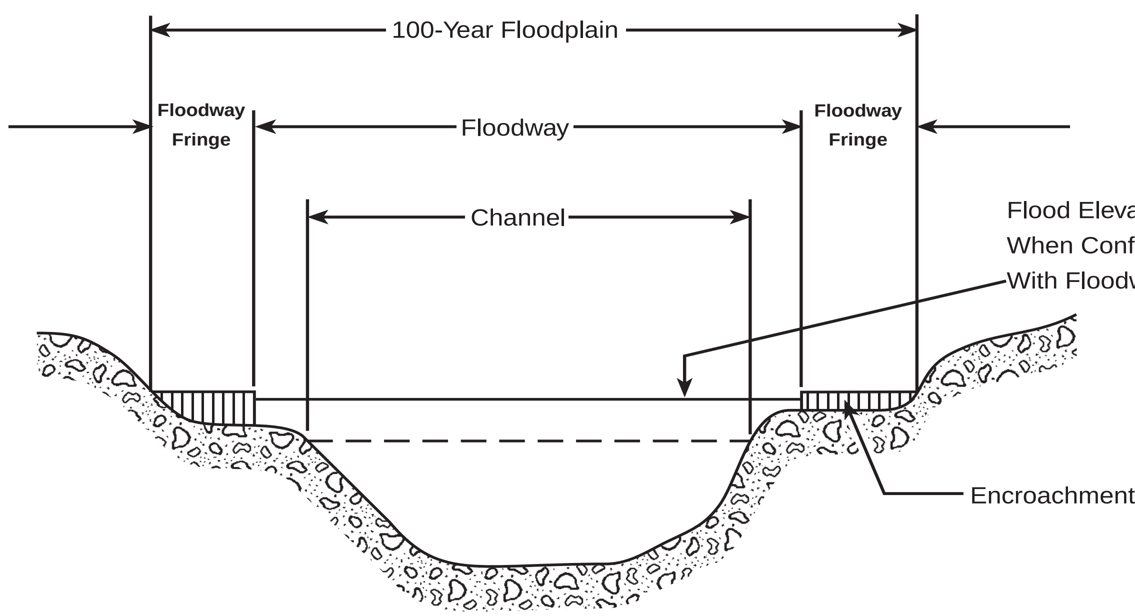
100-Year Floodplain:
The channel and the areas neighboring any water course which have been covered by the 100-year flood. The floodplain encompasses both the floodway and the floodway fringe.

100-Year Flood:
The flood having a one percent probability of being equaled or exceeded in any given year.

Base Flood Elevation:
The water surface elevation corresponding to a 100-year flood.

Floodway:
The channel of a stream and the portions of the floodplain adjacent to the channel which are required to carry and discharge efficiently the peak flood flow of the 100-year flood of any stream.

Floodway Fringe:
The areas lying outside the floodway but within the boundary of the 100-year flood.



virtue of this definition, an incorporated town is considered independent of unincorporated areas, which are collectively defined as a separate community.

SURFACE-WATER QUALITY

Surface-water quality is an important factor in developing sustainable and beneficial land and water use strategies. The presence of high-quality surface water can facilitate or enhance development by providing water suitable for public supply, industrial cooling, irrigation, livestock, recreation and aquatic life. In contrast, the value of a surface-water resource is diminished by bacterial contamination, high levels of nutrients, or unacceptable concentrations of inorganic and/or organic chemicals.

Degradation of water quality may result from urban, industrial, and agricultural land uses, since practices associated with these functions may introduce sources of pollution into the watershed. Wastewater discharge, contaminated runoff, *combined sewer overflows* (CSO), atmospheric deposition, and accidental spills or discharges are examples of these sources. Problems with water-quality degradation may be further complicated by the needs of multiple users for a limited supply of water. Pollution sources may be grouped together along the banks of a river or lakeshore to obtain this much needed resource. Their combined discharges can be detrimental to aquatic life and human health. Water quality degradation can occur in both urban and agricultural areas if sufficient pollution-control practices are not properly implemented.

National Pollutant Discharge Elimination System

Rivers, streams, and ditches in the Maumee River basin are used to assimilate wastewater discharged primarily from municipal and industrial facilities. A facility is required to treat its effluent to maintain the water-quality standards established for the receiving watercourse, or be granted an exemption (Rule 1, Article 2, Title 327 of the Indiana Administrative Code).

The concentration of polluting materials in these effluents are regulated by the National Pollutant Discharge Elimination System (NPDES) permit program administered in Indiana by the Indiana Department of Environmental Management (IDEM). All facilities which discharge to Indiana waters must apply for and receive an NPDES permit. The discharge limits set in the permit are designed to protect all designated uses of the receiving watercourse.

Treated effluent discharged into streams normally requires dilution to maintain water-quality requirements. Because the volume of water in streams is at a minimum during dry weather, low-flow periods are used as the basis of design for wastewater-treatment facilities.

Appendix 8 lists most of the NPDES-permitted municipal, non-municipal and industrial wastewater-treatment facilities in the Maumee River basin. Some facilities including motels, mobile home parks, and private businesses, are not listed because of insufficient data. Average flows and design flows are shown for the wastewater treatment facilities to indicate present capacities, and the ability of the system to meet projected increases in domestic water use. Discharges for industrial facilities are also shown where data are available.

Figure 31 shows the locations of the facilities tabulated in appendix 8 which discharge approximately one million gallons per day or more. Two different stream-flow characteristics are shown: the 7-day, 10 year low flow (7Q10), and average flow. The 7Q10 is used to determine the level of wastewater treatment needed to meet water-quality standards, and the average flow is a general measure of water volume in the stream.

Designated surface water uses

In the past, the Indiana Department of Environmental Management estimated there were approximately 90,000 miles of open channel waterways in the state of Indiana. In this report, new guidelines developed by the U.S. Environmental Protection Agency (USEPA) for estimating stream miles have been incorporated. This system utilizes 1:100,000 USGS Digital Line Graph (DLG) and USEPA River Reach File 3 (RF3) computerized databases, which list perennial streams greater than one mile in length. This new system, adopted to insure more consistent estimates, calculates Indiana's stream miles at approximately 35,673. It should be noted that all waterways (not just those incorporated in the new river mile estimates) are considered "waters of the state" and are protected by Indiana stream pollution control laws.

The IDEM assigns one or more specific designated surface water use (DSWU) classifications to the streams of the state. These classifications reflect the benefits that can be derived from the stream for both humans and wildlife. The types of DSWUs in Indiana include: aquatic life, recreation, agriculture, industrial, and public-water supply as well as other more specific classifications. Of the 35,670 stream miles listed in RF3, approximately 21,094 have sufficient all-weather flow and other physical characteristics to reasonably be expected to support designated uses.

In a recent evaluation of the Maumee River basin, IDEM assessed 764 stream miles for aquatic life and full-body contact recreational use. Of these 764 stream miles, 649 miles (85 percent) fully support the aquatic life designated use, 31 miles (4 percent) were fully supporting, but threatened, 9 miles (1 percent) were partially supportive, and 75 miles (10 percent) did not support this use. For recreational use, 110 miles (14 percent) were fully supporting, and the remaining 654 miles (86 percent) were non-supportive (figure 39).

The majority of river reaches which did not support recreational use were impaired by high levels of coliform bacteria, specifically E. coli. Coliform bacteria are usually found in the intestines of humans and warm-blooded animals and are excreted with body wastes. High levels of these bacteria in a lake or stream could indicate possible contamination by raw or under-treated sewage, and the subsequent risk that disease-causing microorganisms are present in the water. Sixty-three of 81 water-quality sampling sites tested failed solely or in part due to high levels of bacteria (Indiana Department of Environmental Management, [1995]).

The causes of this impairment consist of both *point* and *non-point sources* (NPS) of pollution. Portions of the St. Marys River, Yellow Creek, Big Run Drain, Garrett City Ditch, and King Lake Ditch have experienced problems with E. coli contamination due to non-compliance of sewage treatment facilities. Other stream reaches, such as portions of the Maumee River, Habegger Ditch, Marsh Ditch and Edgerton-Carson Ditch, suffer from E. coli contamination resulting from combined sewer overflows. In addition, many of the other streams not meeting recreational use standards have been identified by IDEM as being impacted by agricultural run-off, septic systems, and other non-point sources of pollution.

It should also be noted that the sampling of many stream reaches near the Maumee River was conducted soon after a major rain event. Increased runoff due to storms increases the NPS pollution load. Therefore, the recreational impairment of these stream reaches may not be characteristic of the conditions throughout the year.

The majority of river reaches which did not support aquatic life were impaired by low levels of dissolved oxygen (DO) in the water column. Dissolved oxygen concentrations can be affected by the levels of oxidizable organic matter in a lake or stream. In the aquatic environment the decay of organic matter is often facilitated by oxygen-consuming bacteria. These bacteria degrade the organic matter through oxidizing reactions to obtain energy for metabolic functions.

When high levels of oxidizable organic matter are present in a lake or stream, enough dissolved oxygen may be consumed during the decay process that the water body may become uninhabitable for many aquatic species. In extreme cases, anaerobic (no available oxygen) conditions may develop. Very high levels of organic matter may develop in surface waters as a result of NPS discharges, combined sewer overflows and discharge of under-treated wastewater.

Thirteen of 81 water-quality sampling sites experienced impairment of designated uses to some degree as a result of low DO levels (Indiana Department of Environmental Management, [1995]). Impairment of Yellow Creek, King Lake Ditch, and Garrett City Ditch was a result of problems with sewage treatment plants in the area. Habegger Ditch was impaired due to a system of combined sewer overflows. Willow Creek Branch, Willow Creek Ditch and Bullman Ditch experienced problems with septic systems. The causes of impairment of Gerke Ditch, Blue Creek, Houk Ditch, Snyder Ditch, Swartz-Carnahan Ditch, and Tiernan Ditch are unknown.

According to the IDEM, sediments of some streams within the Maumee River basin have been contaminated with *toxic* substances such as copper, lead, cyanide, oil, *polychlorinated biphenyls* (PCBs), *polynuclear aromatic hydrocarbons* (PAHs), pesticides and other materials, as a result of human activities. If these toxins accumulate in high enough concentrations, they can pose a threat to human health, aquatic life, and the environment (U. S. Environmental Protection Agency, 1992).

Animals that live on the bottoms of rivers and lakes (such as crustaceans and insect larvae) may ingest or absorb toxic chemicals from contaminated sediments in their environment. Because these animals form an integral part of the aquatic food chain, problems that affect them may affect the fish and wildlife population. Humans may then be at risk by eating contaminated fish and wildlife (see sidebar entitled **Fish consumption advisory**).

Except in rare instances, dischargers of toxic substances throughout the basin are in compliance with their NPDES permits. However, violations of applicable standards for some toxic substances are still intermittently detected in waters and sediments in the Maumee River basin. In most locations where toxins have been found, they are at levels of low concern. However, an unnamed tributary in Fort Wayne contained antimony levels of medium concern; and levels of metals and organic chemicals in the sediments of Harvester Ditch, a tributary of the Maumee River

Fish consumption advisory

Fish may accumulate certain contaminants from the environment in fat, muscle, and other tissues. Therefore, the state of Indiana issues fish consumption advisories for streams and lakes that may contain fish exposed to bioaccumulating contaminants. Fish consumption advisories are suggested (non-enforceable) restrictions on the size and/or type of fish that should be eaten. The state issues a fish consumption advisory when tissue concentrations of certain bioaccumulating contaminants exceed acceptable risk levels for human health. People who regularly eat sport fish, women of childbearing age, and children are particularly susceptible to contaminants that build up over time. In the past, fish consumption advisories were based on recommendations given by the U.S. Food and Drug Administration (FDA) standards for toxic contaminants. However, it was determined that the standards did not take into account the amount of fish consumed by some anglers, or the fact that many anglers tend to consume fish from one geographical area. In response to this finding, new criteria were developed that are more protective than the old FDA standards. These criteria are based mainly on polychlorinated biphenyls (PCBs), pesticides, and heavy metals, the contaminants most frequently encountered in Indiana fish that necessitate guidance. Because of this change, more species of fish and several new geographical areas have been added to the advisory.

The IDEM collects fish specimens for tissue analysis at locations throughout the state. An interagency Fish Consumption Advisory Committee, consisting of representatives from IDNR, IDEM, and ISDH, evaluates the results of the fish tissue analysis and develops the fish consumption advisories. The Indiana State Department of Health officially issues the final fish consumption advisories for the state (Indiana Department of Environmental Management, [1995]).

The advisory is developed by analyzing the amount of contamination bioaccumulated in fish and assigning a number, 1-5, to indicate the level of risk. These numbers and their recommended consumption rate are listed as follows:

Level 1 Unrestricted consumption
Level 2 One meal* a week (52 meals a year)
Level 3 One meal* a month (12 meals a year)
Level 4 One meal* every two months (six meals a year)
Level 5 Do not consume, high level of contamination.

* One meal is considered to be eight ounces (before cooking) of trimmed, skinned fish for a 150-pound person.

The ISDH released the following advisories for the Maumee River basin in 1995** (Indiana Department of Natural Resources, 1995b). From the Maumee River in Allen County, Redhorse over 17 inches are level 4, and from 14-17 inches are considered level 3. From the St. Joseph River in Allen County, channel catfish over 21 inches are level 5, and from 18-21 inches are at level 3. From the St. Marys River in Allen County, Largemouth bass over 16 inches are considered level 4, and from 11-16 inches are level 3. In addition, carp in all Maumee basin rivers and streams are listed under the following risk levels: those from 15-20 inches are level 3, from 21-25 inches are level 4, and over 25 inches are level 5. Fish at levels one and two were not listed due to the minimal risk involved.

** A new fish consumption advisory is presently being developed and should be available late in 1996.

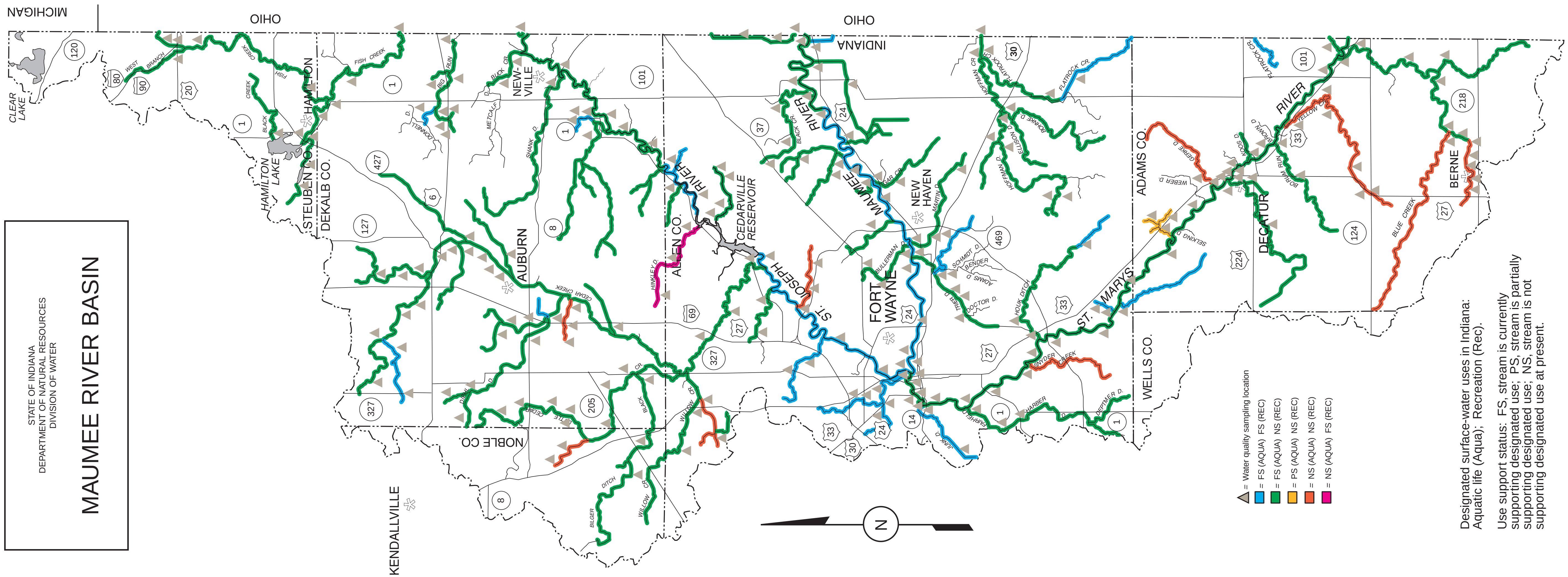
near Fort Wayne, are high enough to threaten the designated use support status for aquatic life (Indiana Department of Environmental Management, [1995]).

Other stream reaches have been seriously degraded in the past due to toxic substances. Willow Creek, a tributary of Cedar Creek, contained such high levels of chromium, copper, iron, lead, tin, silver, and cyanide, that a consent decree was reached between the Indiana Stream Pollution Control Board and the discharger. The consent decree required the discharger to divert its wastewater from Willow Creek to the Ft. Wayne Municipal Sewage Treatment Plant, and to dredge the streambed for 200 feet from the point of discharge to remove the contaminated sediments (Indiana Department of Environmental Management, [1995]). This project was completed in 1989 and has had a positive impact on the water quality of Willow and Cedar creeks.

Water-quality standards

Water-quality standards are legally-established limits for various physical, chemical, or biological parameters that may affect the use, safety, or aesthetics of water resources. Federal and state agencies establish numerical and/or narrative standards that are used as one criterion for assessing water quality. This report compares levels of selected constituents measured in streams and lakes in the Maumee River basin with state and federal water-quality standards.

In Indiana, water-quality standards are promulgated under Rule 1, Article 2, Title 327 of the Administrative Code (327 IAC 2-1). The rule defines the minimum water-quality standards which apply to all waters of the state at all times. Minimum standards require that waters of the state be free of substances from *anthropogenic* sources that may have detrimental effects on water quality. Specifically, the rule extends this restriction to substances that: 1) can have adverse effects on the aesthetic aspects of a water body, and/or 2) are in amounts sufficient to be acutely toxic to humans, aquatic life, plants or animals. In addition, waters of the state whose quality exceeds these minimum standards must be maintained at this level unless limited degradation is justifiable for necessary eco-



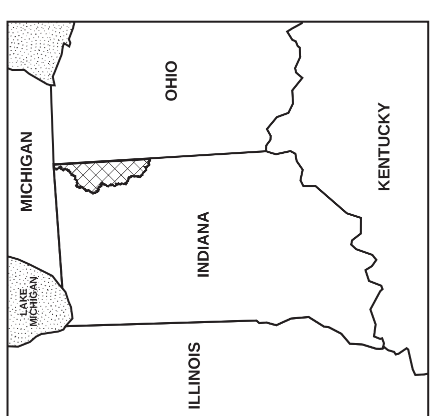


Figure 39. Designated uses and use - support status of selected streams
(adapted from Indiana Department of Environmental Management (IDEM) 1992 - 1993 305(b) (1995) and selected IDEM files

nomic or social reasons, and the level of anticipated degradation will not interfere with present or possible beneficial uses. Standards outlined in the rule are established for specific water-quality parameters and stream-use situations (table 19). The regulations also specify that when a stream is designated for more than one use, the most protective standards apply.

Water-quality standards are reviewed and revised to accommodate new environmental and public-health concerns, or when new data indicates the allowable level of a specific contaminate should be changed. It is thus possible for the use-support status of a stream or lake to change even though water quality remains constant.

In the following section, the quality of major streams in the Maumee basin is evaluated relative to 1990 promulgated state water-quality standards. This evaluation will help illustrate progress toward contemporary water-quality goals. In addition certain surface-water resources within the Maumee basin are used for public drinking supplies, and will be compared to drinking water standards and guidelines. These guidelines are defined in the Safe Drinking Water Act (SDWA) passed by Congress in 1974, and apply to all *public water systems*.

The federal criteria applied to water for human consumption include the *maximum contaminant level* (MCL) and the *secondary maximum contaminant level* (SMCL). The MCLs are legally established limits for the concentrations of specific constituents to protect human health. The MCLs are enforced for *finished water* treated and distributed specifically for public supply. The SMCLs are recommended, nonenforceable standards established to protect aesthetic properties of drinking water, such as taste and odor. Although not all streams within the basin are sources for public water supply, water quality in these streams may be compared to federal drinking-water guidelines for descriptive purposes. The established MCLs and SMCLs for certain inorganic ions are listed in appendix 9.

Water-quality monitoring and data collection

Long-term monitoring of water quality in Indiana was initially the responsibility of the Indiana State Board of Health (ISBH, now Indiana State Department of Health). In 1957, the ISBH began collecting and analyzing surface water samples from a network of 49 stations located along streams throughout the state. The ISBH maintained and expanded this stream monitoring network until 1986, when the Office of Water Management of the Indiana Department of Environmental Management (IDEM) assumed responsibility. This network presently consists of 106 water-quality monitoring stations.

Near-surface *grab samples* are collected on a monthly or quarterly basis at IDEM monitoring stations. The grab samples are analyzed in the field and laboratory to quantify the values of numerous water-quality parameters. The data obtained in the process are used to detect changes in surface-water quality, evaluate pollution-abatement strategies, estimate background levels of various chemical constituents, determine if streams meet designated uses, and to help document compliance with state and federal pollution-control mandates.

At present, the IDEM collects samples at six active monitoring stations in the Maumee River basin (figure 40, table 20). Samples are analyzed monthly for a variety of physical parameters, chemical constituents, and biological-quality indicators. Some of these parameters include *biochemical oxygen demand* (BOD), dissolved oxygen (DO), total phosphorus, ammonia, nitrate-nitrite, and bacteria. In addition, four of these stations are sampled on a quarterly basis to test for various inorganic and organic toxins. Regular monitoring of toxic substances is also conducted by IDEM through analyses of fish tissue and sediments collected biennially at 23 CORE program stations. Three of these stations are located on the main river systems within the Maumee basin, the St. Marys River (STM 0.2), St. Joseph River (STJ 0.5), and the Maumee River (M 129).

Plankton data from rivers in the Maumee River basin were collected at certain monitoring stations from 1958 until 1990 (figure 40, table 20). The reported data consists of the relative proportions of blue-green algae, green algae, and *diatoms* detected in a 125 ml sample. The dominating type of algae present in a stream can provide insight into the quality of that surface water system. However, plankton data from streams may be difficult to interpret. They may be present due to ambient conditions within the stream, or because they were washed in from lakes, wetlands or nearby tributaries.

Regular measurements of radiation levels in water samples were made by the ISBH at selected monitoring station in the Maumee basin (figure 40, table 20).

Table 19. Surface-water quality standards in Indiana

All surface-water resources in the state of Indiana are protected by water-quality standards established in subsection (a) of 327 IAC 2-1-6 (1992). These standards essentially state that acutely or chronically toxic chemicals and noxious substances must not be present in surface waters at levels that will have detrimental effects on water quality.

Additional aspects of this law define standards that are preferentially applied to surface-water bodies on the basis of use. These additional standards are enforced to help assure that Indiana's surface-water resources can fulfill designated uses for humans and wildlife. Standards for protecting surface-water uses are generally specific for particular parameters which can limit or prevent the potential use of surface-water resources. For example, limits on Escherichia coli (E. coli) bacteria are enforced to protect people from disease caused by possible sewage contamination. Streams or lakes which violate E. coli standards would probably not be considered safe for body contact recreation or water supply. A listing of fundamental surface-water uses in the Maumee River basin and their corresponding water-quality standards are outlined below.

Designated stream-use	Specific standards defined under 327 IAC 2-1-6 (1992)
Recreational (full-body contact)	E. coli may not exceed 125/100ml as a geometric mean of 5 or more samples equally spaced over 30 days, nor exceed 235/100ml in any single sample over a thirty day period.
Public Supply[1]	Coliform bacteria cannot exceed 5000/100 ml as a monthly average nor exceed 5000 /100ml in 20 percent of all monthly samples, or 20,000/100ml in 5 percent of all monthly samples. E. coli limits are the same as those established for recreational use streams. Concentrations of either sulfates or chlorides must not exceed 250 mg/L. Radiation levels due to radium-226 and strontium-90 must not exceed 3.0 pCi/L, respectively (in the known absence of strontium-90 and other alpha emitters, beta particle activity of up to 1000 pCi/L is acceptable).
Industrial Supply[2]	Total dissolved solids (TDS) cannot exceed 750mg/L (a specific conductance of 1,200 µmhos/cm at 25^o C can be considered equivalent to a TDS of 750mg/L).
Agricultural use	Waters must meet all requirements specified in 327 IAC 2-1-6(a) (the minimum water-quality standards).
Aquatic life[3]	A pH range of 6.0-9.0 is allowed. Dissolved oxygen levels must average at least 5.0mg/L daily, without being lower than 4.0mg/L at any time. Maximum temperature increase due to anthropogenic activity may not exceed 5^{o}F (2.8^{o}C) in streams and 3^{o}F (1.7^o C) in lakes and reservoirs. No substances which impart unpalatable flavor to fish or offensive odor may be discharged into designated aquatic life streams.
Cold Water Fisheries[3]	A 6.0mg/L minimum dissolved oxygen level (7.0mg/L in spawning areas during spawning season) is required. Any temperature increases due to anthropogenic activity can not exceed 2^o F (1.1^o C). Maximum water temperature must not exceed 65^o F (18.3^o C) during the spawning season, and 70^o F (21.1^o C) during the rest of the year. The same limits on pH and discharge of noxious substances specified for aquatic-life designation streams also apply to cold water fish streams. Spy Run in Fort Wayne is designated a cold water fishery.
Limited use streams	In addition to standards established in subsection (a), limited use streams must meet the standards established for recreational and industrial uses. Aerobic conditions must prevail at all times. In DeKalb County, Hilkey [sic] Ditch from the County Line Cheese Company outfall to North County Line Road and Hindman Ditch from the Ralph Sechler Company outfall downstream to its confluence with Bear Creek are limited use streams.
Exceptional use streams	The quality of waters designated for exceptional use shall be maintained without degradation, unless it is demonstrated that limited degradation is justifiable on the basis of necessary economic or social reasons, and that the degradation would not interfere with present beneficial uses.
Outstanding state resource	These waters shall be maintained at their present high quality without degradation. Cedar Creek in Allen and DeKalb Counties, from river mile 13.7 to its confluence with the St. Joseph River has been designated an outstanding state resource.

[1] Standards apply at the point where water is withdrawn for treatment. Water distributed for public supply must also meet drinking water standards defined in 327 IAC 8-2.
[2] Standards apply at the point where water is withdrawn for use.
[3] Standards on excessive pH (above 9) do not apply when daily high pH values are correlated with photosynthetic activity by plants.

Table 20. IDEM water-quality monitoring stations in the Maumee River basin

{Complied from Indiana water-quality monitoring station records-rivers and streams, Indiana State Board of Health (1957-1984) and Indiana Department of Environmental Management (1985-1991). Site locations displayed in figure 40.}

Water quality: Samples collected each month at most stations.

Plankton/algae: Samples collected each month.

Toxics: Samples collected 3-4 times each year, measurements of specific parameters vary with location.

Radiation: Samples collected each month until 1978. After 1978, three consecutive samples were combined and analyzed four times a year.

Location	IDEM code	Water quality	Plankton/algae	Toxics	Radiation
Maumee River					
Woodburn	M 114[1]	1965-present	1971, 1974-79	1989-present	1971, 1973-85
Fort Wayne	M 116	1971-85			1983
New Haven	M 129[2]	1957-present	1958-70	1989-present	1957-73
St. Joseph River					
Fort Wayne	STJ 0.5[3]	1973-present	1978-90	1989-present	
Mayhew Rd. bridge	STJ 8	1957-72	1960-70		
St. Marys River					
Fort Wayne	STM 0.2	1986-present	1986-90	1989-present	
Fort Wayne	STM 11[4]	1957-present	1960-70		
Pleasant Mills	STM 37[5]	1979-present	1979		

[1] Previously designated M 95 (1965-85)
[2] Previously designated M 110 (1957-1985)
[3] Previously designated STJ 0 (1973-85)
[4] Previously designated STM 12 (1957-85)
[5] Previously designated STM 33 (1973-85)

Radiation quality is expressed as measured alpha particle and beta particle activities in both the suspended sediment load and dissolved solids load of a sample. Monthly data collection began in 1957 and continued until quarterly sampling was initiated in 1978. Regular measurement of radiation levels in samples from the monitoring network ended after 1985.

The U.S. Geological Survey has collected limited water-quality data from streams in the Maumee River basin during its research and resource-evaluation efforts. Water-quality data was gathered in the 1960s on the Maumee River at New Haven and the St. Joseph River at Newville. Parameters measured include pH, dissolved oxygen, sediment, *anions*, *cations*, and nutrients.

In 1991, the U.S. Geological Survey began to implement the National Water Quality Assessment (NAWQA) program. The purpose of this program is to describe the status and trends in water quality for the nation’s surface and ground-water resources. A NAWQA study on the Lake Erie-Lake St. Clair Basin began in 1994. This study unit drains approximately 22,300 mi^2 and includes the Maumee River basin in Indiana. The Maumee River is the principle water course in this hydrologic unit with an average discharge into Lake Erie of 4,990 ft^3/s (Myers and Finnegan, 1995).

Three sampling sites have been proposed within the Indiana portion of the Maumee basin. The first two sites are located on the Maumee River at New Haven and the St. Joseph River at Newville. The third site under consideration would be located on Fish Creek, a tributary of the St. Joseph River. Sampling is expected to begin early in 1996 and continue through 1998.

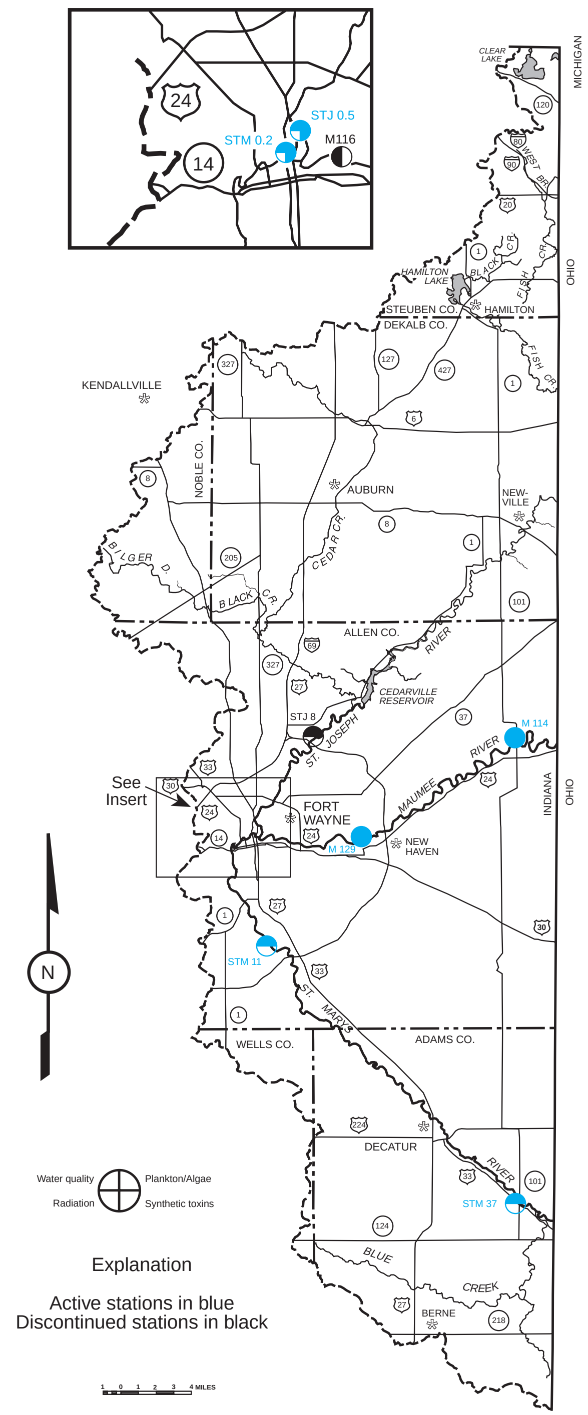


Figure 40. Surface-water quality stations

Stream quality

Sources for data

Data from selected IDEM monitoring stations were used to analyze the water quality of streams in the Maumee River basin. Data were gathered from stations along the Maumee River (M114, M129), the St. Joseph River (STJ 0.5), and the St. Marys River (STM 0.2, STM 11, STM 37)(figure 40). These three rivers represent the major drainage of the Maumee basin. A general lack of adequate data for headwater streams in this region precludes a meaningful analysis of the smaller streams.

The data used for this report encompass a fifteen year period (1978-1993) and were collected at the above mentioned fixed water-quality stations. The water-quality parameters examined include dissolved oxygen (DO), pH, *specific conductance* at 25^{o} C, hardness, chloride, total iron, nitrate-nitrite, and phosphorus.

Seasonal variations in water quality

The median values of dissolved oxygen and specific conductance for each climatic season (winter, spring, summer, and fall) were compared to discern possible seasonal trends in water quality. Dissolved oxygen and specific conductance were examined for temporal trends because seasonal variations are often observed in these parameters, and specific limits for their levels have been established for certain stream uses (table 19). Possible seasonal variations in DO concentration and specific conductance levels could, therefore, be a factor in stream-quality assessment.

Of the monitoring stations examined, the highest seasonal median dissolved oxygen levels are observed in winter and the lowest during the summer (figure 41). Because the largest contrasts in median water temperature (figure 42) are also observed between winter and summer, this trend in DO levels probably reflects the changes in oxygen solubility due to seasonal variations in average water temperature. At all the monitoring stations examined, higher median DO concentrations and lower median temperatures occur during fall as opposed to spring. However, at two of the stations (STM 11 and STM 37), the spring and fall differences in median dissolved oxygen are negligible. These discrepancies may reflect other factors which

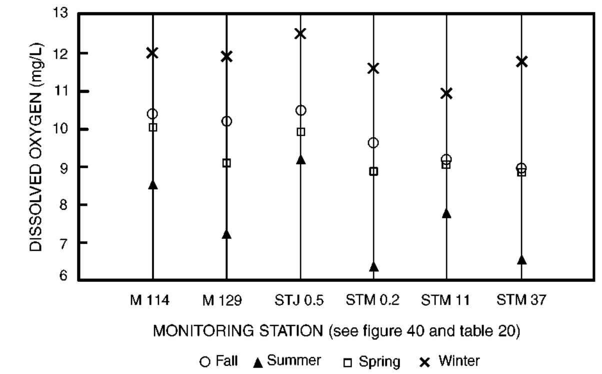


Figure 41. Seasonal median dissolved oxygen at selected monitoring stations

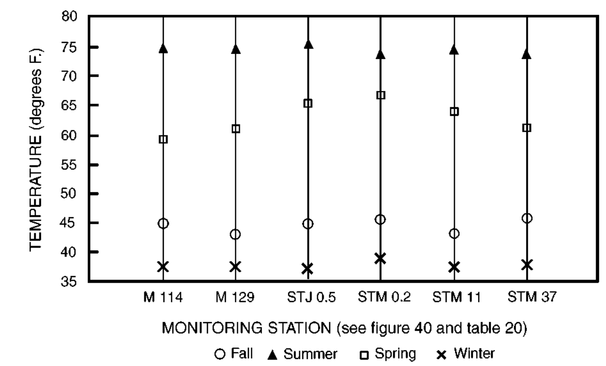


Figure 42. Seasonal median temperature at selected monitoring stations

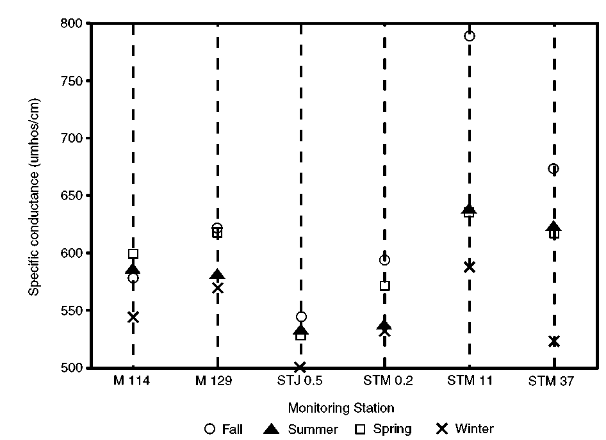


Figure 43. Seasonal median specific conductance at selected monitoring stations

influence the dissolved oxygen content of streams (see sidebar entitled **Factors affecting surface-water quality**).

Graphs of median specific conductance (MSC) in water from selected monitoring stations are displayed in figure 43. The largest seasonal difference in MSC is detected in water samples from the St. Marys just upstream of Fort Wayne (STM 11). The MSC value for samples collected during the fall exceed that of samples collected in the winter by approximately 200 µmhos/cm for this station. This seasonal fluctuation is mirrored to a lesser degree at station STM 37 on the Maumee River. Fall and winter measurements of specific conductance differ by approximately 150 µmhos/cm at this station. The other stations monitored (M 114, M129, STJ 0.5, and STM 0.2) appear fairly consistent throughout the year. It is possible, however, that some of the annual variability in the specific conductance levels of these streams relates to seasonal influences.

Figure 44 illustrates median monthly nitrate-nitrite levels from monitoring stations on the St. Joseph, St. Marys, and Maumee Rivers. There appear to be large seasonal and spacial variations in the nitrate-nitrite levels of these rivers. In general, the seasonal trend mirrors that of runoff from the land surface (figure 25). This may be a result of NPS pollution entering the receiving streams during storm events. The major deviation from this trend occurs during the months of June and July, and is probably the result of extensive application of nitrogen-based fertilizers during this time period. Agricultural uses account for approximately 88 percent of the land surface in the basin, and may be a significant source of NPS pollution. However, median monthly nitrate-nitrite levels in these major river systems did not exceed the maximum contaminant level of 10 mg/L set forth in the drinking water regulations (figure 45). This may not, however, necessarily reflect the condition of the smaller tributaries in the basin. Water from many small and medium-sized rivers in agricultural areas have been found to contain nitrate concentrations exceeding 10 mg/L at times (Harmeson and others, 1971).

Spacial variations in water quality

Box plots are often used to display the median and percentile ranges of a data set. These graphs are use-

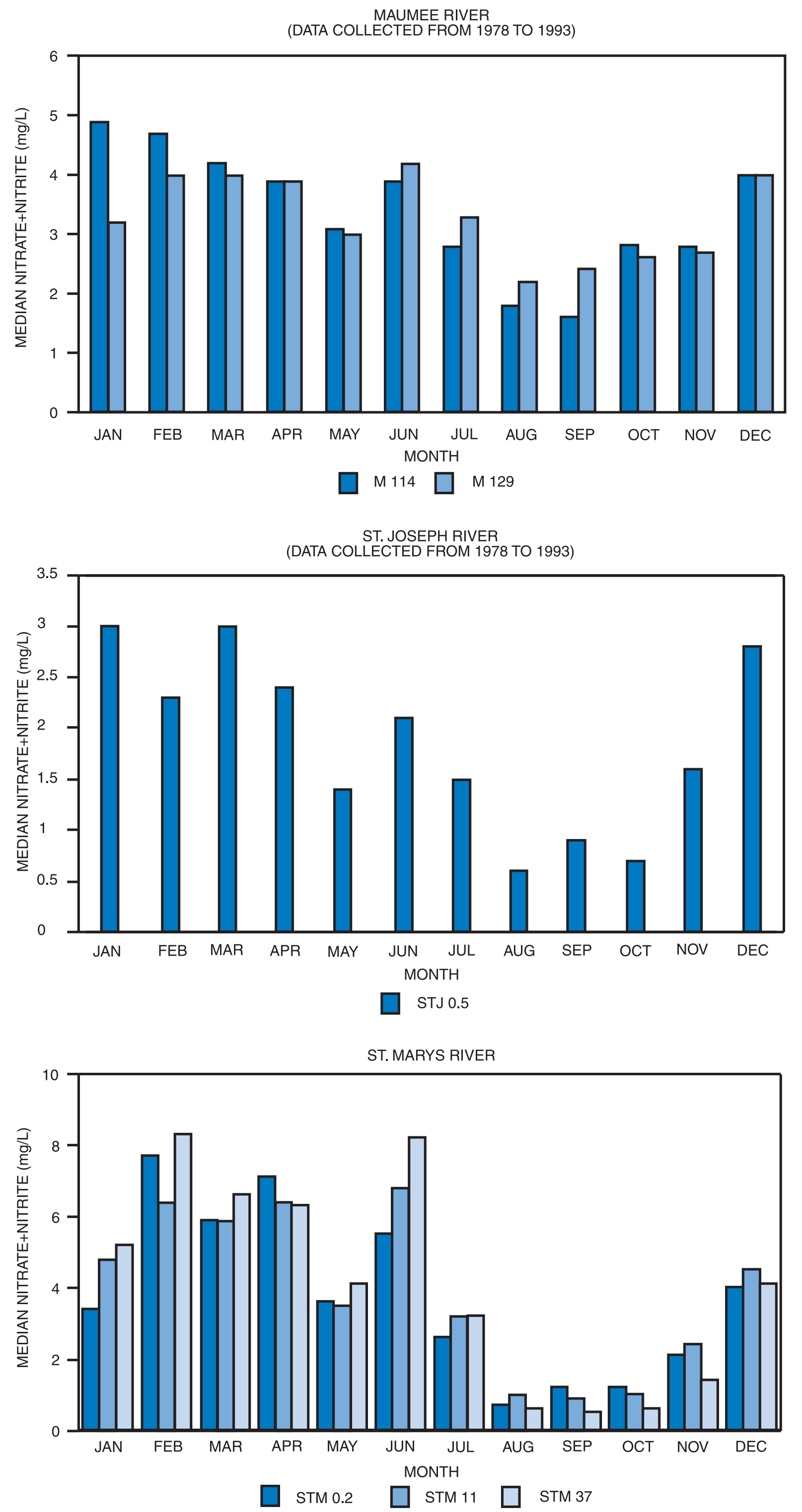
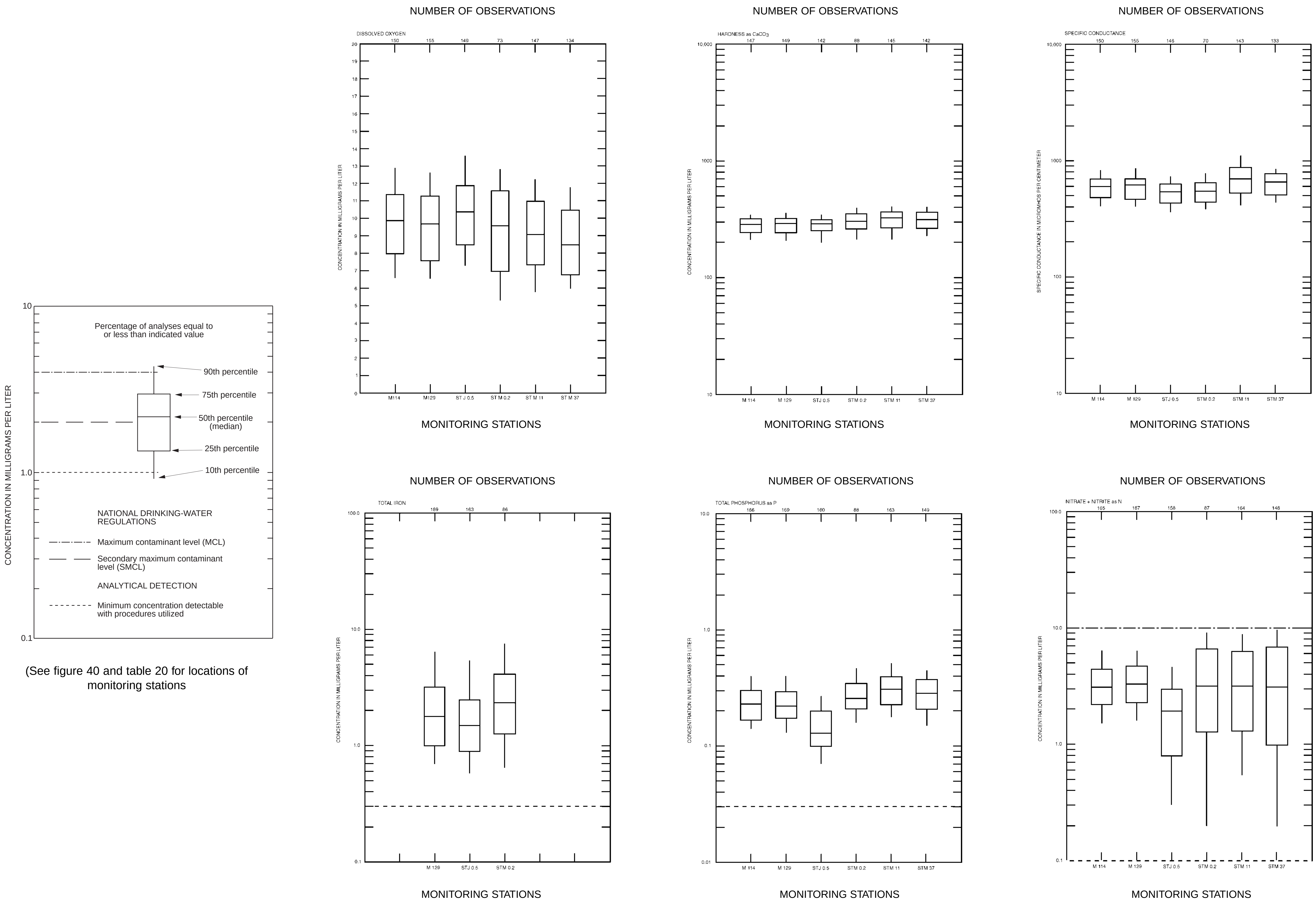


Figure 44. Median monthly nitrate+nitrite levels for selected monitoring stations



(See figure 40 and table 20 for locations of monitoring stations)

Figure 45. Statistical summary of selected water - quality constituents for selected stream monitoring stations

ful for providing a concise visual summary of a single data set, and for comparison among data sets. Box plots for water-quality data from selected monitoring stations are displayed in figure 45.

Variability in the levels of dissolved oxygen (DO) are observed among different streams in the Maumee River basin (figure 45). The highest median dissolved oxygen concentration (10.4 mg/L) is observed in water samples from the St. Joseph River just north of Fort Wayne (monitoring station STJ 0.5). Median DO values are also relatively high in samples collected at the other fixed monitoring stations in the basin ranging from 8.5 mg/L on the St. Marys River near the Indiana-Ohio border (STM 37) to 9.9 mg/L on the Maumee River near the Indiana-Ohio border (M114).

In addition to variability among streams, differences in median DO levels are observed along different reaches of the same stream. In the St. Marys River, there is a trend of increasing median DO levels as the river flows from near Ohio (STM 37) to the city of Fort Wayne, Indiana (STM 0.2). This apparent increase in median DO may reflect the water quality of contributing tributaries and/or ambient conditions within different stream reaches (see sidebar entitled **Factors affecting surface-water quality**).

Box plots of specific conductance levels in water samples from the selected monitoring stations are displayed in figure 45. The highest median specific conductance levels were observed in samples from the St. Marys River near Ft. Wayne. Differences in median specific conductance levels among and within streams may relate to factors which affect the dissolved solute concentrations of surface waters. Such factors include: local variations in the abundance of soluble minerals, differences in stream discharge, differences in the volume of base flow, and anthropogenic sources of dissolved constituents. Temperature may also have a profound affect on specific conductance. Therefore, the standard temperature for laboratory measurements is 25^{o} C.

Box plots of hardness levels in samples from the selected monitoring stations are displayed in figure 45. Medium hardness levels range from approximately 280 mg/L ($CaCo_3$ equivalent) in samples from the Maumee River near the Indiana-Ohio border (M 114) to 330 mg/L ($CaCo_3$ equivalent) from the St. Marys River near the south side of Ft. Wayne (STM 11). This range of hardness values would classify the waters from these stations as "very hard" in the hardness classification scale of Dufor and Becker (1964).

Dufor and Becker Hardness Scale:	
0-60 mg/L $CaCo_3$	soft water
61-120 mg/L $CaCo_3$	moderately hard water
121-180 mg/L $CaCo_3$	hard water
180 - mg/L $CaCo_3$	very hard water

Hardness is an important factor in surface-water quality because the minimum water-quality criterion for certain metals are functions of hardness. Applicable criteria outlined in the Indiana minimum water-quality requirements (327 IAC 2-1-6) include the *acute aquatic criterion* (AAC) and the *chronic aquatic criterion* (CAC). The present AACs and CACs for cadmium, chromium ($^{+}$3), copper, lead, nickel, silver, and zinc are not defined as whole number limits, but rather as exponential functions of hardness. The greater the hardness value, the higher the allowable concentrations of these pollutants. Therefore it is possible that different AACs and CACs would apply to different streams, or even distinct reaches of the same stream due to ambient hardness values.

The box plots for iron in samples from selected monitoring stations are displayed in figure 45. Median total iron levels are highest in samples from the St. Marys River with a median concentration of 2.35 mg/L. Median levels at all three selected monitoring stations exceed the secondary maximum contaminant level of 0.3 mg/L indicated by federal drinking water regulations. In fact 100 percent of the samples collected at all three stations exceed these requirements. However, natural concentrations of iron in aquatic systems vary widely, and these levels are probably not an indication of pollution from anthropogenic sources.

Box plots of median total phosphorus levels are displayed for monitoring stations within the Maumee River basin (figure 45). Levels range from a median concentration of 0.31 mg/L at STM 11 on the St. Marys River to 0.13 mg/L at STJ 0.5 on the St. Joseph River.

Phosphorous plays an important role in surface-water quality. In aquatic systems, phosphorus is often the limiting nutrient. The more phosphorus available for plant uptake, the higher the productivity of the aquatic system. Although not generally a serious problem in rivers and streams, high concentrations of phosphorus can have a profound effect on downstream lakes. Increased concentrations of phosphorus can lead to high productivity resulting in lake

Factors affecting surface-water quality

The efficient management of water resources requires knowledge of the naturally-occurring and human-induced processes that can influence the chemistry and quality of surface waters. Surface-water quality is influenced by numerous physical, chemical and biological factors which generally vary in time and with location. Describing the effects of these factors and variations in their influence is critical for developing strategies to protect water quality while permitting reasonable levels of water use (Hem, 1993).

Many of the current efforts to protect surface water resources emphasize controlling degradation associated with industry, agriculture, municipal waste disposal, flow diversion and other anthropogenic activities. Pollutants and waste products from these and other sources can enter surface-water systems through inadequately treated wastewater discharges, runoff, soil erosion, atmospheric deposition, chemical spills, and combined sewer overflows. Human activities that alter the flow characteristics or physical state of a stream, such as dam building, dredging or channelization may affect both water chemistry and sediment transport. Surface-water quality can also be influenced by irrigation and ground-water pumping (Hem, 1993).

Any effects human activities have on water quality depends on the types and volumes of pollutants released, and the extent of dilution that occurs in the receiving surface-water body. Adverse effects from human activities can also be minimized by proper wastewater treatment, adequate solid-waste disposal, erosion control, and other pollution control practices, Municipalities, industry, and other water users are required to protect the quality of surface-water resources they utilize. In many cases, specific obligations are defined in federal, state and local regulations. The effects of anthropogenic activities on water quality will also be modified by the hydrologic and chemical conditions of the receiving surface-water system.

Surface-water quality is also influenced by natural conditions in the environment. These natural conditions consist of the various physical, chemical and biological aspects of a watershed. Examples include climate, geology, soil type, vegetation and stream ecology. Natural influences on water quality must be quantified to accurately describe variations in water quality, and to discern possible human-induced effects on water resources.

In many temperate areas, variations in water quality over time can be correlated with seasonal changes in the prevailing meteorological conditions. Both the temperature and volume of precipitation influence processes such as the weathering of rocks. Alternating wet and dry seasons may thus promote seasonal variability in weathering reactions which produce soluble minerals. This variability in weathering may result in seasonal differences in the volume and types of ions transported into surface waters by direct runoff, creating seasonal variations in solute chemistry.

Seasonal trends in the concentrations of certain anthropogenic chemicals are sometimes observed for surface waters. Such trends are most commonly associated with chemicals used over wide areas of agricultural or urbanized watersheds and during certain months of the year. Such chemicals can be transported to streams by runoff after precipitation or snow-melting events. Examples of anthropogenic chemicals which could reach seasonal high levels in surface water include deicing salts for roads, nitrogen-based fertilizers, and pesticides.

Water temperature can be a particularly important parameter in water-quality studies. Many aquatic organisms can survive and function only within a particular range of water temperatures. These organisms may die, fail to reproduce, or suffer other adverse effects if the appropriate temperature range is exceeded. The effect of most concern, is probably the inverse relation between water temperature and dissolved oxygen (DO) levels. Most gases, including oxygen, become less soluble in water as temperature increases. It is therefore, possible to detect the lowest average DO levels of the year during summer and early fall when ambient water temperatures reach yearly high levels. Localized increases in water temperature and decreases in DO levels can also occur if effluents are discharged at much higher temperatures than water in the receiving stream.

Geologic conditions in a drainage basin can be a significant control on the solute chemistry of surface waters. The types and concentrations of dissolved ions in most waters are influenced by the chemical composition of minerals in contact with the water body. Soluble minerals in bedrock, soil or weathered geologic material may be the principle source of dissolved inorganic ions in unpolluted streams and lakes. Water quality will also be influenced by a variety of other geologic factors including the purity, solubility and crystal size of the minerals; rock texture and porosity; regional structure; and the presence or absence of fissures (Hem, 1985).

The aquatic biota, consisting of all plants, animals and microorganisms inhabiting a stream or lake, can be a significant influence on the chemistry of surface waters. Biological influences on water quality can result from the metabolic processes performed by organisms to maintain life functions and reproduction. These metabolic processes often influence the rates of chemical reactions. One example is the oxidation of organic matter. Certain microorganisms obtain metabolic energy from organic matter through cellular reactions involving oxygen. This organism-mediated process can promote rapid decomposition of organic matter in the aquatic environment, and may have significant effects on the dissolved oxygen levels of surface waters.

Aquatic organisms also remove and redistribute certain constituents from the aquatic environment. Essential nutrients including iron, phosphorous and nitrogen are removed to maintain metabolic functions and physical growth. Other constituents, such as calcium and silica, are extracted from the aquatic environment for the development of shells and skeletons. Absorption by aquatic organisms can significantly influence and even control the concentration of certain ions in unpolluted waters (Hem, 1985).

Photosynthesis by algae and aquatic plants often has noticeable effects on the chemistry of surface waters. During photosynthesis, dissolved carbon dioxide is removed from the water column. The removal of this gas can result in a noticeable increase in the pH of water in a lake or stream. Oxygen is a byproduct of the photosynthesis process, so increases in dissolved oxygen levels may result from photosynthetic activity. Because photosynthesis requires sunlight, plants can only sustain this process during daylight hours. In some surface water systems, this daily variation in photosynthetic activity results in discernible twenty-four hour cycles in pH and dissolved oxygen concentrations (Hem, 1985).

The types and numbers of aquatic plants and animals must also be considered in water-quality assessments, because the presence of certain organisms can seriously limit the utility of a lake or stream. Disease-causing bacteria, parasites or viruses can make a surface-water body unsafe for swimming, fishing, or use as a water supply. Algae and aquatic plants are normally vital parts of the aquatic ecosystem; however, excessive growth of these organisms due to eutrophication can cause serious water-quality problems. Severe problems can also result when non-indigenous species of plants and animals are introduced into a surface-water system.

eutrophication.

In studying these three river systems, the St. Joseph, St. Marys, and Maumee Rivers, one major trend is apparent. The St. Joseph River is of highest quality, and the St. Marys suffers the most from water quality degradation. The Maumee River, which has its beginning in the confluence of the St. Joseph and St. Marys rivers reflects an “average” water quality due in part to the mixing of the two rivers. The high quality of the St. Joseph River may reflect the degree of compliance of industry and sewage treatment plants with their NPDES permits, and the many water quality and soil conservation efforts that have taken place in the northern part of the basin. Water quality in the St. Joseph River is also enhanced by the large quantities of high-quality ground water that flow into the system.

Water quality and stream biology

Analyzing the types and numbers of organisms in a stream or lake can provide valuable information concerning water quality. Such biological assessments are based on the principle that organisms respond differently to varying degrees of pollution. Many organisms are considered pollution-intolerant because they are killed or otherwise reduced in number in response to pollutants. In contrast, pollution-tolerant organisms are more capable of withstanding the low dissolved-oxygen levels associated with pollution by organic matter. Other organisms are classified as *facultative* because they can live under a variety of water-quality conditions. Facultative species can usually survive some water-quality degradation and may be found in moderately polluted or *eutrophic* waters (Terrell and Perfetti, 1991).

Water pollution can affect both the total number of organisms and the species diversity. The aquatic community in an unpolluted aquatic system will generally be composed of numerous types of organisms, including pollution-tolerant, pollution-intolerant and facultative species. By contrast, turbid oxygen-deficient water bodies are often populated by only a few species of pollution tolerant organisms (although number of organisms present may be great). Surface waters affected by toxic substances may be characterized by both low numbers of organisms and a lack of biological diversity (Terrell and Perfetti, 1991).

In addition to water pollution, various naturally occurring factors, such as low flow, high suspended sediment levels, and inappropriate streambed material may also limit the types and numbers of organisms in a particular surface-water system. Therefore, any biological evaluation of water quality must include a survey of the quantity, quality, and range of aquatic habitats available.

Macroinvertebrates and water quality

Macroinvertebrates are an important tool for the evaluation of water quality in aquatic systems. They offer many advantages not possible with other organisms. Because they are *sessile* or have limited migration patterns, macroinvertebrates are good indicators of localized conditions, and are useful for assessing site specific impacts (U.S. Environmental Protection Agency, 1989). Macroinvertebrates also integrate the effects of short-term environmental variations. Most species have a complex life cycle of one year or more. Sensitive stages will respond quickly to stress, while the overall population will respond more slowly. In addition, sampling is relatively easy and inexpensive.

The Indiana Department of Environmental Management has been sampling *benthic* macroinvertebrates throughout the state using Rapid Bioassessment Protocols (RBPs) developed by the U.S. Environmental Protection Agency (1989). The success of the program relies on a proper habitat assessment which provides numerical evaluations of the physical and chemical characteristics of the stream. This assessment along with biological sampling and analysis which adheres to strict techniques to insure quality control, can provide a good appraisal of the ecological integrity of the stream.

The Indiana Department of Environmental Management’s macroinvertebrate program consists of two distinct phases following sampling. Phase I involves identification and enumeration of samples to the family taxonomic level, followed by preliminary analysis for site classification. Phase II is a complete identification of samples to the lowest possible *taxonomic* level. Rigorous analysis of this data will provide a database for use in regulatory enforcement and proper stream management.

Phase I has been completed for the Maumee River basin. Twenty-six sites were sampled representing the three major drainage systems in the basin, the St. Marys, St. Joseph, and Maumee Rivers. This provisional macroinvertebrate index of biotic integrity (mIBI) allows evaluated sites to be characterized as severely impaired, moderately impaired, slightly impaired, or non-impaired. Fifteen sites were evaluated in the St. Joseph River drainage. Eleven of these sites were classified as slightly impaired and four were considered moderately impaired. In the St. Marys River drainage, of the six sites sampled, one was ranked as non-impaired, four were slightly impaired, and one was moderately impaired. In the Maumee River drainage, two of five sites were considered slightly impaired, and three were moderately impaired.

Further analysis of the data in Phase II will allow more detailed information regarding the causes of impairment. It should be noted that the family level provisional mIBI can result in cold water effects giving a false positive for toxic effects (Indiana Department of Environmental Management, [1995]). Therefore, any cold water effects should be noted in the habitat analysis. Future analysis at lower taxonomic classifications should eliminate this problem. To date, family level taxonomic analysis has provided data adequately sensitive for the detection of gross biological perturbations in the aquatic community (Indiana Department of Environmental Management, [1995]).

Fish and water quality

Fish also play a major role in many studies designed to evaluate water quality. Unlike the macroinvertebrates, fish live for extended periods of time and assimilate the chemical, physical, and biological histories of the waters. Fish also represent a broad spectrum of community tolerances from very sensitive to highly tolerant, and they react to chemical, physical and biological degradation in characteristic response patterns. These and additional attributes make fish desirable components of biological assessments and monitoring programs.

Fish population sampling is one biological method used by the USEPA and the IDEM to assess Indiana water quality. In 1991, 77 [sic] sites in the Maumee River basin were sampled, and subsequently evaluated to develop an Index of Biotic Integrity (IBI) for the basin (Simon, 1994). The object of the study was to evaluate the biological integrity of the Maumee River drainage based on "least impacted" reference sites for establishing baseline conditions. "Pristine" areas were unavailable due to extensive modifications of the landscape involving urbanization, stream alteration, agriculture, and industrialization.

Biological community trends were evaluated using a basin approach within an *ecoregion* framework. Ecoregions (recognized by Homoya and others, 1985) were considered because distinct ecoregions have different expectations for biological communities. The Maumee River basin consists of parts of the Eastern Corn Belt Plain and the Huron-Erie Lake Plain ecoregions.

Habitat diversity has a major effect on the types of organisms that may be found, and must be considered in any evaluation of the biological community. A representative sample requires that the entire range of stream habitat including riffles, runs, pools, and extra-channel habitat be sampled, especially on large river systems (Simon, 1994). The Quality Habitat Evaluation Index takes into account these important attributes of the habitat and was used in the development of the IBI for the basin.

The IBI relies on multiple parameters, which are founded on biological community concepts, to evaluate complex systems. Quantitative criteria are established to determine water quality based on: species richness and composition, *trophic* and reproductive constituents, and fish abundance and condition. Separate *metrics* were developed for headwater streams (drainage areas less than 20 mi^2) and wadable rivers (drainage areas ranging from 20 to 1000 mi^2). Scoring criteria were also modified when sample size was small (Simon, 1994). Index of Biotic Integrity scores range from no fish to excellent (table 21).

The three major rivers in the Maumee basin and their tributaries were evaluated using the IBI (Simon, 1994). Overall trends were toward increasing biological integrity with increasing drainage area. Along the Maumee River, twenty-one sites were surveyed, and scores ranged from a low of no fish to good-excellent (score=55, one site). Numerically, the dominating species were *cyprinids*, *catostomids*, and *centrarchids*. Highest scores were obtained in the mainstem Maumee, while declining conditions occurred in the headwaters and minor tributaries.

Thirty-three sites were sampled on the St. Joseph River and its tributaries. This river, dominated by cyprinid, centrarchid, and catostomid species, contained the most diverse fish community sampled, having 58 recorded species. Tributaries of the St. Joseph River, including Fish Creek and Cedar Creek, are extremely diverse. However, there are problems with degradation of headwater streams. Scores throughout this system ranged from 14 to a high of 57 on the St. Joseph River at Johnny Appleseed park near Fort Wayne. Many unique species and three state threatened species are found in these waters.

Twenty-three sites were sampled along the St. Marys River and its tributaries. Forty-seven different species were collected, with fish numbers being dominated by centrarchid, cyprinid, and catostomid species. Index of Biotic Integrity scores ranged from very poor (12) to good (49). Scores were found to increase as drainage area increased. Headwaters of the St. Marys were degraded and greatly affected by high nutrient inputs from non-point sources (Simon, 1994). However, several species unique to the basin including many endangered and threatened species were found in these waters. Additional fish sampling information for streams and lakes within the basin may be found in appendix 10.

Table 21. Attributed of Index of Biotic Integrity (IBI) classification, total IBI scores, and integrity classis (from Karr and others, 1986)

Total IBI score	Integrity class	Attributes
58-60	Excellent	Comparable to the best situation without human disturbance; all regionally expected species for the habitat and stream size,including the most intorerant forms, are present with a full array of age (size) classes; balanced trophic structure.
48-52	Good	Species richness somewhat below expectation, especially due to loss of the most intolerant forms; some species are present with less than optimal abundance or size distributions; trophic structure shows some signs of stress.
40-44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g. increasing frequency of omnivores and other tolerant species); older age classes of top predators may be rare.
28-34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.
12-22	Very Poor	Few fish present, mostly introduced or tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.
	No fish	Repeated sampling finds no fish.

Lake quality

Sources of data

The Maumee River basin contains about 2500 acres (nearly four square miles) of open water in natural lakes and reservoirs. Many of these lakes are subject to point source and NPS pollution in the form of excess nutrients. This nutrient input results in increased lake productivity leading to accelerated *eutrophication*. Monitoring and management programs indicate the extent of eutrophication and prescribe measures to control nutrient inputs from point and non-point sources. The major state and federal programs are identified below.

In 1970 the Indiana State Board of Health (ISBH, currently the Indiana State Department of Health) began sampling public freshwater lakes and reservoirs for physical, chemical and biological data. The goal of the sampling, now coordinated by the IDEM, was to generate a database from which a classification system could be developed for comparing lake quality, and to establish a priority system for lake management and restoration.

The agency then developed an **Indiana Lake Classification System and Management Plan** in the mid-80s and assigned eutrophication indices to many of the lakes in the state. Staff defined and combined ten trophic parameters to derive a composite numerical eutrophication index. This index has been used extensively to evaluate lakes throughout Indiana (Indiana Department of Environmental Management, 1986a). Nine of the selected basin lakes and reservoirs in table 13 have been placed in the classification system and management plan.

On the federal level, the U.S. Environmental Protection Agency (USEPA) conducted a National Eutrophication Survey in 1973 and 1974 in which 27 Indiana lakes and reservoirs were sampled. Biological and chemical indicators were used to rank each lake according to trophic state. The USEPA also quantified major point and non-point sources. The results provided the first comprehensive nutrient loading survey for any of Indiana's lakes. Within the Maumee basin, Hamilton Lake in Steuben County was included in the survey; approximately 95 percent of the phosphorus entering the lake came from septic systems and other non-point sources (National Eutrophication Survey, 1976).

Through the Clean Lakes Program, which is administered cooperatively by the USEPA and the State of Indiana (IDEM), many of Indiana's lakes were resampled in recent years by the School of Public and Environmental Affairs (SPEA) at Indiana University. In Indiana, the program is administered cooperatively by the USEPA and IDEM. The Clean Lakes Program, which provides funds for studies and management activities on publicly-owned freshwater lakes, seeks to encourage participation at the local level to refine and implement plans outlined in the IDEM's Indiana Lake Classification System and Management Plan. The primary purpose of recent sampling activities was to detect apparent lake quality trends comparing trophic indes numbers determined in the mid-1970s with those determined more recently. Maumee basin lakes resampled at least once in recent years include: Ball, Cedarville, Clear, Hamilton, Indian, Long, and Round.

The IDEM also samples fish tissue and sediments to assess the extent of contamination by toxic and bioconcentrating substances in lakes and reservoirs having high recreational use or a potential for contamination. In the Maumee basin, fish tissues and sediments were sampled at the Cedarville Reservoir in 1988. In addition, the St. Joseph Reservoir has been sampled biennially since 1984. All of the fish samples taken contained *contaminant* levels below Food and Drug Administration *Action Levels*. No consumption advisories currently exist for lakes or reservoirs in the Maumee basin.

Sediment monitoring has become an increasingly important tool for detecting loading of pollutants in lakes and reservoirs. Many potential contaminants are easier to detect in sediments because the concentrations are greater than those normally found in the water column, and sediments are usually less mobile than water and can be used more reliably to locate sources of pollutants. Nutrients, many organic compounds, and heavy metals can become tightly bound to sediments. Once released, these particles are made available to the biological community through physical or chemical processes. Remedial action projects may include the removal of these contaminated sediments. In the Maumee basin, the St. Joseph Reservoir was the only major water body monitored by IDEM.

Assessment of lake quality

The Indiana Trophic State Index, developed in accordance with The Indiana Lake Classification System dictated by Section 303(e) of Public Law 92-500, divides lakes into four distinct categories, Class I through Class IV. *Eutrophy* points are assigned for different chemical, physical and biological parameters. Scores range from 0-75 with the lower scores indicating higher quality.

Class I (0-25 eutrophy points) includes lakes of highest quality. These lakes often exhibit *oligotrophic* or *mesotrophic* characteristics. Class II lakes (26-50 eutrophy points) are generally productive lakes that often support large populations of macrophytes and algae, but lake uses are seldom impaired. Class III lakes (51-75 eutrophy points) are lakes of poor quality. These lakes often have extensive populations of macrophytes and algae that impair lake uses. Blue-green algae are dominant and often form nuisance blooms during most summer months. Oxygen depletion can result during hot summers and under ice cover in the winter resulting in fish kills. These lakes are generally highly influenced by anthropogenic activities and have an accelerated rate of *senescence*. Class IV lakes consist of remnant and oxbow lakes. They are generally small, shallow water bodies in an advanced state of senescence, and cannot realistically be rated or compared using the eutrophication index.

Recent data are available for nine major lakes and reservoirs in the Maumee River basin. These lakes do not range widely in water-quality characteristics, lake *morphometry*, and management needs (appendix 11). Nearly all the lakes are classified as Class I or Class II and rarely have water-quality problems that impair attainable lake uses. The only remaining lake (Cedar Lake) classifies as highly productive (Class III). None of the lakes in the basin included in the Indiana Lake Classification System were assigned Class IV status. Although some Class IV lakes may exist in the basin, these may have been mapped as wetlands rather than lakes due to their morphology or hydraulic regime.

Improvements in water quality for many lakes within Indiana are evident between the early 1970s and mid 1980s. These trends are due to improvements in the treatment of point sources of pollution such as sewage treatment facilities and industrial discharges. Because phosphorus is often the limiting nutrient in aquatic systems and may lead to lake eutrophication, the situation may have been improved by the phosphorus detergent ban initiated in the early 1970s. The new challenge is the treatment of non-point sources of pollution. Much work has been done in this area in the past few years, and the results are apparent in figure 46. Figure 46 illustrates trends in water quality of five natural lakes and one reservoir in the Maumee River basin.

The most dramatic improvement is evident in Cedarville Reservoir. It dropped 37 eutrophy points and moved from a Class III to Class II lake. Cedarville Reservoir is a small, shallow impoundment that has a large contributing drainage area. Consequently, it has a short *hydraulic residence time* and responds very quickly to any changes in the water quality of upstream reaches. In recent years many programs have been adopted in the area to address non-point source pollution. Conservation tillage, land taken out of farm production and placed in the Conservation Reserve Program, and other *best management practices* may have contributed to decreased sediment and nutrient loads to this reservoir leading to increased water quality.

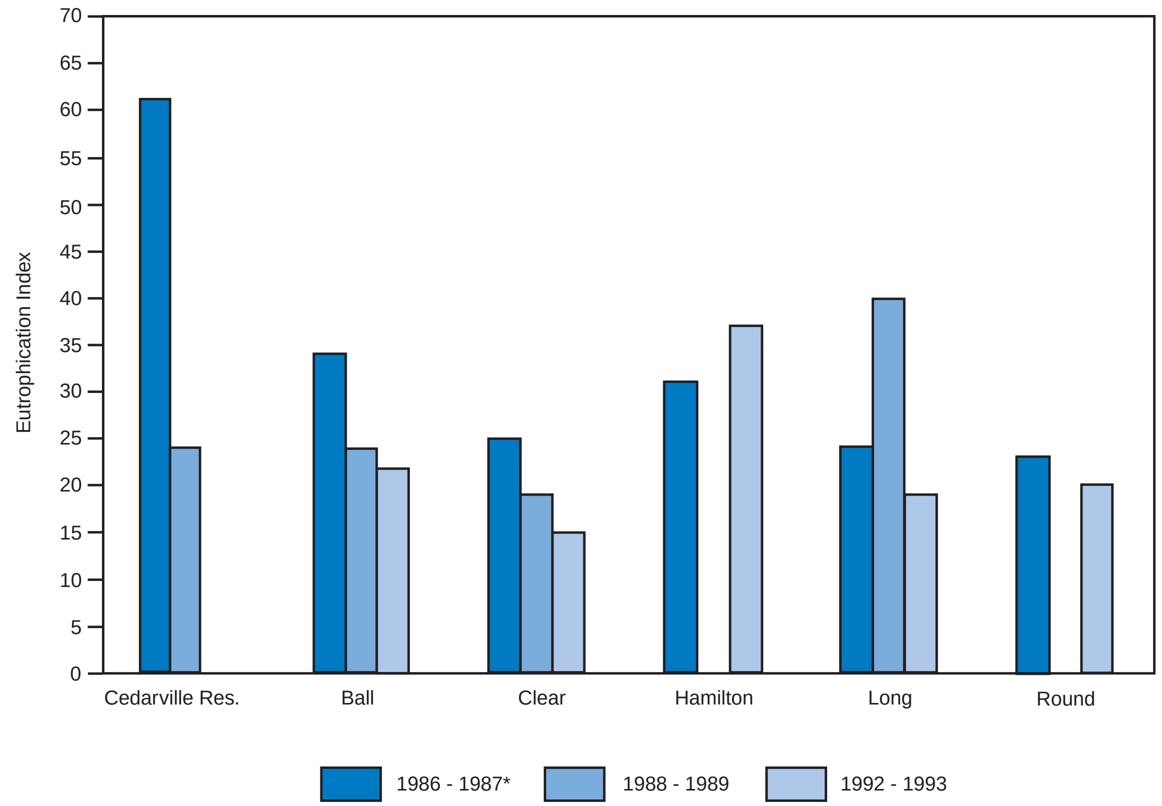
Ball, Clear, Long and Round Lakes all seem to indicate an overall improvement in water quality. Ball Lake moved from a Class II to a Class I lake. Clear and Long lakes, while remaining in the same class, had a decrease in eutrophy points from 1986 to 1992. The dramatic increase in eutrophy points for Long Lake in 1988 may be due to sampling during an algal bloom and may not be indicative of the lake quality throughout the year. Hamilton Lake may be declining in water quality, but the difference of only six eutrophy points between 1986 and 1992 is probably insignificant. It is evident that continued improvement of point sources of pollution and great gains in the area of non-point source pollution control are resulting in an overall improvement of lake quality throughout the Maumee River basin.

Water-quality management efforts in the Maumee River basin

In the past, efforts concerning water quality were focused on the effects of point source pollution. Progress in this area has been exceptional with only one percent of our municipal point source discharges being released without treatment (Baker, 1992). In recent years, much attention has been directed to the treatment of non-point source (NPS) pollution. As illustrated by figure 47, NPS pollution comprises a major portion of the total pollution sources for US rivers and lakes (U.S. Environmental Protection Agency, 1986e). In response, many studies have been conducted on possible solutions to the problem of NPS pollution. Three of these studies involved specific watersheds within the Maumee River basin, and the fourth study involved the entire basin.

The Black Creek watershed project

In 1972, funded under provisions of the 1969 Water Quality Act, a study was begun to determine how non-point source pollution might be controlled in a typical agricultural watershed, the Black Creek watershed in Allen County, IN (Lake and Morrison, 1977a). The agencies involved included the Allen County Soil and Water Conservation District, the U.S. Department of



Numbers are based on information provided by the Department of Environmental Management 305 (b) reports

* May reflect some data collected in the mid-70s

Figure 46. Lake quality (1986-1992)

Agriculture Soil Conservation District, Purdue University, University of Illinois, and the U.S. Environmental Protection Agency.

The 12,038 acre Black Creek watershed was chosen because preliminary research indicated that it was a good representation of the Maumee River basin in terms of soils, land use, conservation needs, and socioeconomic conditions. Black Creek is a major tributary of the Maumee River. It flows from its source near the town of Harlan in Allen County to its confluence with the Maumee River and ultimately drains into Lake Erie.

The concept behind this study was to use it as a model to determine if techniques demonstrated in the Black Creek watershed, if applied throughout the Maumee Basin, would improve water quality in the Maumee River and Lake Erie (Lake and Morrison, 1977b). Several investigations occurred in the Black Creek watershed including: water quality sampling and analysis utilizing grab samples as well as a limited number of automated samplers, demonstrations of conservation tillage techniques, fish and other biological studies to gain an understanding of the aquatic community dynamics, stream bank stabilization studies, rainfall simulation studies to determine erodibility of different soil associations and the effects of conservation tillage practices, and other related investigations. Through these diverse studies, baseline information was obtained and monitoring took place to determine the impact of different *best management practices* on water quality and the aquatic community. Several conclusions were drawn from the study, and a few main points are summarized below.

The water-quality parameter of greatest interest was

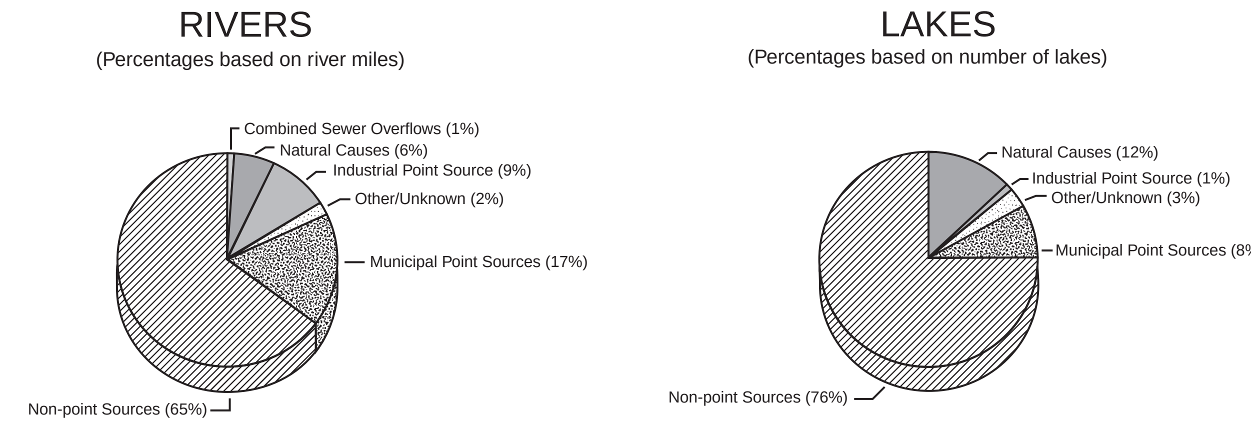


Figure 47. Source of pollution in U.S. rivers and lakes (U.S. Environmental Protection Agency, 1986e)

phosphorus. Phosphorus is often the limiting nutrient in aquatic systems, and control of this nutrient was seen as essential for the health of Lake Erie. Most phosphorus, and other NPS pollutants, could be correlated with sediments. Therefore, sediment control became the main focus. Nitrogen was the one exception. Control of this nutrient could be achieved using nitrification inhibitors, proper timing of nitrogen fertilizer application, and reducing the amount of nitrogen applied.

The key component in soil *erosion* is raindrop impact. Any practice which increases ground cover is beneficial. Conservation tillage is often an effective and economically viable solution. Erosion depends on storm intensity; and the effectiveness of surface cover depends on the amount and quality of the cover. However, with increasing storm intensity, slope angle and length become more critical factors. At the time of the study, the bulk of the sediment entering Black Creek was the result of a few intense storms.

The main benefits gained from this program included: 1) a reduction in sediment loading which resulted in an increase in water quality of the receiving stream, 2) increased scientific knowledge concerning watershed NPS pollution controls, and 3) development of strategies for working with the public on comprehensive watershed management plans. Researchers discovered that involving the public and providing them with information was critical for program success. It was also found that a program with sufficient incentives, technical assistance, and cooperation with all individuals involved can result in land treatment that has a significant effect on water quality.

Another benefit derived from the study was the development of the ANSWERS (Aerial Nonpoint Source Watershed Evaluation Response Simulator) computer model. This model was designed to predict water movement, and thus sediment transport throughout the basin. It was possible, through use of the program, to gain insight into the effects different best management practices would have on the basin. Through the use of ANSWERS, it was determined that the majority of soil erosion was from only 15 percent of the land area. Treatment of these “hot spots” would be more beneficial and cost effective than attempting to treat the entire watershed (Lake, oral commun., 1995).

The Fish Creek watershed project

Fish Creek is a major tributary of the St. Joseph River. It flows from its source in eastern Steuben County to its confluence with the St. Joseph near Edgerton, Ohio. Attention was first drawn to Fish Creek when the White Cat’s Paw Pearlymussel, a federally endangered species, was discovered in the river in DeKalb County. Since the project’s inception, two other endangered mussel species have been found, the Northern Riffleshell, and the Clubshell.

In 1992, the USEPA and IDEM funded $98,340 for the Fish Creek project. Project partners included the U. S. Fish and Wildlife Service (USFWS), Steuben, DeKalb, and Williams County Soil and Water

Conservation Districts, Indiana and Ohio Departments of Natural Resources, Maumee River Basin Commission (MRBC), IDEM, U.S. Geological Survey, Purdue University, the Soil Conservation Service, Agricultural Stabilization and Conservation Service, and The Nature Conservancy (TNC).

In general, the water quality of this area is very good with the exception of some areas exhibiting unacceptable levels of bacteria. The goal is to maintain, and if possible, improve the riverine habitat which is home to the most diverse assemblage of fresh water mussels in the Great Lakes Basin. Thirty-one different mussel species inhabit the river home along with 43 species of fish (Clemens, oral commun., 1994).

The plan utilizes several strategies of land protection and treatment.

1) Agricultural practices. Money is provided for incentives to promote water quality on agricultural land. Soil erosion is the greatest threat to the water quality of Fish Creek, so the majority of the projects are designed to alleviate this problem. The Hamilton Lake Watershed Land Treatment Project and The Maumee River Basin Commission filter strip program have been responsible for the installation of grass filter strips along approximately seven miles of Fish Creek (Fish Creek Project, 1995b). Twenty pieces of no-till farming equipment have been purchased through various cost share programs (Smith, 1994), and since the project's inception, no-till corn has doubled, and no-till soybeans have increased by 15 percent. Presently no-till is used to plant over 50 percent of the row crops in the Fish Creek watershed (Fish Creek Project, 1995b). For estimated costs and yields of no-till versus conventional farming practices, see appendix 12.

2) Wetland restoration. The USFWS has restored a total of 15 acres in three separate areas along Fish Creek. "The Partners for Wildlife Program, administered by the USFWS provides financial and technical assistance to restore drained wetland habitat on private property. Since 1988, the [US]FWS has restored over 700 wetlands in Indiana totaling more than 3,500 acres. Projects in Steuben and DeKalb counties alone account for approximately 30 percent of the restored wetlands under this program" (Fish Creek Project, 1995a).

3) Restoration of *riparian* corridor. Money is provided to landowners to plant trees along the creek. As of spring, 1996, 200 acres of trees have been planted (Clemens, oral commun., 1996). The wooded corridor is one of the main reasons Fish Creek has such high water quality. It provides a buffer from runoff and supports creek bank stabilization. In addition, it provides shade for the stream resulting in decreased water temperatures and a corresponding increase in the waters ability to hold oxygen. Typical trees planted along the creek include black walnut, white, red and swamp oak, black cherry, white and green ash, tulip, and red and silver maple.

4) Point source abatement. Funding was approved by the USEPA and the Cole Foundation to convert Hamilton's Waste Water Treatment Plant from a chlorine system to an Ultra Violet disinfection system. The facility went on line in August of 1995.

5) Land acquisition. Erodible farm ground for reforestation and old growth forest has been purchased by different environmental organizations for permanent preservation. One purchase includes 275 acres along Fish Creek known as Douglas Woods. This land consists of 200 acres of forest and wetlands, and 75 acres of tillable land (Indiana Department of Environmental Management, [1995]).

6) The Conservation Reserve Program. The Conservation Reserve Program (CRP) initiated under the 1985 Farm Bill promotes financial incentives for removing land from production for a period of at least 10 years. Upper Fish Creek which consists mostly of marginal farm land has 18,000 of 70,000 acres enrolled in the CRP. Eighty percent of these land owners plan to place their land back into production if the program is discontinued. However, most plan to use some form of conservation tillage. Of this 80 percent, nearly 60 percent plan to utilize a crop rotation program to meet conservation goals, 34 percent plan to incorporate a crop residue management plan, 30 percent plan to install grassed waterways, and only 15 percent do not presently have any conservation practices planned (Lovejoy, 1995).

7) Project monitoring, research, and education. Monitoring, research, and education continue as the project moves forward. These aspects of the project are being addressed in a variety of ways including: a) identification of critical areas in the watershed, b) documentation of landuse, c) water quality monitoring through the use of macroinvertebrate, amphibian, reptile, fish and mussel surveys, d) watershed mapping and modeling, and e) continued contact with local land owners to explain the uniqueness of Fish Creek and the need to preserve this resource.

Unfortunately much of the water-quality data has not been released. As a result of a 1992 diesel fuel spill in Fish Creek, most of the data is being held until litigation is complete. Of the limited data that has been released, studies indicate that fish populations in Fish Creek have not fully recovered from the spill (Ohio EPA, 1995).

The Cedar Creek watershed project

Cedar Creek originates at Cedar Lake in the northwest portion of the Maumee River basin. It drains approximately 174,780 acres before joining with the St. Joseph River just downstream of the Cedarville Reservoir. Cedar Creek is designated as an outstanding state resource from river mile 13.7 to its confluence with the St. Joseph River (327 IAC 2-1-2), and represents several natural communities, many of which are rare in that part of Indiana. Primary communities are forested, but include some prairie, fen, bog, marsh, and lake communities (Homoya and others, 1985).

The headwaters of Cedar Creek have historically been ditched and dredged to increase agricultural land and enhance drainage. These activities increase the land's susceptibility to erosion. According to the Environmental Law Institute (1995), the resulting "sediment deposition in the riparian zone has adversely affected the productivity of stream-side wetlands and woodlands, and caused an overall decline in the productivity of the fisheries...". Cedar Creek also has problems with bacterial contamination. This pollution may originate from a variety of sources including agricultural activities and inadequately performing septic systems.

Several programs have been initiated to restore portions of the Cedar Creek watershed. The U.S. Fish and Wildlife Service (USFWS) has been working to restore ditched and tile-drained kettle wetlands and forested riparian wetlands through the Partners for Wildlife Program. The IDNR designated approximately 350 acres of riparian corridor as a Scenic River. This area receives protection and some maintenance through the IDNR Division of Nature Preserves and some private organizations. In addition, the Allen and DeKalb County Soil and Water Conservation Districts are working with the USFWS to reestablish prairie in the Cedar Creek watershed. This project scheduled over 100 acres of prairie restoration for 20 different landowners in 1995.

Another important effort was the establishment of the Cedar Creek Watershed Alliance. The Alliance, which held its first meeting in September of 1994, is a diverse group of agencies, conservation organizations, landowners, and city of Fort Wayne drinking water interests. The group originally met under the auspices of the Maumee River Basin Commission, but eventually the commission allowed local interests to assume the leadership role. The Alliance is not incorporated or formalized (Seng, written commun., 1996).

The Alliance is working on a watershed management plan which will define its goals and contain vital statistics such as demographics, economics, geology, hydrology, and others aspects of the basin. In order to get baseline information on water quality, the Alliance received Clean Water Act Funds to finance water-quality sampling along Cedar Creek and several of it tributaries. Local people are being encouraged to help conduct the monitoring. In addition, members are working with landowners to encourage participation in the Conservation Reserve Program, the use of conservation tillage, and implementation of other best management practices.

Some of the strengths of the project include: 1) the Coordinated Resource Management training received by many of the people involved, 2) support from the Soil and Water Conservation Districts and the Natural Resource Conservation Service, 3) the ability to parlay local interest and involvement into grant money, and 4) the ability to focus attention on the project due to its important impact on the drinking water resources of Fort Wayne (Seng, written commun., 1996). However, there is still a need to get other stakeholders involved to insure that all interested parties are represented. New people and organizations are always welcome provided they agree to follow the guidelines outlined in the Coordinated Resource Management training.

The Northeast Indiana Conservation Tillage Demonstration Project

The Northeast Indiana Conservation Tillage Demonstration Project (NEICT) was one of the Tri-State Tillage Demonstration Projects funded by the Great Lakes National Program Office of the U.S. Environmental Protection Agency in May of 1981. Included in NEICT was the area which comprises the

Maumee River basin in Indiana. The main objectives of the program were to provide specialized equipment and technical assistance for conservation tillage practices; overcome any difficulties in establishing the new practices; and ultimately to evaluate the effectiveness of conservation tillage in regard to crop yield, acceptance of the practices by farmers, and the potential for water quality improvement (Lake, 1991). Good success with conservation tillage practices has been realized for almost all soil types in the basin except for mucky soils (Clemens, oral commun., 1995).

Demonstrations of no-till and ridge-till technology were conducted throughout the basin, and research on conservation tillage was performed at Maumee Park on the banks of the Maumee River near Fort Wayne from 1982 through 1986. After 1986, limited demonstrations of conservation tillage in Maumee Park were conducted until 1995. Studies within the park investigated different conservation tillage practices and evaluated several hybrids of corn and soybeans. In addition, because of the large Amish communities in the basin, the special needs of draft horse-powered farms were addressed. Appendix 12 summarizes recent crop yields and economic evaluations of conventional tillage and conservation tillage practices.

As previously discussed, conservation tillage practices can help reduce soil erosion. Although the Indiana Department of Natural Resources (1984) reports low soil losses at about 2.0 to 4.9 tons/acre/year from the Maumee River basin, the U.S. Environmental Protection Agency reports high phosphorus losses of more than 2 kg/hectare/year. Soils within the Maumee basin are primarily the product of Wisconsin glacial drift (see **Physical Environment** chapter, section entitled **soils**) and contain high concentrations of clay. The high correlation between phosphorus content and clay content indicates that the fine textured soils in the Maumee basin contribute to high phosphorus loads in the Maumee River (Lake, 1991). To help reduce erosion of these soils, increasing the amount or organic matter in the soil, and increasing soil cover were main objectives of the program.

The potential for soil erosion has been evaluated throughout the state by the Soil Conservation Service and Water Conservation Committee (Indiana Department of Natural Resources, 1980). Estimates of erodibility are based on soil associations. The four categories of soil erosion potential are low, medium, high, and very high. Erodibility in the Maumee River basin ranges from low to medium. Associations with low erodibility are generally deep and very poorly to somewhat drained soils on nearly level and depressional land. Soils with medium erosion potential are deep, somewhat poorly drained, and are found on level to slightly sloping topography.

Soils with medium erosion potential in the Maumee basin are concentrated in Steuben County, the northwest corner of DeKalb County, the central portion of Allen County, and the southwest corner of Adams County. Most other soil associations have a low erodibility rating.