BASIN DESCRIPTIONS AND FLOW CHARACTERISTICS OF OHIO STREAMS

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By Michael C. Schiefer, Ohio Department of Natural Resources,
Division of Water

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Robert Taft, Governor

Samuel Speck, Director

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By Michael C. Schiefer

ABSTRACT

Basin descriptions were prepared to integrate information about basin characteristics and identify factors affecting regimen of flow of Ohio streams. Characteristics of flow at stream gaging stations were studied and interpreted in relation to specific basin characteristics. Ohio weather and climate, physiology, geology, soils, and development are described generally to provide geographic context.

Descriptions of all drainage basins in Ohio and basin maps showing outlines of basins and location of streams are provided. Selected streamflow characteristics useful for characterizing regimen of flow at gaging stations are tabulated for 250 stream gaging stations. The selected flow characteristics include: mean annual runoff, mean base-flow index, flow equaled or exceeded 10, 50, and 90 percent of the time, average 7-day, 2-year low flow, and 2-year recurrence interval flood-peak discharge.

Regulation from water development and hydro-modifications associated with land development affects flows to varying degree at many stream gaging stations in Ohio. Regulation and hydro-modification may significantly affect certain flow characteristics but not others. The range of observed flow characteristics largely unaffected by regulation and hydro-modification are generally as follows: mean annual runoff, 10.1 to 21.2 inches; mean base-flow index, 15 to 85 percent; flow equaled or exceeded 10, 50, and 90 percent of the time, 1.7 to 4.3 cfs per sq. mi., 0.1 to 0.8 cfs per sq. mi., and 0 to 0.4 cfs per sq. mi.; average 7-day, 2-year low-flow indices, 0 to 0.4; and 2-year recurrence interval flood-peak discharge, 6.6 to 280 cubic feet per second per square mile of drainage area. Major factors other than size of drainage area that affect natural regimen of flow include: weather and climate, topographic relief, stream gradients, basin storage, surficial glacial deposits, soils, and land cover.

INTRODUCTION

Ohio is located in an area of the north temperate climatic zone where annual precipitation generates ample runoff to sustain an abundance of perennial stream systems. These stream systems perform essential hydrologic functions and provide many benefits in the process of draining water from the land.

Streams in Ohio drain a wide variety of landscapes that give them differing flow characteristics. Protection and wise use of these stream resources requires information about their drainage basins and characteristics of flow. This information is multi-disciplinary and generally involves cumbersome amounts of data and statistics. Basin descriptions in narrative form help organize the relevant information and provide useful perspective for interpretation of flow data.

Because of the many factors and complex relationships that determine runoff from drainage basins, long-term records of streamflow are needed to characterize flows. Fortunately, many long-term records have been collected at gaging stations throughout Ohio, and considerable data exist regarding the streams and their drainage basins.

Purpose and Scope

This bulletin gives descriptions of drainage basins and characteristics of flow for Ohio streams. Descriptions are presented for all major drainage basins in Ohio where systematic streamflow records have been collected. The descriptions are brief, focusing primarily on factors affecting regimen of flow and not intended to be exhaustive. Factors determining regimens of flow are discussed generally for the state as a whole and specifically for each drainage basin. Streamflows are characterized by use of selected flow statistics that provide information about: mean annual runoff, base flows, flow duration, and frequency of flow events. Comparisons are drawn between streams, and probable causes of variations in flow characteristics are identified.

The information presented in this bulletin is intended to provide background material for detailed studies and general understanding of Ohio streams. Reference is made to many pertinent new publications that have become available in recent years as well as to the classic works. This work is completed pursuant to Chapter 1521 of the Ohio Revised Code that gives the Division of Water responsibility for inventorying the water resources of the state on a watershed basis.

Previous Studies

Brief basin descriptions prefaced tables of mean annual and monthly flow data in Ohio State University, Engineering Experiment Station, Bulletin 127, Ohio Stream Flow, Part II, 1947. Expanded basin descriptions accompanied flow-duration tables in Division of Water, Bulletin 10, Ohio Stream-Flow Characteristics, Part I, Flow Duration, 1949.

Basin descriptions in Bulletin 10 were revised and re-published with updated flow-duration tables in Division of Water, Bulletin 31, Flow Duration of Ohio Streams, 1959.

Flow-duration data have been updated in: Division of Water, Bulletin 42, Flow Duration of Ohio Streams, 1968; U.S. Geological Survey, Open File Report 81-1195, Low-Flow Characteristics of Ohio Streams, 1981; and U.S. Geological Survey, Water Resources Investigations Report 01-4140, Low-Flow Characteristics of Streams in Ohio through Water Year 1997. No basin descriptions are given in this latter series of reports.

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FACTORS DETERMINING REGIMEN OF FLOW

The regimen of flow in a stream depends on two groups of factors: 1) the weather or short-term climatic factors such as precipitation and temperature that vary from day to day as well as the climate or long-term average climatic factors and 2) basin characteristics such as drainage area, topography, geology, soils, land use, and water development (Cross, 1959). The following overview of climatic factors and basin characteristics as they exist in Ohio provides the pertinent geographic context for description of basins and characteristics of flow.

Weather and Climate

The climate of Ohio is classified as humid continental, warm summer type according to a climate classification system widely used in the United States (Noble, 1975). However, the state tends to encompass more than one type of climate because of variations in long-term average climatic factors within its borders, and its location at the transitional boundary between climate types. Variations in long-term average climatic factors contribute to differences in regimen of flow of Ohio streams.

Ohio is situated in the region of the polar westerlies of middle latitude where prevailing winds are from the west, southwest, and northwest. The interior location that the state occupies on the continent is subject to the influence of both polar air and tropical maritime air masses. Alternation of low- and high-pressure air masses accompanying passage of cyclones and anticyclones produces irregularly spaced changes in the weather (Noble, 1975).

The climate is characterized by pronounced seasonal changes in temperature. Mean monthly temperatures range from a low of 29 degrees Fahrenheit in January to a high of 74 degrees Fahrenheit in July (Sanderson, 1950). Seasonal changes in temperature and other climatic factors force a cycle of vegetative growth and dormancy characteristic of the north temperate climatic zone. Evapotranspiration from plant and soil surfaces is relatively high in summer and early fall and relatively low in winter and early spring. The variable amounts of evapotranspiration in combination with fairly uniform amounts of precipitation throughout the year give rise to the regimen of average monthly streamflow typical of Ohio streams, that is, relatively high flows in winter and early spring and relatively low flows in summer and early fall.

Annual water loss due to evapotranspiration correlates closely with mean annual temperature in Ohio. Mean annual temperature for the state as a whole is about 52 degrees Fahrenheit. The southern part of the state has a mean annual temperature of about 56 degrees Fahrenheit while the northern part has a mean annual temperature of about 48 degrees Fahrenheit (Harstine, 1991). The regular latitudinal progression of decreasing mean annual temperature is disrupted in the northern part of the state by the presence of Lake Erie that has a moderating effect on temperatures. Variations in mean annual water loss across Ohio contributes to the variation in mean annual flows of Ohio streams, but to lesser extent than that due to variations in mean annual precipitation.

Ohio lies along the track of cyclonic systems that move across mid-continent from west to east. The vast majority of moisture producing precipitation in Ohio derives from cyclones that form in the lee of the Rocky Mountains. These cyclones track northeastward toward the Great Lakes Region and Ohio River Valley bringing tropical maritime air from the Gulf of Mexico. The cyclonic systems usually track farther north in summer than in winter. In summer, tropical maritime and continental tropical maritime air masses dominate producing high temperatures and frequently high humidity. In winter, polar continental air masses that produce cold dry weather dominate with intermittent, brief interjections of tropical maritime air bringing wet warmer weather (Noble, 1975).

Cyclonic systems normally bring moderate amounts of precipitation to Ohio. Excessive precipitation and significant flooding occur in localized areas almost ever year but only occasionally over extensive areas (Sanderson, 1950). Droughts of relatively short duration are not uncommon, but prolonged deficiency of precipitation leading to severe drought is a relatively rare occurrence in Ohio. Droughts and floods affect the state differentially in time of occurrence and areal coverage.

Frontal lifting of air masses associated with passage of cyclones is the primary mechanism triggering precipitation in Ohio. Normal passage of cyclonic depressions is supplemented with convectional precipitation in summer making it the wettest season of the year. The convectional precipitation is typically produced by thunderstorms moving as squall lines ahead of cold fronts. Thunderstorms are more prevalent in the southwestern part of the state than elsewhere giving rise to more annual precipitation and frequent flash floods from high intensity rainfall (Sanderson, 1950). More stable air masses in fall make it the driest season in most parts of the state. Nevertheless, mean annual precipitation is distributed more or less uniformly throughout the year (Noble, 1975).

Average annual precipitation across Ohio ranges from about 30 inches to 44 inches (Harstine, 1991). Annual precipitation in any given year can vary as much as 15 inches from normal, but departures from normal in most years are generally much less (Noble, 1975).

Average annual precipitation is lowest in the northwestern part of the state. The area between Toledo and Sandusky at the western end of Lake Erie receives the least amount of precipitation. The area also receives the lowest number of thunderstorms due to the cooling and stabilizing effect of Lake Erie on approaching air masses. Areas with the highest average annual precipitation include parts of southern and southwestern Ohio and areas east of Cleveland where significant amounts fall as snow in winter. Lake effect precipitation and orographic lifting are largely responsible for the latter (Noble, 1975).

Variations in mean annual precipitation across the state cause similar variation in mean annual flow of Ohio streams. The effects of variation in mean annual precipitation on streamflows are partly offset by the opposing but generally smaller effects of variation in evapotranspiration.

Basin Characteristics

Variations in climate across Ohio are relatively minor but must be considered along with basin characteristics when comparing regimens of flow in streams. Some streamflow parameters can be normalized by use of ratios to mean annual flow to compensate for climatic differences; but ideally, comparisons should be made between streams with the same climate so that differences in regimen of flow are due entirely to differences in basin characteristics. The complex influences that basin characteristics have on streams in Ohio can be approached constructively from the multiple perspectives of: physiography, geology, soils, land use, and water development.

Physiography. Physiographic classifications provide a key to the general topography and character of the land surface in Ohio and therefore serve as a logical starting point for description of drainage basins. Detailed physiographic classifications for Ohio are mapped and described by Brockman (1996). The physiographic regions in Ohio are shown in figure 1.

Ohio overlaps parts of three physiographic provinces in the United States. Most of the western half of the state is in the Central Lowland Province of the Interior Plains Division while nearly all the eastern half is in the Appalachian Plateaus Province of the Appalachian Highlands Division. The Bluegrass Section of the Interior Low Plateau Province of the Interior Plains Division extends across the Ohio River marginally into southwestern Ohio.

The Central Lowland Province in Ohio is separated from the Appalachian Plateaus Province by a transitional boundary that coincides with the Allegheny Escarpment of erosion resistant sandstones. Sandstones and shales are at or near the surface near the boundary while limestones, dolomites and shales underlie more distant land in the Central Lowland. The rocks in the Central Lowland part of the state are overlain with glacial tills and lacustrine deposits that form a relatively youthful plain only slightly scarred by streams. Two physiographic sections of the Central Lowland Province are represented in Ohio, the Till Plains and the Huron-Erie Lake Plain (Brockman, 1996).

About one-third of Ohio is in the Till Plains Section of the Central Lowland Province. This land is gently rolling, for the most part, and covered with glacial deposits of moderate (100-200 feet) to moderately low (25-60 feet) relief. Moderately high relief (250 feet) exists in the Bellefontaine Upland of the Till Plains. Areas where morainal belts cross the Till Plains are undulating while intervening areas of ground moraine tend to be level. Transitional land bordering the Appalachian Plateaus is more rolling.

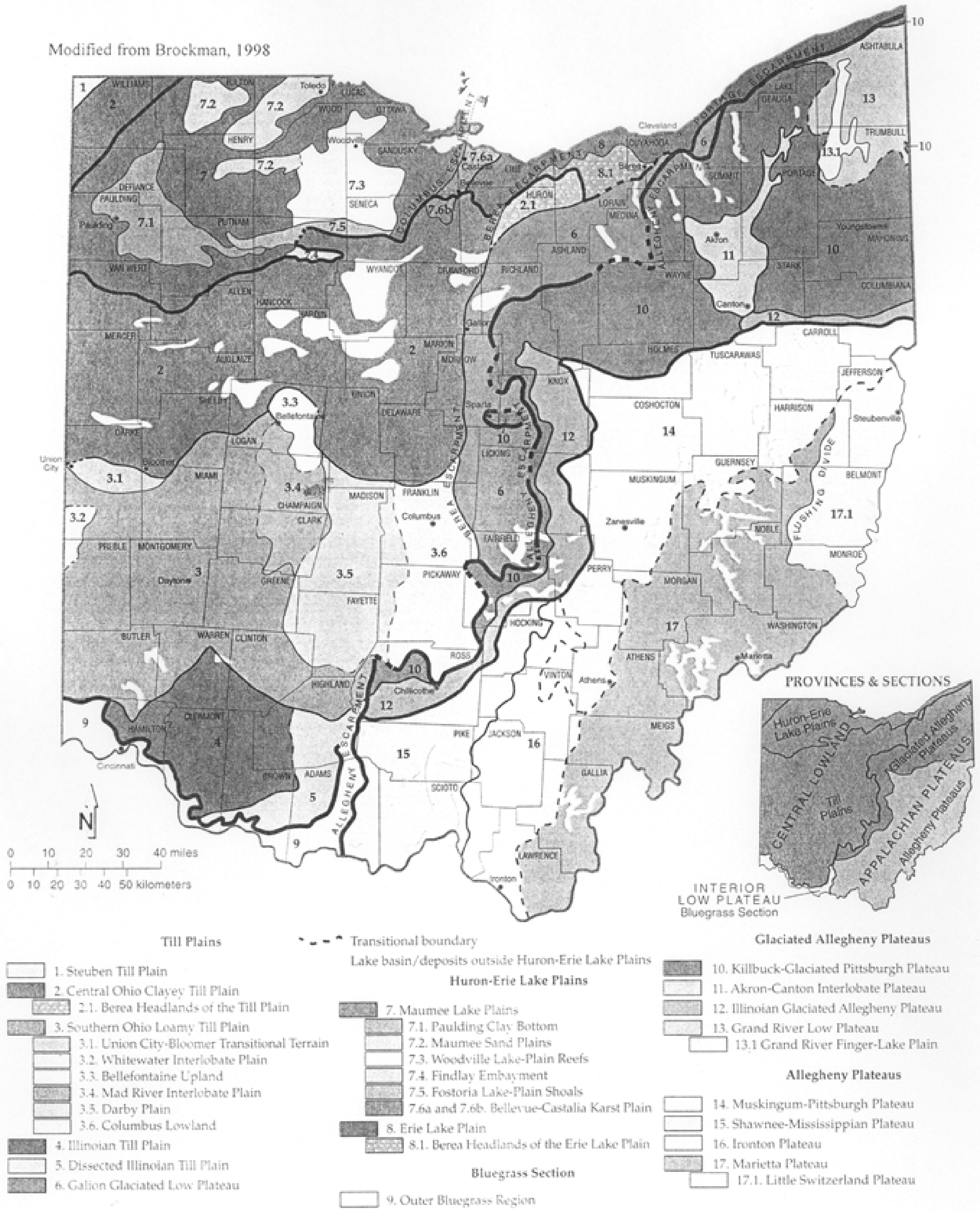


Figure 1. Map of Physiographic Regions of Ohio

The Till Plains include land that drains to Lake Erie and to the Ohio River. Streams draining to Lake Erie are generally smaller and less numerous than those draining to the Ohio River. Streams draining to the Ohio River are more deeply entrenched. (Cross, 1959)

The Till Plains in Ohio are divided into six physiographic regions: 1) the Steuben Till Plain, 2) the Central Ohio Clayey Till Plain, 3) the Southern Ohio Loamy Till Plain, 4) the Illinoian Till Plain, 5) the Dissected Illinoian Till Plain, and 6) the Galion Glaciated Low Plateau. Distinguishing characteristics of the regions include the following:

1. hummocky terrain with rolling hills interspersed with flats and closed depressions in the Steuben Till Plain, few streams, deranged drainage, abundant wetlands;
2. well-defined moraines with intervening flat-lying ground moraine and intermorainal lake basins in the Central Ohio Clayey Till Plain, few large streams, limited sand and gravel outwash, surface of clayey till;
3. moraines commonly associated with boulder belts between relatively flat-lying ground moraine in the Southern Ohio Loamy Till Plain, cut by steep-valleyed large streams, stream valleys filled with outwash alternate between broad floodplains and narrows, surface of loamy till;
4. rolling ground moraine of older till lacking ice constructional features in Illinoian Till Plain, loess cap till deposits, many buried valleys, modern valleys alternate between broad floodplains and bedrock gorges;
5. hilly former till plain with relatively high stream density in Dissected Illinoian Till Plain, loess caps till deposits; and
6. rolling upland mantled with thin to thick drift in Galion Glaciated Low Plateau, transitional to Appalachian Plateaus.

The Central Ohio Clayey Till Plain Region (2.) includes one district, the Berea Headlands of the Till Plain (2.1). Distinguishing characteristics of this district include: gently rolling terrain of thin drift, somewhat poorly drained descending toward Lake Erie, punctuated with "whalebacks" of Berea sandstone.

The Southern Ohio Loamy Till Plain Region (3.) includes six districts: 3.1) the Union City-Bloomer Transitional Terrain, 3.2) the Whitewater Interlobate Plain, 3.3) the Bellefontaine Upland, 3.4) the Mad River Interlobate Plain, 3.5) the Darby Plain, and 3.6) the Columbus Lowland. Distinguishing characteristics of the districts include the following:

3.1 well-defined moraines of low relief with hummocky ground moraine in northern parts of the Union City-Bloomer Transitional Terrain, loamy till capped with loess of moderately low relief in the south;

3.2 upland with hummocky moraines, moraine complexes, kames, boulder belts and broad outwash trains, or plains in Whitewater Interlobate Plain;

3.3 dissected topography of moderately high relief with moraine complexes and boulder belts in Bellefontaine Upland, high gradient major streams, caves and sinkholes, with few glacial depressions;
3.4 extensive outwash, outwash terraces, and bordering moraines in the Mad River Interlobate Plain, springs and cold ground-water fed streams;
3.5 broadly hummocky ground moraine with broad indistinct recessional moraines in the Darby Plain, poorly drained swales between hummocks that held wet prairies, few large streams;
3.6 lowland surrounded by relative upland having broad regional slope in Columbus Lowland, many larger streams.

The Huron-Erie Lake Plain Section of the Central Lowland Province covers a large area of Ice-Age lake-bottom land in northwestern Ohio and a narrow band between Lake Erie and the Portage Escarpment across extreme northeastern Ohio. The boundary of the Lake Plain inland from modern Lake Erie coincides with the margin of the highest Pleistocene lake (Lake Maumee). The Lake Plains are flat lying with low (10 feet) to extremely low (5 feet) relief. Although glaciated, much of the present land surface is covered with lacustrine deposits in the form of clay flats, sand plains, dunes, deltas, and beach ridges. The larger western part of the Lake Plain is separated from the eastern part by a karst plain thinly mantled with till. Channels modified for agricultural drainage are pervasive in the western part of the Lake Plain where drainage density is about 2 miles of stream per square mile of drainage area, lowest in the state (Brockman, 1996).

The Huron-Erie Lake Plain in Ohio is divided into two regions, the Maumee Lake Plains (7.) and the Erie Lake Plain (8.). Distinguishing characteristics of the two regions includes the following:

7. flat lying lake basin with beach ridges, bars, dunes, deltas, and clay flats in the Maumee Lake Plains, slightly dissected by modern streams, contained the former Black Swamp;
8. edge of very low relief Ice-Age lake basin in the Erie Lake Plain separated from modern Lake Erie by shoreline cliffs, major streams in deep gorges.

The Maumee Lake Plains Region (7.) includes six districts: 7.1) the Paulding Clay Bottom, 7.2) the Maumee Sand Plains, 7.3) the Woodville Lake-Plain Reefs, 7.4) the Findlay Embayment, 7.5) the Fostoria Lake-Plain Shoals, and 7.6) the Bellevue-Castalia Karst Plain. Distinguishing characteristics of the districts include the following:

7.1 nearly flat lacustrine plain in the Paulding Lake Plain, contains mostly clayey soils, low-gradient highly meandering streams, extremely low relief;
7.2 lacustrine plain mantled by sand in the Maumee Sand Plains, includes low dunes, interdunal plains, beach ridges, deltas, and sand sheets, well to poorly drained, very low relief;
7.3 lacustrine plain with low dunes and lake margin features in Woodville Lake-Plain Reefs, punctuated with bedrock reefs thinly draped with drift;

7.4 broadly rolling lacustrine plain in Findlay Embayment, with relatively coarse lacustrine sediments;
7.5 lightly eroded moraine with north-south trending hillocks and closed depressions in Fostoria Lake-Plain Shoals, many sandy areas;
7.6 hummocky plain of rock knobs and numerous sinkholes in Bellevue-Castalia Karst Plain, large solution features, and caves, large springs, thinly mantled with drift.

The Erie Lake Plain Region (8.) includes one district, the Berea Headlands of the Erie Lake Plain (8.1). Distinguishing characteristics of the district include sandstone headlands and "whalebacks" of Berea sandstone.

The Bluegrass Section of the Interior Low Plateau Province covers land in extreme southwestern Ohio south of the Till Plains and east of the Appalachian Plateaus. This land in proximity to the Ohio River constitutes the Outer Bluegrass Region (9.).

The Outer Bluegrass Region (9.) has an unglaciated eastern segment and a glaciated western segment. Both segments are dissected plateau of carbonate rocks with moderately high relief (300 feet). High gradient limestone and shale bedrock streams are common. The eastern segment is bounded by the maximum glacial margin and eastern high ridges capped by non-carbonate rocks. Caves and other karst features are present in the eastern segment. The eastern segment is connected to the western segment by Ohio River bluffs. The western segment is bounded by nondissected till plain. Thin pre-Wisconsinan till caps narrow ridges in the western segment (Brockman, 1996).

The western boundary of the Appalachian Plateaus Province is close to Lake Erie at the Ohio-Pennsylvania state line, parallels the lake to Cleveland, then turns southwest across central parts of Ohio and crosses into Kentucky a little west of the Scioto River. The Appalachian Plateaus in Ohio are underlain with sandstones and shales including the coal measures. Two physiographic sections of the Appalachian Plateaus Province are represented in Ohio. These are the Allegheny Plateaus Section and the Glaciated Allegheny Plateaus Section.

The Glaciated Allegheny Plateaus Section of the Appalachian Plateaus Province covers most of northeastern Ohio and extends southward across central and southern parts of the state in a narrow irregular pattern along the Wisconsinan and Illinoian glacial margins. The glaciated plateaus in the northeastern part of the state are smoother and more rolling than the unglaciated plateaus to the south. Valleys are less deep due to glacial erosion of hills and glacial deposition that has filled bottomlands. Drainage density is lower than in the unglaciated plateaus as streams are more widely spaced; drainage patterns transition from dendritic to parallel and trellis forms. Land along the southward extension of the glaciated plateaus is rugged hills like the unglaciated plateaus (Brockman, 1996).

The Glaciated Allegheny Plateaus in Ohio are divided into four physiographic regions: 10) the Killbuck Glaciated Pittsburgh Plateau, 11) the Akron-Canton Interlobate Plateau, 12) the Illinoian Glaciated Allegheny Plateau, and 13) the Grand River Low Plateaus including the Grand River Finger-Lake Plain District (13.1). Distinguishing characteristics of the regions and district include the following:

10. ridges and flat uplands covered with thin drift, dissected by steep valleys in the Killbuck-Glaciated Pittsburgh Plateau, valley segments alternate between broad drift filled and narrow rock walled reaches;
11. area dominated by kames, kame terraces, eskers, kettles, kettle lakes, and wetlands in the Akron-Canton Interlobate Plateau, deranged drainage and many natural lakes;
12. rugged hills with loess and older drift on ridge tops in the Illinoian Glaciated Allegheny Plateau, dissection similar to unglaciated plateau;
13. gently rolling ground with thin to thick drift in the Grand River Low Plateau, poorly drained areas and wetlands common; and

13.1 very low relief in the Grand River Finger-Lake Plain District, lake deposits in steep-sided troughs within the Grand River Low Plateau, cut by glacial and stream erosion, extensive wetlands.

The Allegheny Plateaus Section of the Appalachian Plateaus Province covers about one-third of Ohio including all of the southeastern part of the state. It includes all of the unglaciated land except for that in the Bluegrass Section of the Interior Low Plateau Province. Land in the Allegheny Plateaus part of Ohio is mature hill country with moderate (300-600 feet) to high (400-800 feet) relief. The land is deeply incised by well-developed stream systems leaving narrow ridges and hillocks separated by steep-walled valleys up to 300 feet deep. All of the streams in the area drain to the Ohio River. The largest streams flow in flat-bottom valleys at relatively low gradient. Tributaries to the larger streams are relatively high gradient. Headwater channels with intermittent flows actively engaged in down cutting are common. Drainage patterns are dendritic with drainage density about 5 miles of stream per square mile of drainage area, highest in the state (Brockman, 1996).

A striking physiographic feature of the Allegheny Plateaus in Ohio is the Flushing Divide that forms the western boundary of the highland area drained by relatively short tributaries to the Ohio River and the eastern boundary of the Muskingum River and Little Muskingum River drainages to the west. There is a distinct change in elevation from the highland area to the lower levels of the drainage in the west. The area west of the divide has wider ridges, less direct relief, and fewer small streams than the more markedly dissected terrain in the east. Stream gradients in the short eastward flowing streams are much steeper than those west of the divide (Cross, 1959).

The Allegheny Plateaus in Ohio are divided into four physiographic regions: 14) the Muskingum-Pittsburgh Plateau, 15) the Shawnee-Mississippian Plateau, 16) the Ironton Plateau, and 17) the Marietta Plateau. The Marietta Plateau includes a district, the Little Switzerland Plateau (17.1). Distinguishing characteristics of the regions and district include the following:

14. moderate to high relief in the dissected Muskingum-Pittsburgh Plateau with medium grained bedrock sequences, broad major valleys containing outwash terraces, and tributaries with lacustrine terraces,
15. high relief in the highly dissected Shawnee-Mississippian Plateau with coarse and fine grained bedrock sequences, remnants of ancient clay-filled Teays drainage system extensive in lowlands;
16. moderately high relief in the dissected Ironton Plateau with coarse grained coal bearing rock sequences more common than in other regions, lacustrine clay-filled Teays valley remnants common;
17. high relief in the highly dissected Marietta Plateau with fine grained rocks, red shales and red soils common, remnants of ancient clay-filled Teays drainage system common; and

17.1 high relief in the highly dissected Little Switzerland Plateau with mostly fine-grained rocks, red shales, and red soils common, high gradient shale bed streams, and no Teays drainage remnants.

Geology. The landforms of Ohio are the culmination of geological and climatological conditions existent throughout geologic time. The various conditions of the past are evidenced by the bedrock sequences and surficial glacial deposits found in the state. The character of the rocks and surficial glacial deposits is a primary factor determining the amount of ground water storage in basins in Ohio.

Ohio is underlain with thousands of feet of sedimentary rocks formed during the Paleozoic Era. Sedimentary rocks from all of the Paleozoic Periods (Cambrian, Ordovician, Silurian, Devonian, and Carboniferous-Mississippi, Pennsylvanian, Permian) are found in Ohio. Beneath the sedimentary rocks are igneous and metamorphic rocks of the Precambrian. The geologic map and cross section in figure 2 shows the relative location and position of the rock formations.

The sedimentary rock sequences provide evidence that Early Paleozoic environments were characterized by tropical and subtropical climates, shallow to moderately deep seas with an abundance of mud bars, sand bars, and reefs. Limestone and calcareous shales were the dominant sedimentary deposits. Later Paleozoic environments were characterized by tropical climates, terrestrial streams, deltas, coal swamps, and near shore seas. Sandstones, siltstones, and shales were the dominant sedimentary deposits. Tropical climates prevailed because the continental plate was located in equatorial regions during the Paleozoic 245 to 570 million years ago (Feldmann, 1996).

The sedimentary rocks in Ohio and neighboring states have been subject to uplifting and subsidence caused by tectonic forces. This has resulted in the formation of structural arches and basins. The Cincinnati and Findlay Arches were uplifted west of the subsiding Appalachian Basin during the Arcadian orogeny. Erosion regimes filled the Appalachian Basin with sediment eroded from the Highlands and Arches. Renewed uplifting raised the sediment filled basin (Feldmann, 1996).

Modified from Division of Geological Survey, 1997

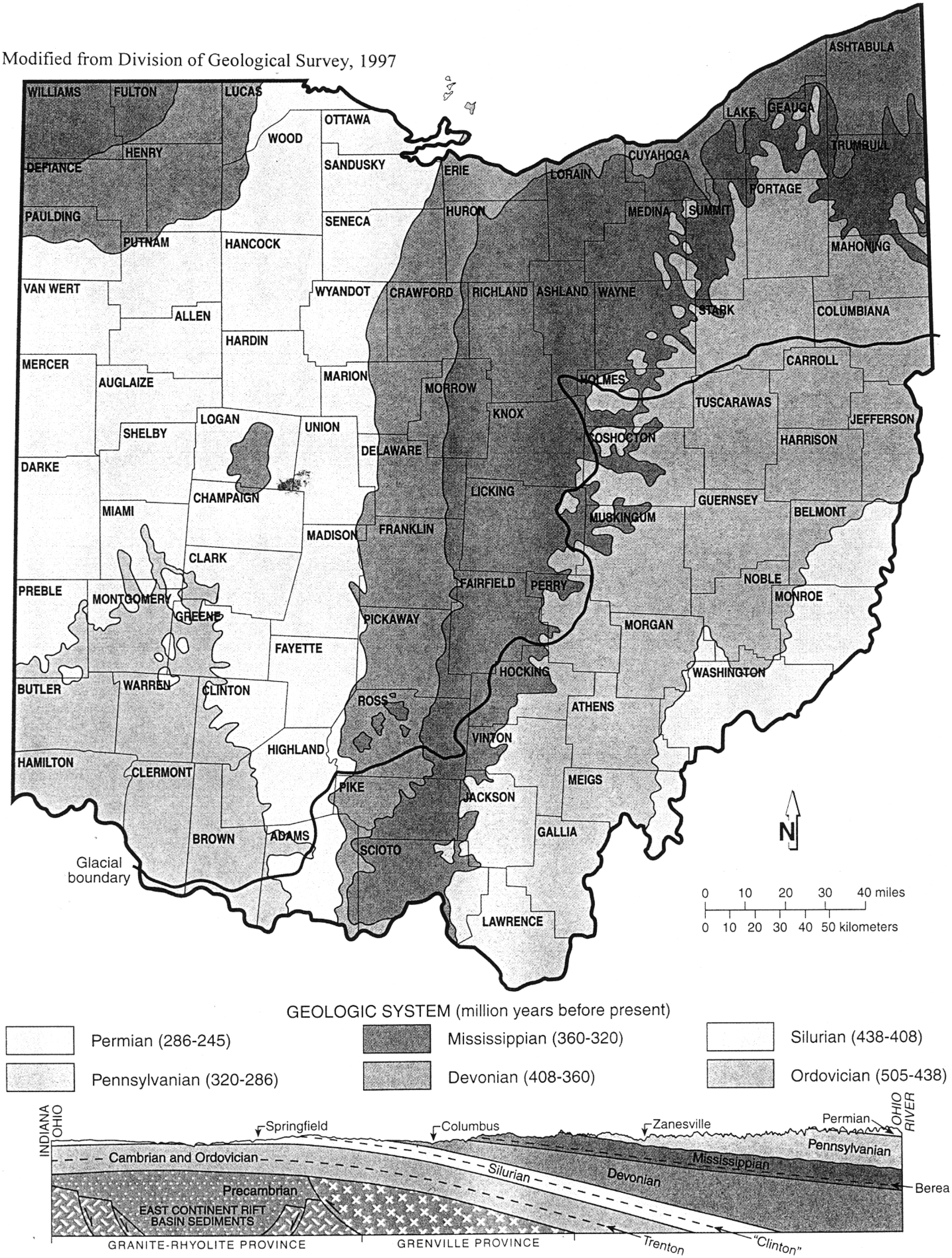


Figure 2. Geologic Map and Cross Section of Ohio

The Cincinnati and Findlay Arches are major geologic structures determining the general exposure of surface rocks in Ohio. The Cincinnati Arch is a broad rounded anticline with a north-south axis that passes under Cincinnati and joins the Findlay Arch with a northeast trending axis toward Lake Erie. The axes slope downward to the north and northeast such that Ordovician rock at the surface in the Cincinnati area is buried beneath increasing amounts of Silurian rock to the north. Rocks east of the Cincinnati and Findlay Arches dip into the Appalachian Basin exposing successively younger rocks at the surface. Rocks west of the Cincinnati Arch dip into the Illinoian Basin while rocks westward of the Findlay Arch dip into the Michigan Basin (Feldmann, 1996).

No sedimentary rocks from the Mesozoic or Cenozoic Eras that followed the Paleozoic are found in Ohio as uplifting, weathering, and erosion removed any that may have existed. Continental deposits of the Pleistocene Ice Age in late Cenozoic and sediments from the Holocene or Recent are the only deposits younger than the Paleozoic Era (Feldmann, 1996).

The sedimentary rocks and permeable surficial deposits largely determine the amount of ground-water storage in drainage basins. Shallow ground-water systems affecting base flow of streams are generally confined to water bearing strata of the surface rocks and permeable surficial deposits, the latter having the greater influence (Stout, 1943). Regional flows of ground water from rock strata contribute significantly to base flows of streams in certain areas of the state.

During the period of erosion that preceded the first glaciation of the Pleistocene Epoch, the surface rocks in Ohio were deeply incised by Teays-Stage drainage systems. The Teays drainage gathered its headwaters in the Piedmont of Virginia and North Carolina. The main stem crossed the Highlands and flowed down the Teays valley to Ohio where it entered the state at Wheelersburg. From there, it flowed north to the vicinity of present day Chillicothe and then turned northwest crossing into Indiana through Mercer County to join the ancient Mississippi system. The Teays was a mature drainage system whose main stem cut a rock valley through Ohio averaging 1.5 miles wide with local relief of 300 to 600 feet. All but the northern and eastern parts of the state were drained by it. The northern and eastern parts were drained by streams contemporary with the Teays but flowing northeast to the Atlantic Ocean rather than to the Gulf of Mexico (Stout, 1943).

The Teays was blocked by the Kansan and pre-Kansan glaciation during the Early Pleistocene creating a glacial lake hundreds of feet deep. During the blockage, silt deposits averaging 20 to 40 feet deep accumulated in the lake bottom. Remnants of these deposits, termed Minford silts, appear as terraces along many present day streams in unglaciated parts of the state and in the bottoms of buried valleys in glaciated areas. The impounded water eventually overflowed to the southwest creating a new outlet known as the Cincinnati River. This post-Kansan drainage is referred to as the Deep Stage drainage because the general level of incising exceeded that of the Teays. Narrow rock valleys of the Deep Stage indicate that it was a more youthful system than the Teays (Stout, 1943).

The Deep Stage drainage was blocked by the Illinoian glaciation that extended south of the Cincinnati River and present day Ohio River. Impounded water overflowed to the northeast. The post-Illinoian drainage was at generally higher levels than either the Teays or Deep Stage and followed in part the course of northeastward flowing streams contemporary with the Teays. Many streams in unglaciated parts of the state reversed flow direction and cut new channels through low divides. The Illinoian glaciation deposited greater quantities of material than the Kansan glaciation leaving varied assortments of sand, gravel, silt and clay along its margin (Stout, 1943).

The post-Illinoian drainage was blocked by the Wisconsinan glaciation in the Late Pleistocene forcing impounded water to overflow again to the southwest along the course of the present day Ohio River. The Wisconsinan glaciation involved several major advances and retreats that left two-thirds of the state covered with varying depths of glacial tills including extensive ground moraine and end moraines in the form of morainal belts across the state. The glacial map in figure 3 shows the relative location of ground moraine and end moraines.

Enormous quantities of sand and gravel were deposited in interlobate areas at the glacial margin. Glacial melt waters extended the impact of glaciation well beyond the margin through transport, sorting, and deposition of sand and gravel in the form of valley trains, terraces, and outwash plains. Loess deposits capped considerable areas in southwestern Ohio as the Late Wisconsinan glaciation retreated. Drainage in unglaciated areas under went another cycle of realignment and stream flow reversals. Streams flowed through valleys representing a composite of valley reaches created during different post-glacial drainage cycles (Stout, 1943).

Ancestral lakes to present day Lake Erie formed during the retreat of Wisconsinan glaciation leaving widespread lacustrine deposits throughout the Lake Plains. Final retreat of the Late Wisconsinan glaciaton allowed for re-establishment of drainage to the northeast and for head cutting into the Till Plains by streams draining to the Ohio River. Ice front streams, wholly or partly aligned with morainal belts, drained to Lake Erie. Glacial lakes in areas of ground moraine became lacustrine lakebeds and in some places, peat bogs.

Soils and Natural Vegetation. Land in Ohio near the glacial margin during the Late Pleistocene supported spruce-dominated communities. As the Late Wisconsinan ice sheet retreated, spruce-dominated communities spread northward reforesting the glacial plains.

The cool, wet climate that prevailed during the Late Pleistocene changed rapidly to a warmer, drier climate about 10,000 years ago. This period of rapid climate change marked the end of the Pleistocene and the beginning of the Holocene. During the Early Holocene, oak-dominated communities replaced the spruce communities in Ohio. Composition of the forests became more mixed as a result of fluctuations in Holocene climate. Warm, humid periods favored development of mixed deciduous forests dominated by beech, maple, elm, ash, and walnut; warm, dry periods favored oak and hickory (Feldmann, 1996).

Modified from Division of Geological Survey, 1995

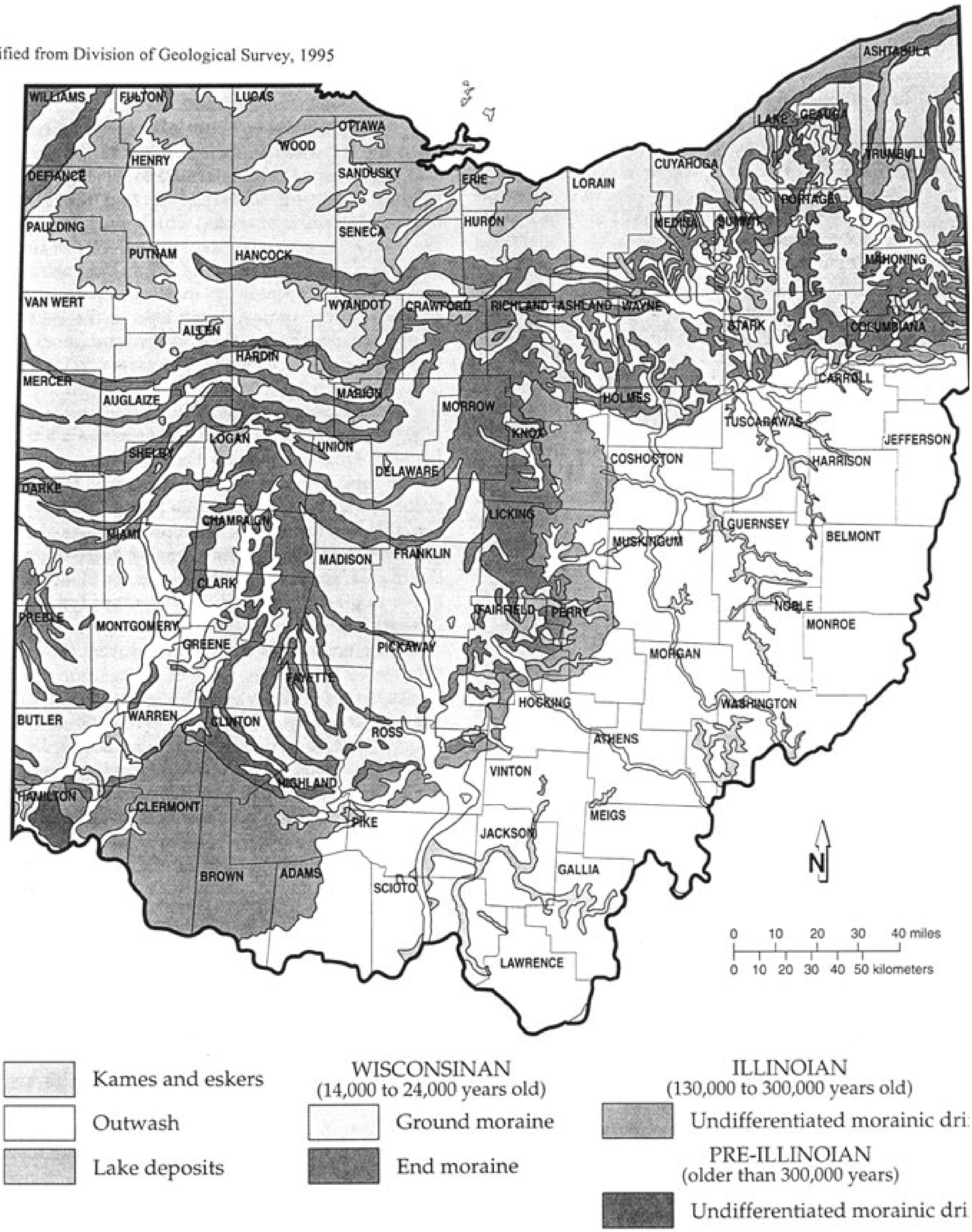


Figure 3. Map of Glacial Deposits of Ohio

The humid temperate climate and deciduous forest cover in Ohio during the Holocene has led to formation of soils belonging to the soil order Alfisol throughout much of the state. Under the system of classification adopted by the National Cooperative Soil Survey, Alfisols are mineral soils with well-developed soil horizons. They are mildly to strongly acid due to leaching of calcium and contain a zone of clay accumulation in the subsoil. Although Alifisols have the largest areal coverage in Ohio, other soil orders are represented including: Entisols, Inceptisols, Mollisols, Ultisols, and Histisols.

Entisols are recent or young mineral soils that lack horizons or have only the beginnings of horizons. Parent material has been only slightly modified.

Inceptisols are mineral soils where horizons have started to develop, but no zone of clay accumulation exits in the subsoil. Subsoil is mottled, gleyed, olive-gray or brighter than parent material.

Mollisols are mineral soils with thick, dark-colored topsoil relatively high in organic content. Subsoil may or may not contain a zone of clay accumulation.

Ultisols are old strongly weathered mineral soils that contain horizons with clay accumulation. Ultisols are strongly acid to greater depth than Alfisols.

Histisols are soils high in organic content that formed under very wet conditions associated with permanent water logging or saturation.

Soil formation is due to the integrative effect of climate and living matter acting on parent material under differing conditions of slope and drainage over periods of time. Most soils in Ohio developed under deciduous forest cover in a humid temperate climate. Ohio has a great variety of soils due mainly to differences in parent material. Differences in slope and drainage contribute to variety by allowing formation of different soils from the same parent material. Weathering and erosion of carbonate parent rock produced high-lime parent material in the western half of the state while weathering and erosion of sandstone and shales produced low-lime parent material in the eastern half of the state. Soils developed from high-lime parent material generally have lower acidity than those developed from low-lime parent material (Dotson, 1954).

The most common soils with greatest areal coverage in Ohio can be categorized as glacially transported soils, lacustrine soils, or residual soils. Each of these broad categories can be subdivided into high-lime or low-lime soils depending on whether parent material was derived primarily from carbonate rock or sandstones and acid shales. Soils occupying relatively small but widely scattered areas in the state include alluvial soils and organic soils. Although relatively small in areal coverage, these latter soils tend to be highly fertile and of economic importance (Noble, 1975).

About 450 soil series have been delineated in Ohio. A soil series consists of soils with profiles that are similar in composition, thickness, and arrangement. Different groups or associations of soil series common to Ohio have been identified by analysis of soil maps.

These associations have been combined into 12 soil regions and identified by the names of soils that are most common in each region. The soil regions coincide with the major categories of parent material. The 12 soil regions as shown in figure 4 are as follows:

Soil Region 1. Hoytville-Nappanee-Paulding-Toledo.
Soil Region 2. Conotton-Conneaut-Allis
Soil Region 3. Blount-Pewamo-Glywood
Soil Region 4. Miamian-Kokomo-Eldean
Soil Region 5. Bennington-Cardington-Centerburg
Soil Region 6. Mahoning-Canfield-Rittman-Chili
Soil Region 7. Clermont-Rossmoyne-Avonburg-Cincinnati
Soil Region 8. Westmoreland-Homewood-Loudonville
Soil Region 9. Eden-Bratton-Brushcreek
Soil Region 10. Shelocta-Brownsville-Lathan-Steinsburg
Soil Region 11. Coshocton-Westmoreland-Berks
Soil Region 12. Gilpin-Upshur-Lowell-Guernsey

Soil Region 1 covers nearly all of the Maumee Lake Plains and some areas in the Central Ohio Clayey Till Plain. Hoytville, Nappanee, Paulding, and Toledo are the dominant soils in this region. Paulding and Toledo soils are Inceptisols that developed from calcareous lake deposited clay and silt under elm-ash swamp forests. Permeability of these soils is very slow. Seasonal high water table is at or near ground surface. Paulding soils dominate the Paulding Clay Bottom while Toledo soils dominate the Maumee Lake Plains near Lake Erie. Toledo and Paulding soils are common on glacial lake sediments in the Central Ohio Clayey Till Plain. Hoytville and Nappanee soils are Alfisols that developed from high-lime clay till under elm-ash swamp forests and beech forests. These level soils have a clayey subsoil that impedes drainage. The very dark gray Hoytville soil is more dominant than the Nappanee. Hoytville and Nappanee soils cover most of the central and southern parts of the Maumee Lake Plains and some areas in the Central Ohio Clayey Till Plain. Sandy soils classified as Entisols developed on the Maumee Sand Plains under oak forests and oak savanna. These highly permeable soils formed in mixed sands and fine sandy loam over calcerous clay. They include Tedrow, Ottokee, and Oakville soils. Entisols are also common on the sandy beach ridges in the lake plains. Soils on the Woodville Lake Plain are predominantly Alfisols developed from thin waved-planned till and lacustrine deposits over dolomite. The Bellevue-Castalia Karst Plain is largely covered with Alfisols developed from thin wave-planned till and lacustrine deposits over limestone. Soils on the Woodville Lake Plain and the Bellevue-Castalia Karst Plain are moderately to slowly permeable.

Soil Region 2 covers all of the Erie Lake Plain and the Portage Escarpment. Conotton, Conneaut, and Allis are the dominant soils in this region. These soils developed under mixed mesophytic, oak, and beech forests. Conneaut and Allis soils along the Erie Lake Plain are Inceptisols with slow permeability developed from Pleistocene Age lacustrine deposits of silt and wave-planed clayey till. The seasonal high water table is at or near ground surface. Conneaut soil formed from lacustrine silt loam and silty glacial till on lake plain flats eastward from Cleveland. Allis soils formed in thin silty-clay till over

Modified from Division of Soil and Water Conservation, 1996

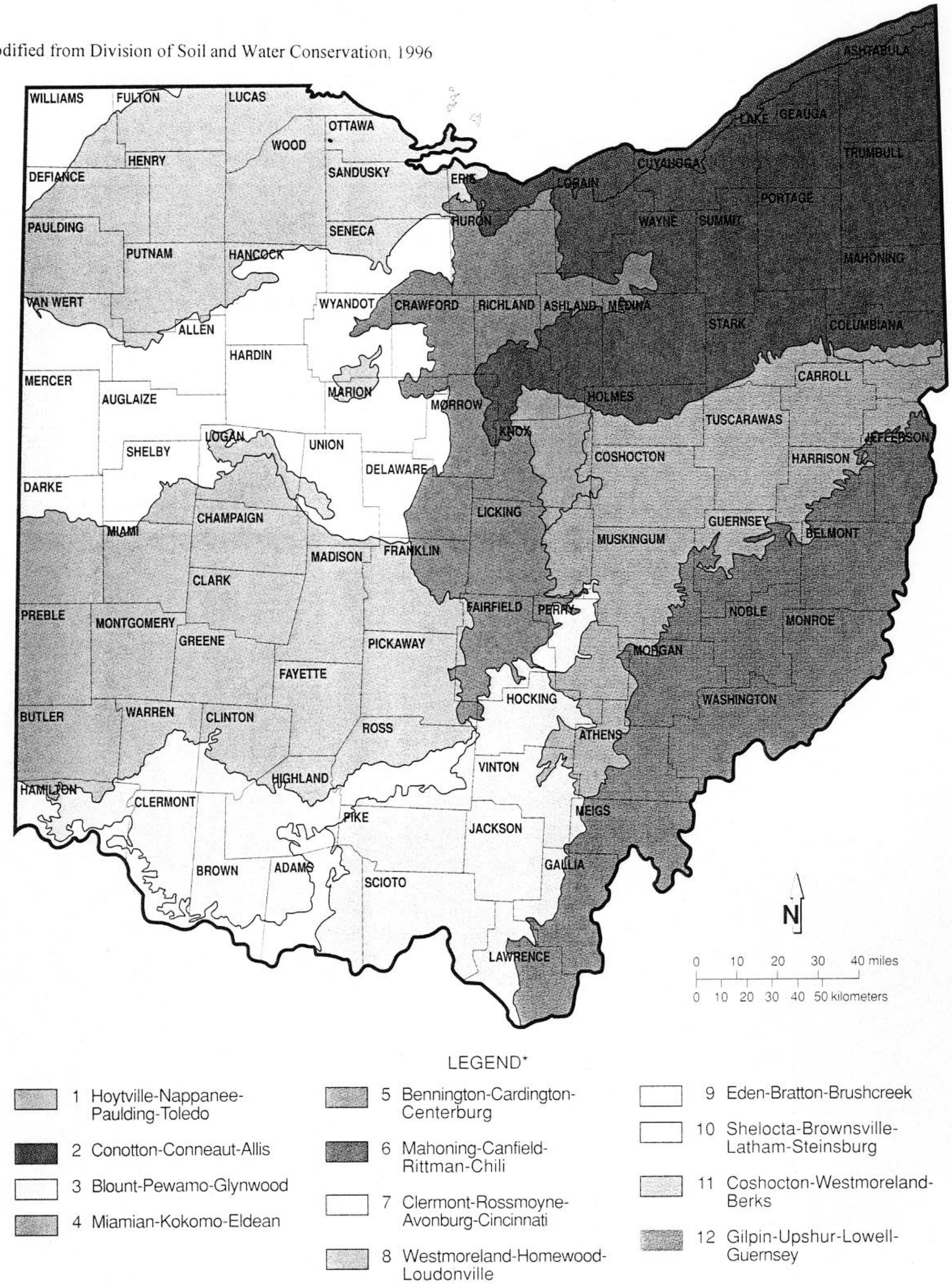


Figure 4. Map of Soil Regions of Ohio

shales and sandstones on lake plain flats westward of Cleveland. Allis soil is more clayey than the Conneaut soil. Conotton soil is an Alfisol that formed on beach ridges along the Portage Escarpment. This soil formed in stratified sands, gravels, and loamy material containing large amounts of sand and gravel. It has rapid permeability. Entisols are also common on the beach ridges along the Erie Lake Plain. The Berea Headlands of the Erie Lake Plain are largely covered with Alfisols of moderate permeability.

Soil Region 3 covers all of the Central Ohio Clayey Till Plain except for areas in Soil Region 1, the Berea Headlands of the Till Plain, and eastern parts of the Till Plain where the surface rock is shale. Blount, Pewamo, and Glynwood are the dominant soils in this region. These soils formed in high-lime Wisconsinan till of moderately fine textured clay loam mainly under beech and elm-ash swamp forests. Blount and Glynwood are Alfisols with slow permeability. Pewamo is a Mollisol with slow permeability and very dark gray topsoil. Bount-Pewamo associations are common on level to depressional areas of ground moraine. Seasonal high water table is at or near ground surface. Blount-Glywood associations are common on undulating end moraines across the region.

Soil Region 4 covers nearly all of the Southern Ohio Loamy Till Plain. Miamian, Kokomo, and Eldean are the dominant soils in this region. These soils formed in high lime, medium textured Wisconsinan till or glacial outwash. Miamian soil is extensive on uplands throughout the region. This soil formed from medium textured loam till and loess mantled till under mixed deciduous forests of beech, mixed oak, and oak-sugar maple. Miamian soil is an Alfisol with moderately slow permeability. Kokomo is common in the Darby Plains and Columbus Lowlands. It is a Mollisol that formed from highly calcareous loam till in broad depressions covered with prairie grasses and wet deciduous forests. The topsoil is very dark brown. Kokomo has moderately slow permeability and seasonal high water table at or near the ground surface. Brookston is another Mollisol common to parts of the region outside the Darby Plains and Columbus Lowland. Miamian, Kokomo, and Brookston soils occur in association with Crosby and Celina, which are Alfisols. Eldean is an Alfisol that formed in loamy glacial outwash material on outwash terraces along larger streams and to lesser extent on kames and eskers. It is moderately permeable and underlain by highly permeable sand and gravel. Fox is another Alfisol similar to Eldean common on outwash terraces in the region.

Soil Region 5 includes most of the Galion Glaciated Low Plateau and eastern parts of the Central Ohio Clayey Till Plain and Southern Ohio Loamy Till Plain. Bennington, Cardington, and Centerburg are the dominant soils in this region. These soils formed in low lime Wisconsinan till containing sandstone and shale fragments and moderate amounts of limestone. All of these soils are Alfisols that developed under beech and elm-ash swamp forests. Bennington-Cardington associations formed in moderately fine textured till. They are common in the northern half of the region. Bennington is slowly permeable and similar to Blount. Cardington is moderately slowly to slowly permeable and is similar to Glynwood. Bennington-Centerburg associations are common in the southern half of this region. Centerburg soil formed in loamy till mantled in places with loess. Permeability of Centerburg soil is moderately slow.

Soil Region 6 includes all of the Glaciated Allegheny Plateaus with low-lime Wisconsinan till in the northern half of the state. Mahoning, Canfield, Rittman, and Chili are the dominant soils in this region. These soils are Alfisols that developed mainly from medium to fine textured glacial till or loamy outwash material under mixed mesophytic, beech, mixed oak, and elm-ash swamp forests. Mahoning soil developed from clay loam and clayey till and has slow permeability. It is common in northern and eastern parts of the region. Canfield-Rittman associations developed from medium to fine textured till and have fragipans that are slowly permeable. These associations are common on till areas in the southern half of the region. Platea soils have a fragipan with very low permeability, and they are common in the Grand River Low Plateau. Soils in the Grand River Finger Lake Plain developed from medium to fine textured till and lacustrine deposits. They have slow permeability. Chili-Canfield associations dominate the Akron-Canton Interlobate Plateau. Chili soil developed in loamy outwash on extensive terraces and kames. It has rapid permeability and is underlain by sand and gravel. Organic soils associated with peat bogs occur in numerous widely scattered areas in this region.

Soil Region 7 covers the Illinoian Till Plain, the Dissected Illinoian Till Plain, and southern parts of the Illinoian Glaciated Allegheny Plateau. Clermont, Rossmoyne, Avonburg, and Cincinnati are dominant soils in this region. These soils developed mainly from loess and Illinoian high-lime glacial till. They are older than those developed from Wisconsinan till and have undergone more extensive leaching of cations. All of these soils are classified as Alfisols. Rossmoyne, Avonburg, and Cincinnati soils have fragipans of slow permeability. Clermont soil lacks a fragipan but is very slowly permeable. Avonburg-Clermont associations are common in central and northern parts of the Illinoian Till Plain. This association developed in loess material over clayey loam till under beech and elm-ash swamp forests. Seasonal high water table is at or near the surface. Rossmoyne-Cincinnati associations are common in southern and western parts of the Illinoian Till Plain. This association formed from loess mantled till under oak-sugar maple and mixed oak. Rossmoyne is common in the Dissected Illinoian Till Plain and southern parts of the Illinoian Glaciated Allegheny Plateau. Cincinnati soil occurs in association with Homewood in southern parts of the Illinoian Glaciated Allegheny Plateau. Homewood is an Alfisol common in Soil Region 8.

Soil Region 8 includes northern parts of the Illinoian Glaciated Allegheny Plateau. Westmoreland, Homewood, and Loudonville are the dominant soils in this region. These soils are Alfisols that developed under mixed mesophytic, mixed oak, and oak-sugar maple forests. Westmoreland soil developed in colluvium and residuum derived from interbedded sandstone, siltstone, and shale on unglaciated hillsides. The soil is deep and moderately permeable. Homewood and Loudonville soils developed from medium to moderately fine textured-glacial till and residuum of underlying sandstone and siltstone. Homewood soil has a fragipan with slow permeability; Loudonville is moderately deep with moderate permeability.

Soil Region 9 covers the Outer Bluegrass Region. Eden, Bratton, and Brushcreek soils are dominant in this region. These soils are Alfisols that developed under mixed mesophytic, mixed oak, and oak-sugar maple forests. Eden soil is common in the southern and western parts of the region. It is a moderately deep, slowly permeable soil found on side slopes and uplands. Eden formed from material weathered from interbedded calcareous shale and limestone. Bratton-Brushcreek associations are common in eastern and northeastern parts of the region. Bratton is a moderately deep soil with moderate permeability found on ridge tops and shoulders of loess capped, dissected limestone uplands. It formed in thin deposits of loess and underlying fine textured residuum of limestone. Brushcreek is a deep, slowly permeable soil found on foot slopes of uplands. This soil formed in residuum and colluvium derived from interbedded calcareous shales and limestones.

Soil Region 10 covers the Shawnee-Mississippian and Ironton Plateaus. Shelocta, Brownsville, Latham, and Steinsburg are the dominant soils in this region. These soils developed under mixed mesophytic and mixed oak forests. They are all strongly acid. Shelocta is a deep Ultisol formed in colluvium from siltstone, shale, and sandstone residuum. It is moderately permeable and common on side slopes, foot slopes, and fans in the region. Latham is a moderately deep Ultisol formed in residuum of shale and siltstone. It has slow permeability and is common on ridge tops and side slopes in the southern part of the region. Brownsville is a deep Inceptisol that formed in residuum and colluvium derived from siltstone and fine-grained sandstone. It has moderate to moderately rapid permeability and is common on hillsides in uplands in the Shawnee-Mississippian Plateau. Steinsburg is a moderately deep Inceptisol that formed in residuum derived from sandstone or, in some areas, conglomerate. It has moderate to rapid permeability and is common on ridge tops, shoulder slopes, and side slopes of upland in the southern part of the Ironton Plateau. Omulga is an Alfisol with a fragipan common along preglacial valleys in the region. This soil formed in loess, colluvium, or old alluvium, and in the underlying lacustrine sediments.

Soil Region 11 covers the Muskingum-Pittsburgh Plateau. Coshocton, Westmoreland, and Berks are the dominant soils in this region. These soils developed under mixed oak, mixed mesophytic, and beech forests. All of these soils are strongly acid. Coshocton soil is a deep Alfisol formed in colluvium and material weathered from shale, siltstone, and sandstone. It has moderately slow to slow permeability and is common on concave parts of ridge tops and lower hillsides in northern parts of the region. Westmoreland is a deep Alfisol formed in colluvium and material weathered from siltstone, shale, sandstone, and limestone. It has moderate permeability and is common on dissected hillsides and ridge tops in the region. Berks is a moderately deep Inceptisol formed in material weathered from siltstone, shale, and sandstone. It has moderate to rapid permeability and is common on ridge tops and hillsides in the region. Chili and Wheeling are Alfisols common on stream terraces bordering the Tuscararus River. These soils formed in glacial outwash and have moderate to rapid permeability.

Soil Region 12 covers the Marietta Plateau and Little Switzerland Plateau. Gilpin, Upshur, Lowell, and Guernsey are the dominant soils in this region. These soils developed under mixed oak, mixed mesophytic, oak-sugar maple, and beech forests. Gilpin is a moderately deep Ultisol common on ridge tops, side slopes, and foot slopes in uplands throughout the region. This soil formed in material weathered from interbedded acid siltstone, shale, and sandstone. Gilpin is moderately permeable. Upshur is common in the Marietta Plateau on ridges, benches, and side slopes in uplands. It is a deep Alfisol that formed in residuum from red shale and siltstone. The subsoil is reddish color and permeability is slow. Runoff is rapid. Guernsey is common in northern part of the Marietta Plateau. It is a deep Alfisol that formed in colluvium and in the underlying residuum derived from siltstone, shale, and some limestone. This soil is moderately slowly permeable to slowly permeable. Lowell is common in the Little Switzerland Plateau on hillsides, ridge tops, foot slopes, and side slopes in uplands. It is a deep, moderately slowly permeable Alfisol formed in colluvium and residuum derived form interbedded limestone, siltstone, and shale. Bethesda, Fairpoint, and Morristown are common on strip mine disturbed material in the region. These soils are Entisols that are moderately slowly permeable.

The dominant soils in the various soil regions of the state vary widely in permeability. The rate that water infiltrates and percolates through soil is controlled in large measure by soil properties such as texture, presence or absence of a fragipan, depth to rock, and location of seasonal high water table. Variation in infiltration rates and permeability of soils in basins is an important factor affecting ground-water recharge rates and low-flow regimens of streams.

Maps of soil-infiltration rates for the state can be constructed from hydrologic soil groups that categorize soils according to minimum rates of infiltration for bare soil after prolonged wetting. Soil-infiltration rate maps can be used in combination with geologic maps of glacial surficial deposits to estimate ground-water recharge-discharge rates in drainage basins in Ohio (Dumouchelle, 2002). Soils formed in glacial till generally are associated with low infiltration and low recharge-discharge rates while soils formed in outwash and alluviums are generally associated with high infiltration rates and high ground-water recharge-discharge rates. Shale and sandstone residual soils generally have moderate infiltration rates and moderate ground-water recharge-discharge rates (Dumouchelle, 2002).

Land Use. The rate that rainfall infiltrates soil or runs off is affected by soil properties and by the kind of land cover associated with different land uses. Land with natural vegetation such as forest and grassland generally has higher rates of infiltration and lower rates of direct runoff than the same land with modified cover such as row crops. Land use in drainage basins therefore determines in part the regimen of flow in streams.

Urbanization is a type of land use that can dramatically decrease infiltration rates and increase direct runoff by creation of impervious surfaces. Generally, urbanization begins to significantly affect streamflow regimens when about 15 percent of the watershed is developed. Many smaller watersheds in Ohio are highly developed, but the larger basins remain much less than 15 percent urbanized. The dominant land use in the larger basins is agriculture and forestry.

The U. S. Department of Agriculture has identified 24 distinct Land Resource Regions in the United States based on the following elements: land use, elevation and topography, climate, water, soils, and potential natural vegetation. The name of each Land Resource Region indicates the principal types of agricultural activities that affect the ecology and economy of the region. (USDA Agricultural Handbook 296) The regions have been subdivided into subregions termed Major Land Resource Areas. Boundaries of the Major Land Resource Areas in Ohio coincide with the soil region boundaries. Four Land Resource Regions and 8 Major Land Resource Areas are represented in Ohio. These are as follows:

Lake States Fruit, Truck, and Dairy Region
- Erie-Huron Lake Plain (MLRA 99)
- Erie Fruit and Truck Area (MLRA 100)

Central Feed Grains and Livestock Region
- Indiana and Ohio Till Plain (MLRA 111)
- Southern Illinois and Indiana Thin Loess and Till Plain (MLRA 114)

East and Central Farming and Forest Region
- Kentucky Bluegrass (MLRA 124)
- Western Allegheny Plateau (MLRA 124)
- Central Allegheny Plateau (MLRA 126)

Northeastern Forage and Forest Region
- Eastern Ohio Till Plain (MLRA139)

The Lake States Fruit, Truck, and Dairy Region includes areas in states bordering the Great Lakes where soil and climate advantage exists for production of fruit and vegetable crops. Proximity to population centers along the lake shores favor dairying and commercial horticulture. Portions of the region covering Ohio include two Major Land Resource Areas: the Erie-Huron Lake Plain (MLRA 99) and the Erie Fruit and Truck Area (MLRA 111).

The Erie-Huron Lake Plain Resource Area includes all of Soil Region 1 in the Maumee Lake Plains. Nearly level crop fields with agricultural drainage ditches and subsurface drains characterize this area. Soybean and corn production predominant, but a wide variety of agricultural activity exists in the area. Tomatoes and sugar beets are important specialty crops. Cattle and hog raising are important livestock operations in addition to dairying. Farmland accounts for nearly all land use outside of urban areas. Cropland typically accounts for 80 to 90 percent of farmland use; pasture generally 10 percent or less. Forestland mostly in the form of woodlots accounts for about 3 to 8 percent of land use. The major area of continuous woodland is in the Oak Openings, a 5 to 10 mile wide belt along the Sand Plains in western Lucas and eastern Fulton Counties. Maumee State Forest and Oak Openings Metro Park are located in the Oak Openings.

The Erie Fruit and Truck Resource Area includes all of Soil Region 2 covering the Erie Lake Plain and Portage Escarpment. Agricultural activity in this area emphasizes production of fruit and vegetable crops as soil and climate advantage exists for these purposes. The area has the most intensive nursery and greenhouse operations in the state. Woodland covers about 15 to 20 percent of the land in this resource area. Urban, industrial, commercial, and other built up land accounts for a third or more of land use.

The Central Feed Grains and Livestock Region includes the area in the Upper Midwest that is generally considered as the Corn Belt. Ohio is in the eastern Corn Belt. Important cash crops in addition to corn are soybeans and wheat. This area is a major producer of hogs and feeder cattle. Portions of the region covering Ohio include two Major Land Resource Areas: the Indiana and Ohio Till Plains (MLRA 111) and the Southern Illinois and Indiana Thin Loess and Till Plain (MLRA 114).

The Indiana and Ohio Till Plains Resource Area includes all of Soil Regions 3, 4, and 5 and parts of Soil Region 1 in the Till Plains. Large fields of corn and soybeans are characteristic of this area. Cash grain is the primary source of farm income in the northern parts of the area; cattle and hog raising are the second largest source of income. Cattle and hogs are primary sources of income in the southern parts with grain used for feed and cash sale. Agricultural activities in western, southwestern, and central parts of the resource area include more emphasis on dairying to serve nearby population centers. Outside of the major metropolitan areas, farmland generally accounts for nearly all land use. Farmland across the area receives similar use despite different emphasis in agricultural activity. About 90 percent of the farmland is used as cropland with pasture and woodlots accounting for the remainder.

The Southern Illinois and Indiana Thin Loess and Till Plain Resource Area includes all of Soil Region 7 covering the Illinoian Till Plain, the Dissected Illinoian Till Plain, and southern parts of the Glaciated Illinoian Plateau. Land use in this area is about 50 percent cropland, 20 percent pasture, 25 percent forestland, and 5 to 10 percent urban and other land uses. Tobacco is the major cash crop but is grown on limited areas. Cattle and hogs are major sources of farm income. Grain crops are used in large measure for livestock feed. Dairying is important in outlying areas around Cincinnati. Timber sales are an additional source of farm income in the eastern parts of this resource area.

The East and Central Farming and Forest Region includes all of Soil Regions 9, 10, 11, and 12. Portions of the region covering Ohio include three Major Land Resource Areas: the Kentucky Bluegrass Resource Area, the Western Allegheny Plateau Area, and the Central Allegheny Plateau Area.

The Kentucky Bluegrass Resource Area includes all of soil region 9 covering the Outer Bluegrass Region. It is about 20 to 30 percent forestland. Over half of the land in the western part of the area in the vicinity of Cincinnati is urban land. Nursery and greenhouse operations are common near this population center. In the eastern half of the resource area, crop and pastureland account for 50 to 60 percent of land use, forestland most of the remainder. Tobacco is the major cash crop. Dairy, cattle and grain farming are common. Hogs account for the majority of livestock raised in the northeastern part of the area.

The Western Allegheny Plateau Resource Area includes all of soil regions 10 and 11 covering the Shawnee-Mississippian and Ironton Plateaus and the Muskingum-Pittsburgh Plateau. The portion of the resource area covering Soil Region 10 in the Shawnee-Mississippian and Ironton Plateaus is 60 to 70 percent forested, the most heavily forested area in the state. Logging operations are common as numerous forest product industries are located in the area. National and state forests cover some of the land. Pasture and cropland account for about 30 percent of land use. Beef cattle are the major source of agricultural income. The portion of the resource area covering Soil Region 11 in the Muskingum-Pittsburgh Plateau is about 40 to 50 percent forestland. Pasture and cropland account for about 30 to 40 percent of land use. Most farms are combined grain and livestock enterprises. General livestock and dairy farms are common. Surface mining for coal affects land to varying degree in most parts of this resource area.

The Central Allegheny Plateau Resource Area includes all of soil region 12 covering the Marietta and Little Switzerland Plateaus. The area is about 50 to 60 percent forested. Forests dominate steeper hillsides. National and state forests cover some of the land. Pasture and cropland cover about 30 percent of the land, the majority being pasture. Beef cattle and dairying are the principal agricultural activities. Cropland is largely limited to bottomlands. In northern parts of the area, 10 to 20 percent of the land is affected by strip mining, the most extensive in the state. The larger towns in the area border the Ohio River.

The Northeastern Forage and Forest Region includes the New England states, most of New York state, the northwest corner of Pennsylvania, and the northeastern part of Ohio. This area in Ohio is characterized by a high degree of urbanization and industrialization. Portions of the region covering Ohio include the Eastern Ohio Till Plain Major Land Resource Area.

The Eastern Ohio Till Plain Resource Area includes all of Soil Region 6 and 8 covering the glaciated Allegheny Plateaus in the northeastern parts of the state. Several of the counties in this resource area are highly urbanized with most land used for commercial, industrial, or residential purposes. Land being held for development purposes is typically former crop and pasture land. Extensive park systems along major streams including the Cuyahoga Valley National Recreation Area constitute most of the forestland in urban counties. Land use outside metropolitan areas in this resource area is generally about 25 percent crop and pasture, 25 percent forestland, and about half residential. Dairying is the principal source of farm income. Fruit crops, mainly apples, are grown commercially where coarser texture soils favor orchards in the southern part of the resource area.

Water Development. In the early 1800s, thousands of small dams were built on the streams in Ohio to power grist and saw mills. Most of these mill dams no longer exist, and there is very little hydro power developed because of the low available head. The major water developments have been for flood control and water supply.

Five large earthen dams were constructed on the major streams above Dayton in the 1920s by the Miami Conservancy District to control floods like the one that occurred in 1913. These structures are automatic retarding basins with no movable gates and no permanent pools.

The Corps of Engineers and Muskingum Watershed Conservancy District built fourteen flood-control dams in the late 1930s in the Muskingum River Basin. All but three of these dams have permanent pools. Since the 1930s, the Corps of Engineers has constructed 14 additional multiple purpose reservoirs in Ohio including: 2 in the Muskingum River Basin, 3 in the Mahoning River Basin, 4 in the Scioto River Basin, 2 in the Little Miami River Basin, and one each in the Hocking River Basin, Mill Creek Basin, and Miami River Basin. All of these large dams significantly affect the flow regimen of streams.

Many water supply reservoirs exist in the state, some of large size such as those at Columbus, Akron, and Youngstown. Stream flow regimens are affected by the larger reservoirs. Many smaller impoundments with limited storage and nearly complete return of diverted flows through wastewater discharge have limited, local effect on streams. Cleveland obtains water supply from Lake Erie and has the largest surface water supply system in the state.

Although surface water provides the majority of water supply used in Ohio, ground-water systems are far more numerous, some are of substantial size such as the ones at Dayton and Canton. Ground-water pumpage from buried valley deposits, where these large systems are located, significantly affects the low-flow regimen of streams.

ESTIMATES AND COMPARISONS OF FLOW CHARACTERISTICS

When making comparisons of flow characteristics between streams, it is the effects of basin characteristics and long-term average climatic factors (climate) that are of primary interest. In order to minimize the effects of short-term variations in climatic factors (weather) on estimates of flow characteristics, it is essential that long-term streamflow data be used when making an analysis.

The need for collection of long-term streamflow data in Ohio has long been recognized. (Columbus Chamber of Commerce, 1923) Systematic collection of streamflow data on a statewide basis began in Ohio in the 1920s. Nearly all gaging was suspended for lack of funds in the 1930s and then resumed in the 1940s till the present time (Shaffer, 2000). This gaging activity has produced a combination of long-term, short-term, and partial-record streamflow data for analysis and interpretation.

Steamflow gaging stations are classed as complete-record or partial-record stations depending on whether continuous daily discharge data are collected or only selected flow parameters. The distinction between short-term and long-term records is dependent on intended use. Generally, records that are 2 or 3 years in length are considered short-term; records of 10 or more years are considered to be long-term.

Stream gaging stations across Ohio where long-term records have been collected and flows are largely unregulated form a network of index stations. These index stations serve dual purposes by providing data for estimation of flow characteristics at the index sites and at nearby partial-record or short-term record sites through application of record extension techniques (Riggs, 1973).

Streamflow records are analyzed for a wide range of purposes. Analyses of particular value for characterizing and comparing regimens of flow include those that provide information about: mean annual runoff, base flows, flow duration, and frequency of flow events.

Mean Annual Runoff

Runoff from drainage basins in Ohio normally follows a distinct seasonal pattern. This is due primarily to variation in evapotranspiration as precipitation tends to be fairly uniformly distributed throughout the year. Average monthly stream flow is normally highest in winter and early spring when evapotranspiration is minimal, and lowest in summer and early fall when evapotranspiration is relatively high. The total amount of water that runs off a basin during the course of a year is termed the annual runoff.

Mean annual runoff is the average amount of water that runs off a basin over a period of years. It is calculated from streamflow records using the cumulative hydrograph or mass curve of flow. The volume of runoff is typically given in equivalent inches of water depth uniformly distributed over the entire basin. Alternatively, it may be given as an average flow rate such as cubic feet per second per square mile of drainage area.

Mean annual runoff from basins in Ohio ranges from about 10 to 21 inches. The variation in runoff correlates closely with the variation in mean annual precipitation across the state. Mean annual runoff from basins in Ohio accounts for roughly one-third of mean annual precipitation and is remarkably uniform in this regard.

The relationship between runoff and precipitation is expressed by the water balance equation wherein runoff equates to precipitation minus losses plus or minus net change in basin storage. Over a period of years, change in basin storage tends to be negligible such that runoff equates to precipitation minus losses with evapotranspiration accounting for nearly all of the latter.

Annual runoff can depart significantly from mean annual runoff because of year-to-year variation in precipitation, evapotranspiration, and basin storage. During drought years, runoff from streams in Ohio may be as little as 4 inches and account for only 15 percent of annual precipitation. During wetter than normal years, runoff may be as much as 24 inches and account for 50 percent of annual precipitation.

Comparisons of characteristics of flow between streams with different mean annual flows may be facilitated by examination of flow statistics in ratio to the mean annual flow. The ratio adjusts for differences in mean annual runoff as well as drainage area size.

Base Flow

Runoff from drainage basins consists of surface runoff, subsurface runoff, and base flow derived from ground-water sources. Surface runoff and subsurface runoff (also termed interflow or quick return flow) are collectively referred to as direct runoff.

The magnitude of runoff components can be estimated by using hydrograph separation techniques to analyze streamflow records. Estimates of mean annual base flow or ground-water discharge are made from cumulative hydrographs of the base-flow component. Base flow in streams is usually highest in Ohio in late winter and early spring when evapotranspiration is minimal and ground-water recharge is highest. Base flow typically recedes in summer and fall, and it generally constitutes nearly all of streamflow during dry weather (low flow) periods.

Mean annual base flow for a stream is usually given in terms of equivalent inches of water depth uniformly distributed over the entire drainage basin. Alternatively, it may be expressed as a percentage of mean annual streamflow. When expressed in the latter manner, it is termed the mean base-flow index.

Comparisons of base flow in streams are facilitated by use of the mean base-flow index because it adjusts for differences in size of drainage area and amount of mean annual flow. Differences in mean base-flow indices are indicative of variations in basin characteristics other than basin size.

The most important basin characteristics influencing base flow of streams in Ohio are surficial geology and soils. Generally, basins with large deposits of glacial sands and gravels have streams with high base flows while basins in glacial tills have streams with low base flows. Basins in unglaciated areas tend to have streams with moderate base flows.

Mean base flow of streams can vary widely from year to year depending on amount of precipitation, evapotranspiration, and change in basin storage. Long-term streamflow records are therefore needed to obtain accurate estimates of mean annual base flow. The mean base-flow index, being a ratio, is less variable from year to year than runoff itself; therefore, reasonable estimates of the index may be obtained from short-term streamflow records. Mean base-flow indices for streams in Ohio range from about 15 to 85 percent.

Flow Duration

Duration analysis of streamflow records provides information about the percent of time that various flow rates are equaled or exceeded. The analysis generally involves arranging mean daily discharge data in order of magnitude and subdividing the ordered data according to percentages of time that specific flows are equaled or exceeded. Duration flows represent the converse of percentile flows, the latter being flow rates that are greater or equal to a given percent of daily mean streamflows.

A large amount of significant generalized information about regimen of flow in streams can be interpreted from flow duration data. Flow duration curves and tables provide information in condensed form that is advantageous for comparing flow characteristics of streams. Discharge in cubic feet per second per square mile is used to facilitate comparison between streams.

Flows that are equaled or exceeded 90 percent of the time approximate the modal or most common rate of flow in streams. These flows are almost entirely from ground-water sources and are indicative of the relative amount of ground-water storage that is effective in maintaining dry-weather flow. Streams with relatively high 90-percent duration flows generally have large amounts of ground-water storage to sustain flows. The 90-percent duration flows of streams in Ohio range from zero to about 0.4 cubic feet per second per square mile.

Streams with large amounts of ground-water storage typically have relatively high 50-percent duration flows as well. Streams with limited amounts of ground-water storage may exhibit relatively high 50-percent duration flows and low 90-percent duration flows because storage is rapidly depleted and insufficient to sustain flows. Streams with little ground-water storage generally have relatively low 50-percent and 90- percent duration flows. The 50-percent duration flows of streams in Ohio range from about 0.1 to 0.8 cubic feet per second per square mile.

Comparison of the 10-percent duration flows of streams can assist in giving a more complete picture of flow characteristics. Although flood flows occur much less than 10 percent of the time, relatively high 10-percent duration flows may indicate a tendency for rapid runoff following heavy rainfall. Generally, the 10-percent duration flow will be high if the 50-percent duration flow is low. The 10-percent duration flows for streams in Ohio range from about 1.7 to 4.3 cubic feet per second per square mile.

Frequency of Flow Events

Frequency analysis of streamflow data provides information about the probability of occurrence of specific flow events. The analysis generally entails ranking events in order of magnitude and assigning frequencies based on a recurrence interval formula. Frequency distribution functions may be fitted to recurrence interval data to extrapolate in time beyond the period of record. Regionalization through regression analysis permits flow data to be extended in space to obtain estimates of flow statistics at short-term or partial-record sites.

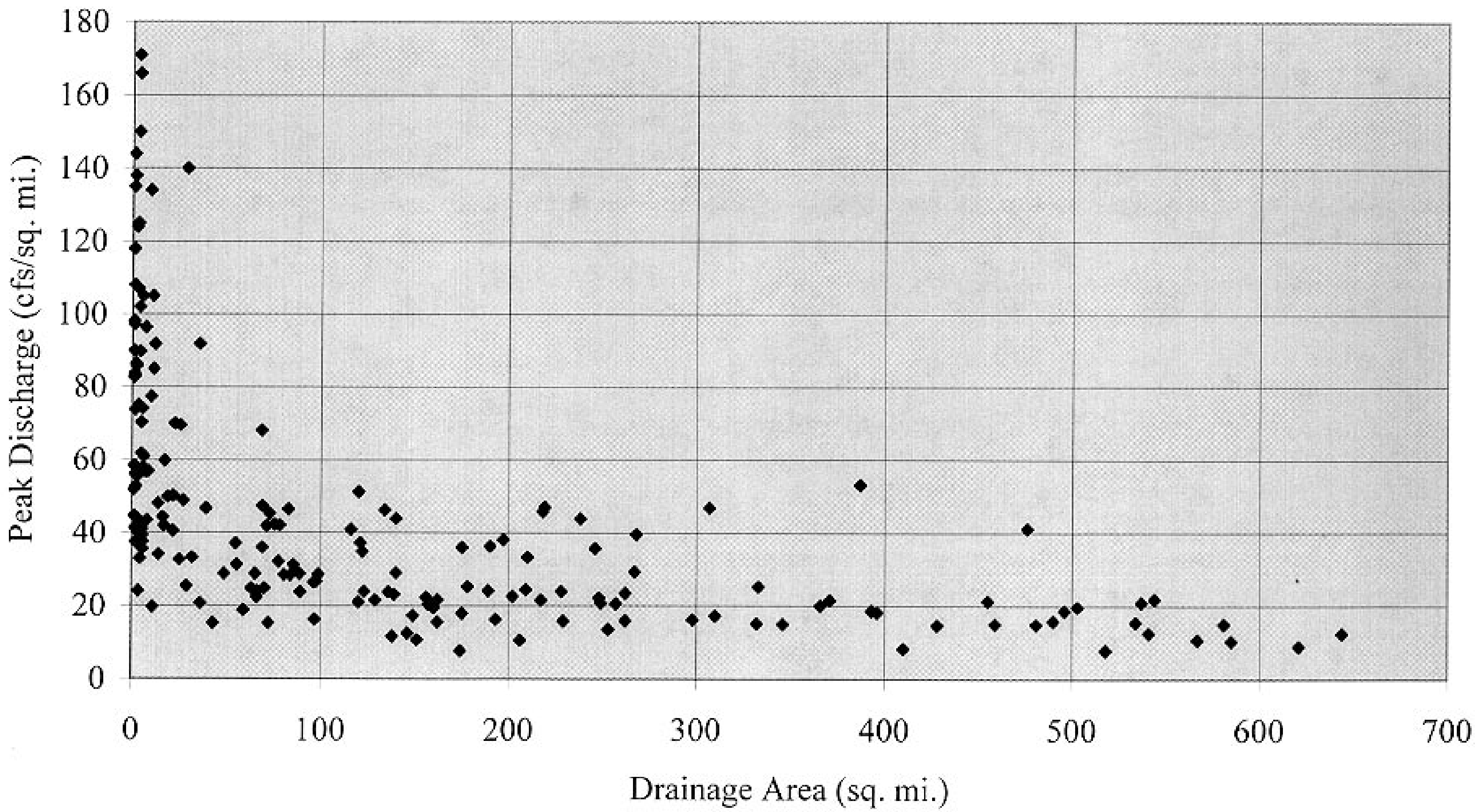
Frequency analysis of streamflow data can provide estimates for many types of flow events. A flow event of particular interest for evaluation of low-flow regimens is the mean 7-day low flow that occurs on average once every other year. This average 7-day, 2-year low flow is closely related to the 90-percent duration flow. The ratio of the average 7-day, 2-year low flow to the mean annual flow is a useful index for comparing sustained flows of streams in Ohio. These ratios or indices range from zero to about 0.4 for streams in Ohio.

Low-flow events corresponding to the average 7-day, 10-year low flow, a threshold statistic significant for waste load allocation in streams, represents flow rates considerably less than the average 7-day, 2-year event. The average 7-day, 10-year low flow usually equates to flow duration equaled or exceeded 95 to 98 percent of the time.

Frequency analysis of streamflow data for high-flow events typically involves estimates of flood-peak discharges for 2-, 10-, 25-, 50-, and 100-year recurrence interval events. Flood-peak discharges represent streamflow that is generally equaled or exceeded 2 percent or less of the time. The 2-year flood-peak discharge is useful for comparison of high-flow regimes because of the relatively high degree of accuracy of estimate.

Estimates of 2-year flood-peak discharge at gaging sites with long-periods of record can be made with a relatively high degree of statistical accuracy due to the relatively large number of 2-year flood-peak discharge events likely to have occurred during the period of record. A plot of 2-year flood-peak discharge versus drainage area for streams in Ohio is shown in figure 5. The plotted data shows a definite trend of lower peak discharge per square mile of drainage area as basin size increases. This is due primarily to different storm rainfall characteristics and attenuation of peak flows by channel and floodplain storage. Variation of flood-peak discharges for given size drainage area reveals the influence of basin characteristics other than size on flood-peak discharge. The relation between

Figure 5. Relation between Drainage Area and 2-Year Reccurence Interval Flood-Peak Discharge for Streams in Ohio



drainage area and flood-peak discharge is useful for comparing high-flow regimes of streams with similar drainage area to identify likely factors causing differences in high-flow characteristics.

A relationship exists between the 2-year flood-peak discharge and geometry of alluvial channels in Ohio, specifically the active channel width (Webber, 1981). The active channel width or bankfull width is defined by a break in the relatively steep bank slope of the stream channel to the more gently sloping surface beyond the channel and coincides with the lower limit of permanent vegetation. Bankfull width of alluvial channels is related mathematically to other channel geometry including meander form. Bankfull flows transport the majority of sediment over a long period of time and are the most significant flows influencing formation and maintenance of channels. The 2-year flood-peak discharge may provide useful information for comparing morphology of alluvial streams in Ohio.

DESCRIPTIONS OF BASINS AND CHARACTERISTICS OF FLOW

Ohio lies along the topographic divide between the Lake Erie drainage and the Ohio River drainage. The relatively low divide is about 750 feet above mean sea level at Fort Wayne and rises irregularly across Ohio toward the northeast approaching Lake Erie closely in the northeast corner of the state. Because of its low profile, the divide has little effect on climatic factors in Ohio except in the snow belt southeast and east of Cleveland where the Portage Escarpment flanking the divide to the north provides orographic lift for significant lake effect precipitation.

The divide between the Lake Erie drainage and the Ohio River drainage in Ohio crosses the Till Plains and Glaciated Allegheny Plateaus roughly along the path of the Wabash End Moraine. All of the land in the Lake Erie Basin is glaciated while only part of the land in the Ohio River Basin is glaciated. Glaciations profoundly influenced stream formation in Ohio.

Streams in the Lake Erie Basin are more youthful than those in the Ohio River Basin and tend to be smaller and shorter. Streams draining to the Ohio River are more deeply entrenched. Mean annual flows or yields of streams draining to Lake Erie are generally lower than those draining to the Ohio River due to latitudinal variation in mean annual precipitation. Yields of streams in the snow belt deviate from this general pattern and are relatively high because of higher mean annual precipitation in the area.

The divide between the Lake Erie drainage and the Ohio River drainage crosses boundaries of physiographic regions, major geologic formations, soil regions, and major land resource areas in the state. This manner of cross cutting is also typical of drainage divides of the larger stream basins in the state. Basin characteristics therefore tend to have a degree of spatial variation that is reflected in the flow characteristics of the streams.

This section describes drainage basins and flow characteristics of streams in Ohio beginning with those in the Lake Erie Basin followed by those in the Ohio River Basin. The basin descriptions include discussion of physiology, geology, soils, land use, water development, and characteristics of flow. Each description includes a basin map and a table of flow characteristics at streams gaging sites. All of the base-flow indices and flood peak discharges given in the tables are for unregulated flows; flow duration and low-flow frequency data include some regulated flows. Data in the tables are from the following sources: U. S. Geological Survey, Water Resources Investigations Report 01-4140, Low-Flow Characteristics of Streams in Ohio through Water Year 1997; Ohio Department of Natural Resources, Division of Water, Bulletin 46, Use of Stream Records and Basin Characteristics to Estimate Ground-Water Recharge Rates in Ohio; U. S. Geological Survey, Water Resources Investigations Report 89-4126, Techniques for Estimating Flood-Peak Discharges for Rural, Unregulated Streams in Ohio.

LAKE ERIE BASIN

About 30 percent of the land in Ohio is in the Lake Erie Basin. Land draining to Lake Erie includes all of the Huron-Erie Lake Plain in Ohio and portions of the Till Plains and Glaciated Allegheny Plateaus.

Streams east of Cleveland gather headwaters in the Glaciated Allegheny Plateaus and flow across a narrow band of Lake Plain to Lake Erie. The larger streams have cut deep gorges through the Portage Escarpment. These are relatively steep gradient streams except for the Grand River that has moderate gradient. They have some of the highest yields of any in the state primarily due to relatively high amounts of mean annual precipitation.

Streams tributary to Lake Erie between Cleveland and Sandusky flow at more moderate gradient than those east of Cleveland but at greater gradient than those west of Sandusky. Most of these streams gather headwaters in the Galion Galciated Plateau and flow across the Berea Headlands before crossing the narrow Lake Plain to Lake Erie.

The larger streams west of Sandusky gather headwaters in end moraines of the Till Plains and flow at relatively low gradient to the Lake Plain where they continue at very low gradient to Lake Erie. These are some of the lowest yielding streams in the state mainly due to relatively low mean annual precipitation.

The basin descriptions given in this section build on the descriptive material given in Division of Water, Bulletin 31. The data tables include recent estimates of flow characteristics at stream gaging stations in the basins.

MAUMEE RIVER BASIN

The Maumee River drains 6,608 square miles including 4,862 in Ohio, 1,283 in Indiana, and 463 in Michigan. The Maumee forms at the confluence of the St. Joseph River and the St. Marys River and flows about 150 stream miles to its mouth in Maumee Bay. The map in figure 6 shows the outline of the basin and flow paths of the main watercourses.

The St. Joseph River and the St. Marys River are both ice front streams that flow along the outer edge of the Fort Wayne Moraine. These rivers discharged to the west before retreat of the glacial ice allowed flow along the present day Maumee. Each river is about 100 miles long. Drainage area of the St. Joseph River at Fort Wayne is 1,085 square miles while that of the St. Marys is 839 square miles.

East Branch and West Branch of the St. Joseph River gather headwaters in the morainal hills of southern Michigan and flow into Ohio joining north of Montpelier. All of the larger tributaries to the St. Joseph lie northwest of the river and gather headwaters in the Wabash Moraine. The largest of these tributaries are Fish Creek with a drainage area of 109 square miles and Cedar Creek with a drainage area of 273 square miles.

Headwaters of the St. Marys River gather along the St. Johns Moraine and flow northward through the Wabash Moraine to the Fort Wayne Moraine. Numerous small tributaries gather along the Wabash Moraine and join the St. Marys as it flows toward Fort Wayne. The largest of these tributaries are Black Creek with a drainage area of 54 square miles and Blue Creek with a drainage area of 82 square miles.

The drainage area of the Maumee River increases from 1,924 square miles at Fort Wayne to 2,315 square miles at Defiance through addition of relatively small drainages along its course, the largest being Gordon Creek with 44 square miles of drainage area. At Defiance, the drainage area of the Maumee and the size of the river channel increase dramatically with the addition of the Tiffin River drainage of 777 square miles and the Auglaize River drainage of 2,435 square miles.

The Tiffin River originates in the morainal hills northwest of Morenci, Michigan in the same general area as the East Branch of the St. Joseph River. Bean Creek, as the Tiffin River is known in Michigan, enters Ohio near Powers in Fulton County and flows southwestward to its confluence with the Maumee River at Defiance. The larger tributaries to the Tiffin in downstream order are Beaver Creek, Brush Creek, Lick Creek, and Mud Creek with drainage areas of 45, 66, 106, and 59 square miles, respectively.

The Auglaize River originates along the St. Johns Moraine and flows westward along the distal side of the Wabash Moraine to Wapakoneta where it turns abruptly northward. The river crosses the Fort Wayne Moraine as it enters Allen County and is joined by Jennings Creek with a drainage area of 69 square miles just north of Delphos. In Putnam County the Ottawa River with a drainage area of 365 square miles joins the Auglaize doubling its drainage area to 703 square miles. Not far downstream, the Blanchard River with a

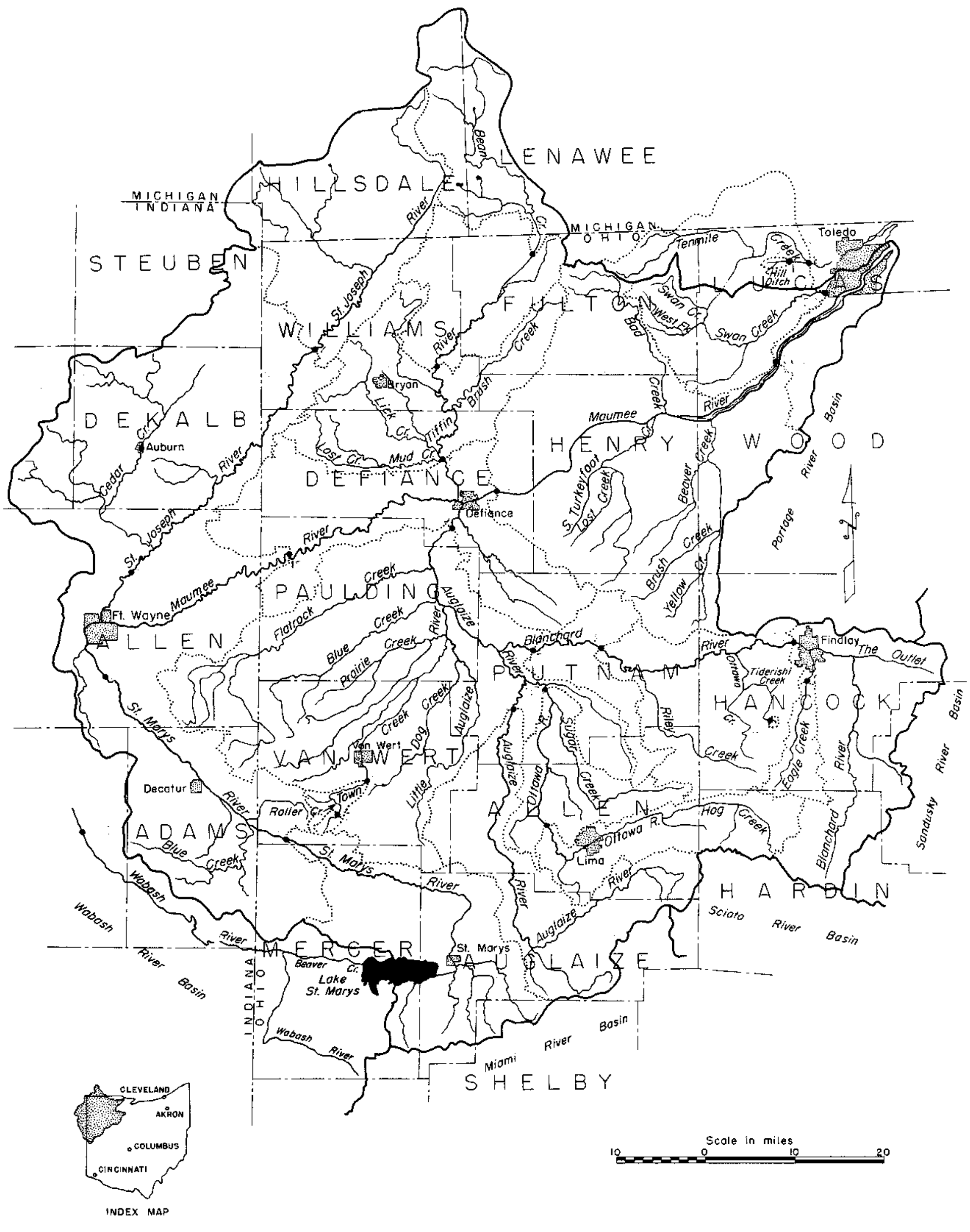


Figure 6. Map of Maumee River Basin.

drainage area of 771 square miles joins the Auglaize, doubling its drainage area to 1,496 square miles. Major tributaries to the Auglaize between the Blanchard and the Maumee in downstream order include Little Auglaize River, Blue Creek, Flatrock Creek, and Powell Creek with drainage areas of 405, 108, 195, and 98 square miles, respectively.

From the confluence with the Auglaize River, drainage area of the Maumee River increases from 5,528 square miles to 6,608 square miles at Maumee Bay. The largest tributaries contributing to the increase in downstream order are South Turkeyfoot Creek, North Turkeyfoot Creek, Bad Creek, Beaver Creek, and Swan Creek with drainage areas of 149, 75, 65, 186, and 204 square miles, respectively.

The Ottawa River (Ten Mile Creek) lies north of the Maumee River and drains 172 square miles directly to Lake Erie. Some of the land west of the Ottawa River drainage in northern Fulton County drains to the River Raisin in Michigan.

Physiography

The central portion of the Maumee River Basin is in the Huron-Erie Lake Plains while peripheral areas are in the Till Plains. The Ottawa River and bordering tributaries to the River Raisin are in the Lake Plains.

Headwaters of the St. Joseph River and its western tributaries gather along the Wabash Moraine in the Steuben Till Plain, a hummocky terrain of moderately low relief with rolling hills, interspersed flats and closed depressions, wetlands, and deranged drainage. The main stem of the river flows in the Central Ohio Clayey Till Plain along a highly sinuous course at average gradient of about 1.5 feet per mile. Headwaters of the St. Marys River gather along the St. Johns Moraine in the Central Ohio Clayey Till Plain. The St. Marys flows across the Central Ohio Clayey Till Plain at an average gradient of about 2.5 feet per mile and joins the St. Joseph River at the western edge of the Maumee Lake Plain. The moraine along the southern boundary of the basin is gently rolling and more subdued than the hummocky moraine along the boundary in the Steuben Till Plain.

The Maumee River between Fort Wayne and Defiance meanders along a winding course with a very low gradient of about 1.2 feet per mile. The river flows onto the Paulding Clay Bottom not far inside Ohio and joins the Tiffin and Auglaize River at the eastern edge of the Paulding Plain in Defiance.

Headwaters of the Tiffin River gather in the hummocky terrain of the Steuben Till Plain and flow across the Central Ohio Clayey Till Plain onto the Maumee Lake Plain. The Tiffin flows across the Maumee Sand Plains in Fulton County as does Brush Creek, its major eastern tributary. Along its lower reaches, the Tiffin flows across the Paulding Clay Bottom.

Headwaters of the Auglaize River gather along the St. Johns Moraine in the Central Ohio Clayey Till Plain. The river flows along a winding course at average fall of about 3.2 feet per mile northward to its confluence with the Maumee. The Auglaize crosses from till plain to the lake plain in northern Allen County and enters the Paulding Clay Bottom in Putnam County. The largest tributary to the Auglaize, the Blanchard, originates in Hardin County on the Central Ohio Clayey Till Plain and flows north to the Findlay Embayment, a lacustrine plain with relatively coarse sediments. The Blanchard flows at average fall of about 1 foot per mile along the Findlay Embayment and Defiance Moraine onto the Paulding Clay Bottom in western Hancock County. Streams in the Auglaize River Basin have cut through thin till to bedrock in many locations. Channel bottoms of bedrock with shifting alluvial sediments are common along lower reaches of the Blanchard River.

The Maumee River between Defiance and Maumee Bay flows in a much more linear pattern than the reach between Fort Wayne and Defiance. Gradient of the river is very low averaging about 1.2 feet per mile, but the gradient varies considerably. Between Waterville and Maumee, the river flows on bedrock at gradient of about 5 feet per mile. North Turkeyfoot Creek, South Turkeyfoot Creek, and Beaver Creek are mainly confined to the Lake Plains while Bad Creek and Swan Creek flow across areas of the Sand Plains before joining the Maumee. Waters of the Ottawa River gather on the Lake Plains and flow across the Sand Plains to the lake.

Geology

The Maumee River Basin lies along the western flank of the Findlay Arch where Silurian, Devonian, and Mississippian-age rocks occur at or near the surface. Rocks in the eastern part of the basin along the axis of the arch are the oldest with successively younger rocks surfacing toward the northwestern part of the basin. The bedrock in the basin is relatively dense with limited ground water storage in rock fractures. Although rock exposures along streams in the basin are common, the effect of ground water discharge from the rock on base flows is not great.

Surficial deposits in the Lake Plains portion of the basin consist of wave-planed glacial till and lacustrine deposits of fine sand, silt, and clay. These deposits are of low permeability in most areas, but deep deposits of relatively permeable sand exist mainly in the sand plains. Beach ridges in the Lake Plains generally consist of shallow permeable sand with limited ground-water storage that is typically perched on top of low permeability till or lake clays.

Surficial deposits in the Till Plains portion of the basin consist of glacial drift and lacustrine deposits. The glacial drift is in the form of ground moraine with a series of end moraines superimposed as morainal belts. Thickness of the ground moraine atop the bedrock varies greatly within the basin and is generally of low permeability. Lens of permeable sand and gravel are common in much of the thicker ground moraine. Some lacustrine areas of relatively impermeable silt and clay exist amid the ground moraine in the southern portion of the basin.

Four morainal belts cross the southern portion of the basin including the Defiance, Fort Wayne, Wabash, and St. Johns. Portions of the St. Johns Moraine along the southern boundary of the basin contain permeable sands and gravel in the form of kames and eskers. The other moraines contain limited amounts of permeable deposits. The Fort Wayne and Wabash Moraines extend northward from Fort Wayne across extreme northwestern Ohio into southern Michigan. Deep permeable sands and gravel along these moraines store considerable ground water to sustain stream flows.

Soils

The Lake Plains in the central portion of the Maumee River Basin are dominated by Hoytville-Nappanee-Paulding-Toledo soils of Soil Region 1. The Till Plain portions of the basin are dominated by Blount-Pewamo-Glywood soils of Soil Region 3.

Slowly permeable Hoytville clay loam is the most wide spread soil in the Maumee Lake Plains. Toledo clay soils dominant the Paulding Clay Plain and lake plain areas in and around Toledo. The Sand Plains and beach ridges contain areas of moderate to rapidly permeable soils including Ottokee, Tedrow, and Oakville sandy loams and sands.

The extensive areas of slowly permeable soils and limited ground water storage that exist in most of the basin results in low volumes of ground water discharge to sustain base flows of streams. Streams that gather headwaters in the morainal hills along the northwestern part of the basin, however, receive substantial ground water discharge to sustain base flows.

Land Use

The Maumee River Basin is in parts of two Land Resource Regions. The central part of the basin is in the Erie-Huron Lake Plain Resource Area of the Lake States Fruit, Truck and Dairy Region while peripheral areas are in the Indiana and Ohio Till Plain Resource Area of the Central Feed Grains and Livestock Region.

Although the Maumee River Basin includes some major urban centers, the majority of the land in the basin is used for farming. Cash grain crops and specialty crops such as tomatoes and sugar beets dominate farming operations in the Lake Plains area. Feed grains and livestock are prevalent in the Till Plains, and cash grain farming is an important part of these operations. Toledo is a major grain export terminal supplying world markets.

Removal of forest cover in the Maumee River Basin for agriculture has been so extensive that only about 3 to 5 percent of the land remains wooded. Scattered woodlots and river corridors account for most of the woodland. The largest contiguous woodlands are on the Sand Plains in the Oak Openings Metro Park and Maumee State Forest.

Surface and subsurface drainage works completed to eliminate the Black Swamp and facilitate farming operations in the Maumee River Basin are some of the most extensive works of this type that exist anywhere. Most of the headwater channels and tributaries of the major streams in the southern part of the basin are channelized. Extensive surface drainage modifications were completed before systematic stream flow measurements began in the 1920s. Historic observations of flow conditions before major drainage work in the basin are sparse.

Water Development

The relatively flat topography of the Maumee River Basin presents few good sites for development of on-stream reservoirs, and not many large ones have been constructed. Cedarville Reservoir on the St. Joseph River is an important on-stream reservoir that supplies Fort Wayne. At Defiance, there is a relatively large hydroelectric power dam on the Auglaize River. Grand Lake straddles the Lake Erie-Ohio River divide capturing water from tributaries of the Wabash River and St. Marys River for the Ohio-Erie Canal. There are three large low head dams of canal era vintage on the Maumee River at Independence and Grand Rapids.

Off-stream reservoirs are well suited for storage of water supply in the Maumee River Basin and are common. These reservoirs are created by enclosing land with earth embankments. Water is pumped from nearby streams during high flow periods to fill the impoundment. Communities in the basin with off-stream storage reservoirs include: Lima, Van Wert, Paulding, Findlay, Ottawa, Archbold, Wauseon, Delta, Swanton, and Metamora.

Many of the smaller communities in the Maumee Basin obtain adequate source of supply from bedrock aquifers, but development of large quantities of supply from these aquifers is generally restrained by dewatering conflicts and highly mineralized water at greater depths.

Abundant sand and gravel deposits in deep till in extreme northwestern Ohio and neighboring areas of Michigan and Indiana yield ground water for communities in the area. Auburn, located along Cedar Creek in Indiana, has the largest ground water supply system in the Maumee Basin. Wapakoneta with the second largest is situated over a sizeable outwash area along the Wabash Moraine.

Many industries in the Maumee Basin obtain part or all of their supply from ground water sources. Return flows from independent industrial supplies significantly augment stream flows at Fort Wayne and Lima.

Most communities located along the Maumee River downstream from Fort Wayne obtain supply from the river. Bowling Green, although not located along the river, obtains its supply from the river and discharges wastewater to the Portage River Basin. Toledo and Oregon obtain large quantities of water supply directly from Lake Erie. Toledo distributes water as far west as eastern Fulton County.

Flow Characteristics

Recent estimates of flow characteristics are available for 37 stream gaging stations in the Maumee River Basin and 2 stations in the Ottawa River Basin. Selected flow characteristics at these gaging sites are given in table 1.

The Maumee River Basin includes streams with some of the lowest mean annual flows in the state. Mean annual runoff of the Maumee River at Waterville equates to 10.7 inches, ranking at the low end of the range for Ohio streams. Mean annual precipitation is relatively low and fairly evenly distributed across the basin such that mean annual runoff of streams deviates little from that at Waterville.

Mean annual runoff is slightly higher in the northwestern part of the basin than elsewhere. Mean annual runoff of the St. Joseph River and Tiffin River each equate to about 11 inches. The Maumee River at Antwerp has mean annual flow of 10.9 inches, an amount that is representative of runoff from both the St. Marys River and St. Joseph River. Mean annual runoff of streams in the southern portion of the basin is generally lower than those in the northwestern part of the basin. Mean annual flow of the Auglaize River near Defiance is 10.4 inches. The relatively high mean annual runoff in table 1 for the Auglaize River near Fort Jennings includes a wetter than normal period of record and canal diversions from Grand Lake. Municipal and industrial water supply operations at Lima result in relatively high mean annual flow of 11.1 inches in the Ottawa River at Allentown. The Blanchard River at Findlay with 10.1 inches of runoff is the lowest registered in the basin. Mean annual runoff of the Ottawa River at Toledo and Swan Creek are probably at least as low as the Blanchard because of lower mean annual precipitation near the lake. The 11.2 inches of runoff given in Table 1 for the Ottawa River at Toledo is high because of imported water from Lake Erie and a period of record covering wetter than normal years.

Base-flow characteristics of streams in the Maumee River Basin are much more variable than mean annual flow characteristics. Mean base-flow indices indicate that ground water may contribute as little as 25 percent of mean annual flow of streams in the southern till plains area of the basin while streams in the northwestern part may derive as much as 65 percent of mean annual flow from ground water discharge. Streams in the latter category include the St. Joseph River and Tiffin River that originate in the morainal hills of southern Michigan and receive ground-water contributions from abundant sand and gravel deposits. The relatively low mean base-flow index of Unnamed Tributary to Lost Creek at Farmer of 25.6 is noteworthy because it is indicative of the minimal ground water that tributaries to the lower Tiffin River receive from the inner flank of the Fort Wayne Moraine. Streams representative of the relatively low base-flow indices in the southern portion of the basin include Town Creek near Van Wert that originates on the inner flank of the Fort Wayne Moraine and Eagle Creek at Findlay that originates on the ground moraine south of Findlay. Swan Creek with a relatively high mean base-flow index of 50 apparently receives substantial ground-water contribution from the extensive deep sand deposits of the Maumee Sand Plains.

Fifty percent duration flows of streams in the Maumee River Basin vary in similar manner as the base-flow indices. The median flows for streams in the upper basin are moderate at about 0.3 cfs per square mile indicating moderate amounts of ground-water storage to sustain base flows. Fifty percent flows of streams in the southern till plain areas of the basin are relatively low, averaging about 0.2 cfs per square mile indicating minimal amounts of ground-water storage to sustain flows. The 50-percent duration flow of the Maumee River at Waterville of 0.27 cfs per square mile indicates moderate amounts of ground-water storage exist in the basin to sustain base flows. The unusually high 50-percent duration flow of 0.37 cfs per square mile given in Table 1 for the Maumee River near Defiance is for a relatively short and wetter period of record. The lowest 50-percent duration flows occur in the Blanchard River Basin. Eagle Creek with 50-percent duration flow of 0.11 cfs per square mile is very low.

Streams in the western and northwestern parts of the Maumee River Basin have higher 90-percent duration flows than those in other parts of the basin. Bean Creek at Powers with 90-percent duration flow of 0.08 cfs per square mile is highest in the basin. Tributaries downstream of Powers like Beaver Creek near Stryker with 90-percent duration flow of 0.03 cfs per square mile contribute relatively less ground water to sustain stream flow resulting in 90-percent duration flow for Tiffin River at Stryker of 0.06 cfs per square mile. East Branch of St. Joseph River near Pioneer with 90-percent duration flow of 0.06 cfs per square mile is representative of the St. Joseph Basin. The 90-percent duration flow of 0.07 cfs per square mile of the Maumee River at Antwerp reflects augmentation at Fort Wayne as the relative base flow in the St. Marys River is less than in the St. Joseph River.

The 90-percent duration flows of streams in the Auglaize River Basin are low compared to those in the upper part of the Maumee Basin. The 90-percent duration flow of the Auglaize River near Defiance of 0.017 cfs per square mile is representative of base-flow conditions in the basin. The Auglaize River at Uniopolis gathers along the St. Johns Moraine where it receives limited ground-water contribution to sustain 90-percent duration flow of 0.013 cfs per square mile. The 90-percent duration flow of the Auglaize River at Buckland reported in Bulletin 40 is 0.025 cfs per square mile. Ground-water contributions from outwash deposits at Wapakoneta and wastewater discharge add to base flow at the Buckland station. The 90-percent duration flow of the Auglaize River near Fort Jennings is relatively high at 0.05 cfs per square mile reflecting further contribution to base flow from Grand Lake canal diversions and wastewater discharge at Delphos. The 90-percent duration flow for Ottawa River at Allentown of 0.119 cfs per square mile is exceptionally high for the Maumee Basin and due primarily to wastewater discharge at Lima and return flows from independent industrial supplies. Smaller streams such as the Blanchard River at Mount Blanchard and Eagle Creek near Findlay have 90-percent duration flows of zero or near zero. The 90-percent duration flow of the Blanchard River at Findlay of 0.025 cfs per square mile is relatively low despite the gage location directly downstream of the wastewater outfall for Findlay. The relatively low 90-percent duration flow of 0.008 cfs per square mile for North Turkeyfoot Creek near Liberty Center is typical of tributary streams in clayey areas of the Maumee Lake Plain.

The relatively high 90-percent duration flow of the Ottawa River at Toledo of 0.06 cfs per square mile is for a period of record that includes substantial upstream wastewater discharge at Sylvania. Bulletin 40 gives 90-percent duration flow of 0.008 cfs per square mile based on period of record before relatively large amounts of wastewater where discharged.

The 10-percent duration flows of streams in the Maumee River Basin are relatively low averaging about 2.2 cfs per square mile. Peak discharges for 2-year recurrence interval floods are also relatively low averaging about 8 cfs per square mile for the larger streams and proportionately more for smaller streams. Low permeability of soils in much of the basin favors direct surface runoff, but the flat topography tends to attenuate flood peaks. Areas of hummocky terrain in the northwestern parts of the basin contain large amounts of natural storage that attenuates flood peaks. Floods in the Maumee Basin are characterized by slowly rising flood stages of prolonged duration. Extensive channelization in the basin has resulted in many enlarged channels.

TABLE 1

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Maumee River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	50% (cfs (cfs/sq. mi.))	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Hill Ditch near Richards 04176900	3.52	-	-	-	-	-	-	85 (24.1)
Ottawa River at Toledo 04177000	150	130 (0.87) (11.8)	40.2	335 (2.23)	45 (0.30)	9.1 (0.061)	6.6 (0.051)	-
East Branch St. Joseph River near Pioneer 04177100	158	-	-	-	-	9.1 (0.058)	9.6	-
Eagle Cr. Trib. near Montpelier 04177400	1.84	-	-	-	-	-	-	69 (37.5)
St. Joseph River Near Blakeslee 04177500	394	-	58.6	-	-	-	-	-
Fish Creek at Hamilton, Indiana 04177720	37.5	-	-	-	-	-	-	346 (9.2)
St. Joseph R. near Newville, Indiana 04178000	610	495 (0.81) (11.0)	-	-	-	-	-	4330 (7.1)
St. Marys River at Decatur, Indiana 04181500	621	488 (0.79) (10.7)	-	-	-	-	-	5580 (9.0)
Maumee River at Antwerp 04183500	2129	1710 (0.80) (10.9)	-	4770 (2.24)	636 (0.30)	149 (0.070)	122 (0.071)	14100 (6.6)
Race Track Run at Hicksville 04183750	0.34	-	-	-	-	-	-	46 (135)

TABLE 1

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Maumee River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	 50% cfs (cfs/sq. mi.)	 90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Bean Creek at Powers 04184500	206	167 (0.81) (11.0)	65.4	416 (2.02)	64 (0.31)	17 (0.083)	14 (0.084)	2180 (10.6)
Spring Creek at Fayette 04184750	2.58	-	-	-	-	-	-	240 (93.0)
Bean Creek Trib. near Fayette 04184760	0.56	-	-	-	-	-	-	53 (94.6)
Tiffin River at Stryker 04185000	410	333 (0.81) (11.0)	-	938 (2.29)	125 (0.30)	23 (0.056)	18 (0.054)	3450 (8.4)
Beaver Cr. Trib. near Montpelier 04185150	0.40	-	-	-	-	-	-	75 (188)
Beaver Creek near Stryker 04185200	44.8	-	-	-	-	1.4 (0.031)	1.1	-
Unnamed Trib. to Lost Cr. near Farmer 04185440	4.23	4.32 (1.02) (13.9)	25.9	8.7	0.6	0	0	-
Auglaize River near Uniopolis 04185795	89.3	-	-	-	-	1.2 (0.013)	1.0	-
Auglaize R. Trib. near Spencerville 04185945	0.51	-	-	-	-	-	-	75 (147)
Auglaize River near Fort Jennings 04186500	332	307 (0.92) (12.5)	-	746 (2.25)	83 (0.25)	18 (0.054)	12 (0.039)	5040 (15.2)
King Run near Harrod 04186800	0.53	-	-	-	-	-	-	88 (166)

TABLE 1

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Maumee River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Ottawa River at Allentown 04187500	160	131 (0.82) (11.1)	-	288 (1.80)	36 (0.23)	19 (0.119)	18 (0.137)	3100 (19.4)
Rattlesnake Cr. near Cairo 04187945	1.45	-	-	-	-	-	-	120 (82.8)
Blanchard River at Mount Blanchard 04188300	109	-	-	-	-	0.3 (0.003)	0.2	-
Eagle Creek near Findlay 04188500	55.0	48.0 (0.87) (11.8)	25.7	102 (1.85)	6.0 (0.11)	0.1 (0.002)	0	2040 (37.1)
Blanchard River near Findlay 04189000	346	258 (0.75) (10.1)	30.9	634 (1.83)	59 (0.17)	9.7 (0.028)	8.6 (0.025)	5220 (15.1)
Tiderishi Creek near Jenera 04189100	4.65	-	-	-	-	-	-	200 (43.0)
Blanchard River at Glandorf 04189500	644	604 (0.94) (12.7)	35.2	1970 (3.06)	158 (0.25)	22 (0.034)	13 (0.022)	8020 (12.5)
Little Auglaize R. Trib. at Ottoville 04190350	1.04	-	-	-	-	-	-	54 (51.9)
Roller Cr. at Ohio City 04190500	5.14	-	-	-	-	-	-	211 (41.0)
Town Creek near Van Wert 04191000	21.2	-	25.3	-	-	-	-	-
Beetree Run near Junction 04191480	1.66	-	-	-	-	-	-	93 (56.0)

TABLE 1

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Maumee River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Auglaize River near Defiance 04191500	2318	1780 (0.77) (10.4)	-	4990 (2.15)	436 (0.19)	40 (0.017)	39 (0.017)	25600 (11.0)
Powell Creek near Defiance 04191600	95.6	-	-	-	-	0	0	-
Maumee River near Defiance 04192500	5545	5040 (0.91) (12.3)	-	13900 (2.51)	2050 (0.37)	382 (0.069)	285 (0.051)	44200 (8.0)
N. Turkeyfoot Cr. Liberty Center 04192650	74.2	-	-	-	-	0.6 (0.008)	0.4	-
Reitz Run at Waterville 04192900	0.98	-	-	-	-	-	-	36 (36.7)
Maumee River at Waterville 04193500	6330	5002 (0.79) (10.7)	-	14500 (2.29)	1740 (0.27)	277 (0.044)	225 (0.036)	50700 (8.0)
Swan Creek at Toledo 04194000	199	-	52.5	-	-	-	-	-

PORTAGE AND SANDUSKY RIVER BASINS

The Portage River and Sandusky River drain 581 and 1420 square miles, respectively. Streams tributary to Lake Erie between the Portage River and Maumee River drain an additional 362 square miles. The larger of these tributaries are Toussaint Creek, Crane Creek, and Cedar Creek. Muddy Creek lies between the Portage River and Sandusky River and drains 111 square miles into Muddy Creek Bay. The map in figure 7 shows the outlines of the basins and flow paths of the main watercourses.

Headwaters of the Portage River gather in multiple branches along the Defiance End Moraine. The Portage River itself forms at the confluence of Middle Branch and South Branch and flows about 33 stream miles to its mouth at Port Clinton. Drainage areas of Middle Branch and South Branch are 225 and 110 square miles, respectively. North Branch joins the main stem at Pemberville. Drainage area of North Branch is 59 square miles. Originally, it was much larger before being truncated by construction of Cutoff Ditch that diverts 104 square miles of headwater drainage into Beaver Creek, a tributary to the Maumee River. Sugar Creek with a drainage area of 59 square miles joins the main stem below Elmore, and the Little Portage with drainage area of 32 square miles including Nine Mile Creek joins the river near its mouth.

The Sandusky River forms at the confluence of Paramour Creek and Allen Run and extends about 115 stream miles to its mouth in Sandusky Bay. Paramour Creek gathers in morainal hills near Crestline. The Sandusky River is joined by Broken Sword Creek southwest of Nevada. The Broken Sword has drainage area of 95 square miles. Not far downstream, the Little Sandusky contributes 38 square miles of drainage area. Tymochtee Creek drains 302 square miles in the western part of the upper basin and joins the Sandusky about midway between Upper Sandusky and Tiffin. Sycamore Creek, Honey Creek, and Rock Creek flow into the Sandusky from the east contributing 64, 179, and 35 square miles, respectively. Most of the western half of the lower basin is drained by Wolf Creek with a drainage area of 158 square miles. Muskellunge Creek drains 47 square miles of the lower western basin joining the Sandusky north of Fremont. Green Creek drains 81 square miles of the lower eastern part of the basin and joins the Sandusky at its mouth in Sandusky Bay.

Physiography

The Portage River Basin lies almost entirely in the Maumee Lake Plains. Headwaters gather in the Fostoria Lake Plain Shoals, a portion of the Defiance End Moraine lightly eroded by ancient Lake Maumee. The multiple branches of the Portage flow across the Woodville Lake Plain Reefs, a very low relief lacustrine plain punctuated by ancient bedrock reefs thinly mantled with till. Headwaters of Toussaint Creek, Crane Creek, Cedar Creek, and Muddy Creek gather in the Woodville Lake Plain Reefs.

Headwater channels in the Portage River Basin are very low gradient streams averaging about 2 feet per mile. The headwater streams for the most part consist of constructed drainage ditches including many trellis-like networks. Upper reaches of most streams in

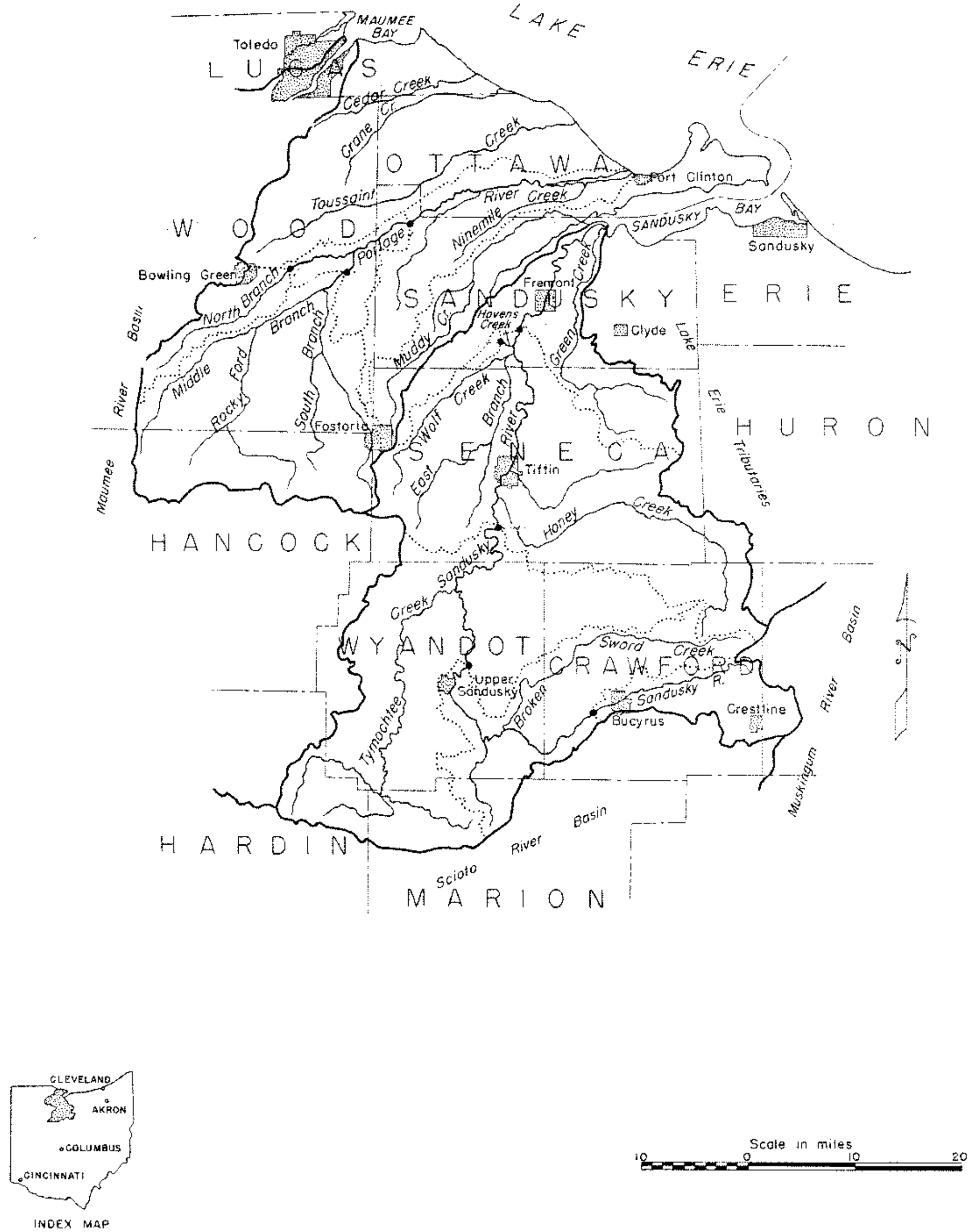


Figure 7. Map of Portage and Sandusky River Basins.

the basin have been channelized. Channel gradients along middle reaches of streams in the basin average about 5 feet per mile. The streams meander in slightly entrenched floodplains. The lower 10 miles of the Portage River below Oak Harbor flows at near lake level. Streams in the Portage River Basin have eroded through the thin till to bedrock in many locations.

The Sandusky River Basin is about equally divided between the Till Plains and the Lake Plains. The upper portion of the basin is in the Central Ohio Clayey Till Plain while the lower portion is in the Maumee Lake Plains. Paramour Creek, at the head of the Sandusky River, gathers in the Galion Glaciated Low Plateau. From the confluence of Paramour Creek and Allen Run, the Sandusky flows southwestward along the outer margin of the Wabash End Moraine. At the Crawford-Wyandot county line, the river crosses the moraine and flows northwest toward Upper Sandusky crossing the Fort Wayne Moraine along the way. About midway between Upper Sandusky and Tiffin the river crosses the Defiance End Moraine. At Tiffin, it leaves the till plain and flows onto the lake plain.

The gradient of the Sandusky River is extremely variable. In some places the fall is 2 feet per mile and in other places, such as north of Tiffin, it is 25 feet per mile. The stream gradient reflects underlying substrates. Just north of Tiffin the substrate is thick erodible deltaic silt; near Fremont the stream flows directly on Silurian dolomite. In many places the river and its tributaries have cut through thin till to bedrock. Cobble and gravel substrate along its reaches consist of rounded granite and carbonate rock fragments. Upper reaches in the Galion Glaciated Low Plateaus contain sandstone and shale bed material. The Sandusky is a mildly entrenched river that meanders considerably along its course.

Geology

The bedrock at or near the surface in the Portage River Basin and nearly all the Sandusky River Basin consists of limestone, dolomite, and shale of Silurian and Devonian age. Headwater streams of the Sandusky are underlain with sandstone, limestone, and shale of Late Mississippian age. The bedrock is relatively dense and ground water storage is not great. The water table in the rock generally lies at or below drainage.

The overburden of glacial drift and lacustrine deposits is generally thin and for the most part consists of materials with relatively low permeability. Sandy lacustrine deposits are generally shallow and underlain by material of low permeability. Fractures in till afford some passages for ground water recharge.

Headwater areas of the Sandusky River gather where drift thickens in end moraines with relatively greater amounts of permeable sand and gravel deposits. The portion of the Defiance End Moraine where the Sandusky crosses contains significant amounts of sand and gravel deposits, and there are buried valleys with permeable deposits in the area. Flowing springs near the river are indicative of a ground water discharge area. East of

Fremont, a shallow buried valley exists along Green Creek. The buried valley contains sand and gravel deposits that yield considerable amounts of ground water.

Soils

Nearly all of the Portage River Basin lies within Soil Region 1. Hoytville silty clay loam occurs over large areas with less extensive areas of Ottokee and Tedrow sandy loam. Toledo silty clay and shallow sandy materials are also common. Low permeability of the Hoytville and Toledo soils restricts ground water recharge.

Soils in the Sandusky River Basin are more varied than in the Portage River Basin. Soil Regions 1, 3, and 5 are represented. Hoytville silty clay loam dominates the lower Lake Plain portion of the basin with less extensive areas of Ottokee and Tedrow sandy loam. Blount-Pewamo-Glynwood soils of Region 3 dominant the upper western portion of the basin while Bennington-Cardington soils of Region 5 dominate the eastern part of the upper basin. Blount-Pewamo-Glynwood soils of the upper western basin have slow permeability similar to Hoytville soils of the lower basin. Bennington-Cardington soils are moderately to slowly permeable.

Land Use

The Portage River Basin is in the Erie-Huron Lake Plain Resource Area. Farmland accounts for the vast majority of land use with most land used for cash grain and specialty crops. Fruit crops are common near the lake. Coastal land between Toussaint Creek and Maumee Bay is largely reserved for wildlife refuges. Rock quarries in the Toussaint drainage discharge significant amounts of ground water to the creek.

The Sandusky River Basin is divided between two land resource areas. The lower basin lies in the Erie-Huron Lake Plain Resource Area while the upper basin is in the Ohio-Indiana Till Plain Resource Area. Land use in the lower portion of the basin is dominated by farmland used for cash grain crops, specialty crops, and fruit crops. The upper portion of the basin is dominated by farmland used for grain crops and livestock production. Pasture and woodland account for about 10 percent of land use. A number of rock quarries discharge ground water to tributaries of the Sandusky River.

Water Development

The largest water developments in the Portage River Basin are the municipal water supply and wastewater systems at Bowling Green and Fostoria. Bowling Green obtains water from the Maumee River and discharges wastewater to North Branch of the Portage. Fostoria pumps water from East Branch into numerous off-stream storage impoundments and discharges wastewater back to East Branch. North Baltimore and McComb obtain their supply from tributaries of Middle Branch by means of off-stream storage. Ground water supplies many of the smaller communities in the basin. The largest systems are at Pemberville, Woodville, and Gibsonburg. Wastewater discharge at Bowling Green significantly augments low flows of North Branch as does discharge from Fostoria into

East Branch. Return flows from other systems impact low-flow characteristics of streams in the basin locally to a lesser degree.

The Sandusky River serves as source of water supply for Bucyrus, Upper Sandusky, Tiffin and Fremont. Bucyrus and Upper Sandusky pump water into off-stream storage while Tiffin and Fremont withdraw water directly from behind low-head dams. The Ballville low-head dam at Fremont has about 180 million gallons of storage. Attica and New Washington obtain source of supply from Honey Creek utilizing off-stream impoundments. An off-stream reservoir near Marseilles in Wyandot County is filled from Tymochtee Creek and supplies water for wetland management on the Killdeer Plains Wildlife Area. A number of communities obtain source of supply from ground water, the largest systems being at Crestline and Carey. Green Springs obtains water supply from wells. Wastewater return flows generated by water supply systems in the basin affect low-flow characteristics of streams to varying degrees.

Flow Characteristics

Recent estimates of flow characteristics are available for 17 stream gaging stations in the Sandusky River Basin and 1 stream gaging station in the Portage River Basin. Selected flow characteristics at these gaging sites are given in table 2.

Mean annual flow of the Portage River at Woodville equates to 10.9 inches of runoff. This amount of runoff is at the low end of the range for Ohio streams and is largely due to relatively low mean annual precipitation in the basin, lowest in the state. The mean base flow index of 26 for the Portage River at Woodville indicates that only about a quarter of mean annual flow is derived from ground-water sources. This relatively low base-flow index is typical of many streams in northwestern Ohio. The 50-percent duration flow of 0.018 cfs per square mile is relatively low, indicating that ground-water storage in the basin is limited. Ground-water recharge is impeded by slowly permeable soils. Relatively impermeable till and clayey lacustrine deposits cover much of the basin. The glacial till and bedrock yield little ground water to sustain flow of streams.

The 90-percent duration flow of 0.023 cfs per square mile for the Portage River at Woodville is low for but not as low as it might be if not for low-flow regulation. Flows from North Branch enter upstream of the Woodville gage and include substantial augmentation from wastewater discharges at Bowling Green. The wastewater discharge has little effect on mean annual flow of the river at Woodville but adds measurably to low flows. Low-flow characteristics of the Portage River at Pemberville upstream of the confluence with North Branch given in Bulletin 40 include 90-percent duration flow of 0.007 cfs per square mile. This value is typical of low-flow characteristics of unregulated streams in the Portage Basin. The 90-percent duration flows of streams with 50 to 100 square miles of drainage area are typically zero or near zero flow. Bulletin 40 includes a 90-percent duration flow estimate for Toussaint Creek at Limestone of 0.95 cfs where the drainage area is 75 square miles. This relatively high value may be more a result of dewatering flows from rock quarries discharging to the creek than natural ground-water discharges.

The 10-percent duration flow of 2.09 cfs per square mile and 2-year recurrence interval flood-peak discharge of 14.8 cfs per square mile for Portage River at Woodville are relatively low values for Ohio streams. Flat topography of the lake plain, low gradient of the channels, and minor entrenchment allow floodwaters to spread out and move slowly downstream attenuating flood peaks. Incidence of high intensity rainstorms is also lower in the basin than elsewhere in the state. These moderating effects on floods are offset somewhat by slowly permeable soils that favor direct runoff and surface drainage works designed to remove excess water.

Mean annual flow of the Sandusky River at Fremont equates to 11.2 inches, typical runoff for most streams in the basin. Areas east of Bucyrus receive greater amounts of annual precipitation, and this is reflected in the higher mean annual flow of 13.2 inches at Bucyrus. The relatively low mean annual flow of 10.3 inches given in Table 2 for Sandusky River at Mexico is mainly due to differences in period of record rather than basin hydrology. Base flow in the Sandusky River generally accounts for about one-third of mean annual runoff. This amount of base flow is in the lower range for streams in Ohio. Fifty percent duration flows at gaging stations along the Sandusky average about 0.2 cfs per square mile, a relatively low value indicating that ground-water storage in the basin is not great.

The 90-percent duration flows at various stations along the Sandusky are uniformly low averaging about 0.03 cfs per square mile. The uniformity of low flows is somewhat contrary to what the physiology of the basin suggests as the till plain of the upper basin yields only modest ground-water accretions to streams and even less to the lake plain of the lower basin.. Low-flow augmentation from municipal wastewater discharges and dewatering flows from quarries contribute to the uniformity of low flows, but the basin geology remains the most important factor determining the low-flow regimen of streams.

Paramour Creek at Leesville and the Sandusky River near North Robinson exhibit relatively high base-flow characteristics compared to those for the Sandusky River at downstream stations. Wastewater discharge at Crestline could account for the higher base flows, as might ground-water discharge from permeable materials in the morainal drift. Low flows of the Sandusky River at Bucyrus are affected by wastewater discharge that enters immediately upstream of the gage, but marked declines in effluent discharge during dry spells has historically lessened the direct impact on low flows.

Between Bucyrus and Upper Sandusky, the river may receive modest contributions of ground water from the end moraine and alluvial deposits bordering the channel. Base-flow characteristics of Broken Sword Creek and Tymochtee Creek are very low with 90-percent duration flow of 0.006 to 0.007 cfs per square mile. The Broken Sword receives little ground-water contribution from the Fort Wayne End Moraine that it flows along. Tymochtee Creek gathers in a lacustrine plain and flows across till plain neither yielding much ground water to sustain flows.

About half of the drainage area of the Sandusky River at Mexico is contained in the Broken Sword and Tymochtee drainages. That by itself should cause less favorable base flow at Mexico than observations reveal. Wastewater discharge at Upper Sandusky and Carey combined with dewatering flows from the rock quarry at Carey provide some augmentation flows but not of sufficient amount to explain the magnitude of base flows at Mexico. The Sandusky River apparently receives significant ground-water contribution as it crosses through the Defiance End Moraine in vicinity of McCutchenville.

Honey Creek at Melmore has base-flow characteristics slightly more favorable than Broken Sword Creek or Tymochtee Creek, but it receives little ground water to sustain flows from the Defiance Moraine that borders it. Rock Creek, that traverses the Defiance Moraine, has relatively high sustained flows, but the drainage area is too small to make much contribution to sustaining flows in the Sandusky.

Streams in the western portion of the lower basin contribute little base flow to sustain flows in the Sandusky River. The 90-percent duration flows of Wolf Creek and East Branch of Wolf Creek reported in Bulletin 40 are zero or near zero flow. Ground-water discharge to sustain flows in lower reaches of the Sandusky below Tiffin may originate with tributaries draining from the east and from rock exposures along the river.

Base flows of Green Creek near Fremont appear as an anomaly in the Sandusky River Basin. The 90-percent duration flow for Green Creek near Fremont reported in Bulletin 40 equates to 0.18 cfs per square mile, an exceptionally high value for the Sandusky Basin. Base flow of Green Creek is sustained by ground-water discharge from artesian springs originating in the limestone bedrock in the Green Springs area.

The 10-percent duration flows for streams in the Sandusky River Basin are comparatively low averaging 2.2 cfs per square mile. The 2-year recurrence interval flood-peak discharges are also relatively low, ranging from about 40 cfs per square mile for smaller gaged streams to about 12 cfs per square mile for the largest streams. Flat to moderately rolling topography of the basin and the relatively mild gradient of streams allows floodwaters to rise at moderate rates and recede gradually. Violent flash floods are not common in the basin. Channel forming flows, being relatively low, tend to favor channels with comparatively narrow bankfull widths. Accelerated runoff is common in headwater areas where streams have been channelized for drainage and flood control purposes.

TABLE 2

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Portage River and Sandusky River Basins

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Portage River at Woodville 04195500	428	335 (0.78) (10.6)	26.5	895 (2.09)	79 (0.18)	10 (0.023)	7.5 (0.022)	6320 (14.8)
Paramour Creek near Leesville 04195950	27.2	-	42.4	-	-	1.2 (0.044)	1.1	-
Sandusky River near North Robinson 04195970	39.7	-	40.4	-	-	1.6 (0.04)	1.3	-
Sandusky River at Bucyrus 04196000	88.8	88.7 (1.00) (13.6)	32.4	201 (2.26)	22 (0.25)	3.1 (0.035)	2.5 (0.028)	2560 (28.8)
Broken Sword Cr. near Nevada 04196200	83.8	-	37.4	-	-	0.5 (0.006)	0.2	-
Sandusky River near Upper Sandusky 04196500	298	245 (0.82) (11.2)	36.1	615 (2.06)	62 (0.21)	8.0 (0.027)	5.3 (0.022)	4830 (16.2)
Saint James Run near Upper Sandusky 04196700	5.3	-	-	-	-	-	-	209 (39.4)
Tymochtee Creek at Crawford 04196800	229	197 (0.86) (11.7)	29.9	571 (2.49)	39 (0.17)	1.7 (0.007)	0.6 (0.003)	3620 (15.8)
Sandusky River at Mexico 04197000	774	590 (0.76) (10.3)	-	1640 (2.11)	144 (0.19)	24 (0.031)	17 (0.029)	8710 (11.3)
Honey Creek near New Washington 04197020	17.0	-	39.5	-	-	-	-	-
Honey Creek near Caroline 04197052	69.0	-	-	-	-	1.2 (0.017)	1.0	-

TABLE 2

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Portage River and Sandusky River Basins

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%**	**90%** cfs (cfs/sq. mi.)	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Honey Creek at Melmore 04197100	149	133 (0.89) (12.1)	32.4	351 (2.36)	30 (0.20)	1.9 (0.013)	1.4 (0.011)	2580 (17.3)
Rock Creek at Tiffin 04197170	34.6	30.4 (0.88) (11.9)	26.2	59 (1.71)	6.4 (0.18)	1.5 (0.043)	1.2 (0.040)	-
Wolf Creek at Bettsville 04197300	66.2	-	32.2	-	-	-	-	1590 (24.0)
E. Branch Wolf Cr. at Fort Seneca 04197400	70.1	-	34.4	-	-	-	-	1740 (24.8)
Havens Creek at Havens 04197500	4.3	-	-	-	-	-	-	142 (33.0)
Sandusky River near Fremont 04198000	1251	1030 (0.82) (11.2)	-	2760 (2.21)	275 (0.22)	39 (0.031)	28 (0.028)	15700 (12.5)
Muskellunge Cr. near Fremont 04198007	41.8	-	-	-	-	0.06 (0.014)	0.04	-

LAKE ERIE TRIBUTARIES BETWEEN THE SANDUSKY RIVER AND THE CUYAHOGA RIVER

The main tributaries to Lake Erie between the Sandusky River and the Cuyahoga River are the Huron River, the Vermilion River, the Black River, and the Rocky River. These streams have drainage areas of 406, 268, 470, and 293 square miles, respectively. Between the Sandusky River and the Huron River, numerous smaller tributaries including Raccoon Creek, Pickerel Creek, Cold Creek, Mills Creek, and Pipe Creek drain about 275 square miles into the lake. Old Woman Creek, immediately east of the Huron River, drains about 27 square miles into the lake. Beaver Creek, located between Vermilion and Lorain, drains about 45 square miles to the lake. The map in figure 8 shows the outlines of the basins and flow paths of the main watercourses.

Headwaters of the Huron River gather along the Fort Wayne and Defiance Moraines. West Branch of the Huron River originates in the Fort Wayne Moraine south of Willard and drains 262 square miles. East Branch originates in the Defiance Moraine east of Willard and drains 88 square miles. The two branches flow relatively close to each other throughout much of the basin. From the confluence of West Branch and East Branch just west of Milan, the Huron River flows about 14 stream miles across the Lake Plain to its mouth in Lake Erie at Huron.

The Vermilion River originates along the Wabash Moraine in northern Ashland County. From its source, the river flows northward to Lake Erie in a relatively narrow, elongated basin receiving drainage from numerous tributaries of comparable size. These include Buck Creek, Southwest Branch, East Branch, and East Fork with 21, 31, 37 and 35 square miles of drainage area, respectively.

Headwaters of the Black River gather along the Defiance Moraine. The two main branches of the river, East Branch and West Branch, join at Elyria draining 222 and 174 square miles, respectively. West Branch and its main tributaries, Wellington Creek and Charlemont Creek, gather as numerous small tributaries along the moraine and flow northward. East Branch initially flows southward along the outer edge of the moraine to Lodi before reversing course and flowing northward through the moraine to Elyria. East Branch is joined at Lodi by West Fork, a main tributary that flows eastward to Lodi along the outer edge of the moraine. From the confluence of East Branch and West Branch, the Black River flows about 16 stream miles to its mouth in Lake Erie at Lorain. French Creek, with drainage area of 37 square miles, is the main tributary to the Black River between Elyria and Lorain.

The Rocky River gathers headwaters in the hilly moraines that cross through Medina County into southern parts of Cuyahoga County. West Branch Rocky River originates south of Medina in the Wabash Moraine and flows through the Defiance Moraine along its northward course draining 190 square miles. North Branch, with drainage area of 38 square miles, joins West Branch at Medina. East Branch Rocky River originates along the distal side of the Defiance Moraine in southern Cuyahoga County and flows

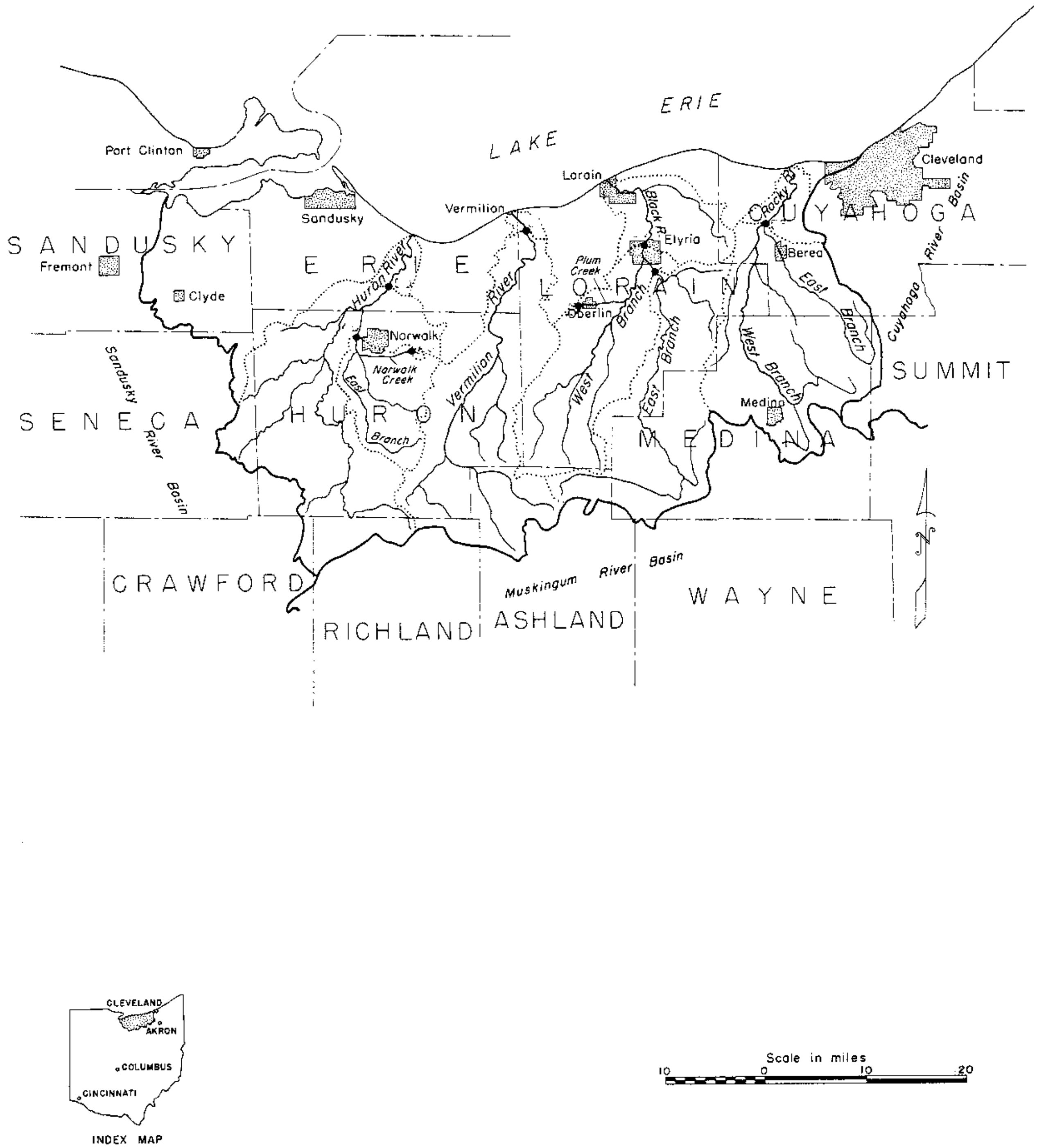


Figure 8. Map of Lake Erie Tributaries between Sandusky River and Cuyahoga River.

southward to the Fort Wayne Moraine where it reverses course and flows back northward through the Defiance Moraine to its confluence with West Branch just north of Berea, draining 77 square miles. From the confluence of East Branch and West Branch, the Rocky River flows about 12 stream miles to its mouth in Lake Erie on the west side of Cleveland.

Physiography

The area draining to Lake Erie between the Sandusky River and the Cuyahoga River includes land in the Huron-Erie Lake Plains, the Till Plains, and the Glaciated Allegheny Plateaus. There is no sharp break between the Till Plains and Lake Plains in the western part of the area. Relief is greater and more pronounced across the escarpments in the eastern part of the area.

Tributaries to Lake Erie between the Sandusky River and Huron River lie in several different physiographic settings. Raccoon Creek and Pickerel Creek are in the extreme eastern part of the Maumee Lake Plains. Cold Creek and Mills Creek are in the Bellevue-Castalia Karst Plain, a hummocky area of rock knobs, sinkholes and large springs thinly mantled by glacial drift. Pipe Creek is in the extreme western part of the Erie Lake Plain. All of these streams are relatively short with moderate gradients.

Three of the larger streams in the area, the Huron, Vermilion, and Black, gather headwaters along the moraines that cross the Galion Glaciated Low Plateau, a rolling upland with thin to thick glacial drift. These streams flow northward from the Plateau across the Berea Headlands and narrow Erie Lake Plain. The Berea Headlands are gently rolling to flat terrain with thin glacial drift atop Berea sandstone. The streams in these basins are moderately entrenched in relatively narrow flat-bottom valleys. The channels are highly sinuous with mild gradients.

Old Woman Creek and Beaver Creek gather headwaters in the Berea Headlands and flow across the narrow Erie Lake Plain to the lake. Average gradient of Old Woman Creek and Beaver Creek is moderately high at about 20 feet per mile. The lower reach of Old Woman Creek is flat and subject to reverse flow from the lake.

Headwaters of the Rocky River gather along morainal hills in the Killbuck-Glaciated Pittsburgh Plateau. West Branch flows across the Galion Glaciated Low Plateau to Berea in a moderately entrenched floodplain with a broad-flat bottom. Just upstream of the Lake Plain the Rocky River has cut a steep-walled narrow gorge in the shale.

Geology

The drainage area tributary to Lake Erie between the Sandusky River and Cuyahoga River lies along the eastern flank of the Findlay Arch. The rocks dip gradually toward the Appalachian Basin exposing successively younger layers of sedimentary rock to the southeast. Surface rocks in the Lake Plains part of the area are mantled with lacustrine deposits and wave-planed till. Rocks in the Till Plains are mantled with thin to thick till. Several recessional moraines cross the southern part of the area.

In the extreme western part of the area, dolomite of Silurian age is covered with Pleistocene-age silt, clay and thin wave-planed till. Northeast trending beach ridges cross south of Clyde. The rocks and overlying till yield little ground water to sustain stream flows. The sandy beach ridges are relatively shallow with limited ground water storage.

The Bellevue-Castalia Karst Plain part of the area contains limestone and dolomites of Devonian age at or near the surface. Rocks in the Karst Plain south of Bellevue are overlain with thin clayey till. North of Bellevue the rocks are overlain with silty, clayey lacustrine deposits and wave-planed till. Sinkholes admit surface water to solution channels in the rock in parts of Seneca County near Bellevue. Large springs discharge ground water to streams in areas of the Karst Plain near the lake. The largest spring is the Blue Hole at Castalia. It discharges large amounts of ground water at the head of Cold Creek.

Most of the southern part of the area that is tributary to Lake Erie between the Sandusky and Cuyahoga is in the Galion Glaciated Low Plateau and contains Mississippian-age shales and sandstones. These rocks are mantled with thin to thick Wisconsinan-age till. Parts of the Defiance, Fort Wayne, and Wabash Moraines cross the area. Neither the rocks nor the till of the ground moraine yield much ground water to streams. Permeable deposits in the moraines yield some ground water to streams. Moraines south and east of Willard contain significant permeable deposit in the form of kames and eskers. Some large lacustrine areas exist between the moraines, the largest being located at Celeryville south of Willard.

The extreme southeastern part of the area is in the Killbuck-Glaciated Pittsburgh Plateau where shales and sandstones of Mississippian and Pennsylvanian age are covered with thin to thick till. The relief of the moraines is greater than those in the Galion Glaciated Low Plateau giving rise to more extensive alluvial deposits. Glacial deposits of permeable material in the moraines are limited.

The Berea Headlands that the larger tributaries cross contain Mississippian-age resistant Berea sandstone. The sandstone is relatively porous and yields some ground water to streams. The Berea Headlands in the Till Plains are covered with thin, clayey till while that in the Lake Plain are covered with clayey lacustrine deposits and wave-planed till.

Northern and central parts of the area in the Erie Lake Plain contain Devonian and Mississippian shales that yield little ground water to streams. These rocks are overlain with Pleistocene-age lacustrine sand, silt, clay and wave-planed till. The till and clayey lacustrine deposits yield little ground water to streams. Sandy lacustrine deposits along beach ridges are relatively shallow and have limited ground water storage.

Soils

The land area tributary to Lake Erie between the Sandusky River and the Cuyahoga River includes parts of Soil Regions 1, 2, 3, 5, and 6. Most of the soils in the area developed from low-lime Wisconsinan till on shales and sandstones. These soils in general are medium to fine textured with low permeability. Soils developed from high-lime Wisconsinan till and calcareous lacustrine deposits are confined to the extreme western part of the area.

Soils in the extreme western part of the area in the Maumee Lake Plains are in Soil Region 1. Toledo soil is dominant near the lake. Hoytville dominates areas farther removed from the lake. These clayey soils have low permeability that restricts ground water recharge. Beach ridges trending northeastward south of Clyde contain sandy permeable soils but are underlain by materials of low permeability.

The Bellevue-Castalia Karst Plain has representation from Soil Regions 1, 2, 3, and 5. The northern half of the Karst Plain is in Soil Regions 1 and 2 where Toledo and Fulton clayey soils are dominant. Slowly permeable soils of Soil Region 3 and 5 dominate areas north and south of Bellevue. Restriction of ground water recharge by slowly permeable soils in the area is partly offset by existence of numerous sinkholes.

Most of the land area draining to Lake Erie between the Sandusky River and the Cuyahoga River lies south of the narrow Erie Lake Plain in Soil Regions 5 and 6. The western half of this area where the Huron River and Vermilion River are located is in Soil Region 5. Moderately slowly permeable to slowly permeable Cardington and Bennington soils are dominant in the basins. The eastern half of the area where the Black River and Rocky River are located is largely in Soil Region 6. Very slowly permeable Mahoning soil is dominant in these basins. Mahoning soil is more restrictive of ground water recharge than Cardington and Bennington and more prone to rapid runoff.

All of the Erie Lake Plain in the area between the Sandusky and Cuyahoga is in Soil Region 2 where slowly permeable Allis soil is dominant. Sandy beach ridges along the lake plain are dominated by rapidly permeable Conotton soil.

Land Use

Land tributary to Lake Erie between the Sandusky River and the Cuyahoga River is in parts of four major land resource areas. The inclusion of many resource areas reflects differences in land use and other elements such as topography, soils, and climate. Land along the lake from Sandusky to Cleveland is nearly all developed. Land in the Till Plains part of the area is much more rural and largely devoted to farmland use.

Land in the western part of the area in Soil Region 1 is in the Erie-Huron Lake Plain Resource Area. Orchards and specialty crops are common in areas near the lake where climate favors production of fruits and vegetables. Farther removed from the lake, land use is devoted primarily to cash grain farms, general livestock production, and dairying.

The land in the eastern part of the area in Soil Region 2 is in the Erie Fruit and Truck Resource Area. Orchards and vegetable specialty crops are common in undeveloped areas south of the lakefront. General farming occurs on land farther removed from the lake.

Land south of the Lake Plain in Soil Regions 3 and 5 is in the Indiana and Ohio Till Plain Resource Area. This land is largely devoted to cash grain farming and general livestock production with some dairying. The large lacustrine area with organic soils at Celeryville is used for high-value truck cropping, an exception to the general pattern of farmland use.

Land in the eastern part of the area in Soil Region 6 is in the Eastern Ohio Till Plain Resource Area. Dairy farms dominate rural land use, but much of this area is in urban and rural residential land use. The level of development in some places is sufficient to significantly affect the hydrologic regimen of streams.

Water Development

There is heavy reliance on surface water for municipal, industrial and domestic supplies in the drainage area tributary to Lake Erie between the Sandusky River and Cuyahoga River. This is due to its proximity to the lake and the limited availability of ground water in most of the area. Ground water serves as the source of supply for some smaller communities and private domestic supplies where well yields are sufficient.

Lake Erie serves as the source of supply for all of the larger towns along the lake in this area and is also tapped to supply some areas considerably inland. Much of the urbanized and rural residential areas in the Rocky River drainage obtain water from Lake Erie through Cleveland. Lake Erie water is distributed through rural water systems to households as far south as Ashland County. The amount of Lake Erie water distributed in the eastern part of the area is significant and generates sufficient wastewater return flows to affect the magnitude of base flows in streams.

Some smaller communities inland from the lake obtains their source of supply from wells developed in permeable deposits along the moraines. The larger towns distant from the lake obtain their supply from streams, typically by use of off-stream storage reservoirs. Clyde, Bellevue, Norwalk, Willard, New London, Wellington, Oberlin, and Median all have off-stream reservoirs. Water is normally diverted into off-stream reservoirs during high flows causing little effect on flow regimen. Wastewater return flows from these systems have some localized effect on magnitude of base flows in streams.

Ground water aquifers in the Berea sandstone are tapped for individual well supplies across the larger part of the area tributary to Lake Erie between the Sandusky River and the Cuyahoga River. Limestone and dolomites in the extreme western part of the area yield ample supplies for private domestic use.

Flow Characteristics

Recent estimates of flow characteristics are available for 16 stream gaging stations along tributaries to Lake Erie between the Sandusky River and the Cuyahoga River. Selected flow characteristics at these gaging sites are given in table 3.

Mean annual runoff of the Huron River at Milan and Black River at Elyria equates to 11.4 and 11.5 inches, respectively; these are relatively low amounts of runoff. The relatively high mean annual runoff of 13.3 inches given in Table 3 for Vermilion River at Vermilion is for a shorter, wetter period of record. Mean annual runoff of the Vermilion should be similar to that of the Huron River and Black River since mean annual precipitation is fairly uniform across the three basins. The Rocky River drainage is located at the western edge of the Snow Belt where mean annual precipitation is significantly higher than that in the other main tributary drainages. Mean annual runoff of 14.4 inches for the Rocky River near Berea reflects the higher amount of precipitation.

Mean annual base flow of streams tributary to Lake Erie between the Sandusky River and Cuyahoga River varies from about a quarter to a little more than a third of mean annual runoff. Base flows of the Huron and Rocky River are generally more favorable than that of the Black and Vermilion. The 90-percent duration flow of 0.04 cfs per square mile for the Huron River at Milan is about the same as that of West Branch and East Branch indicating some uniformity in basin characteristics exists.

Tributaries to Lake Erie between the Sandusky River and Huron River vary considerably in base-flow characteristics. Streams in the Maumee Lake Plains, like Raccoon Creek and Pickerel Creek, are in an area where base flows are naturally low. Base flow of Raccoon Creek, however, is augmented by wastewater discharge at Clyde. Streams in the Bellevue-Castalia Karst Plain like Cold Creek that are fed by large springs have relatively high base flows. Mills Creek at the eastern edge of the Karst Plain lacks large springs, but receives augmentation flows from wastewater discharge at Bellevue and limestone quarry dewatering operations.

Old Woman Creek just east of Huron with 90-percent duration flow of 0.01 cfs per square mile has significantly lower base-flow characteristics than the Huron River. Base-flow characteristics of Old Woman Creek are more like those of the Vermilion River. Mean base-flow index of 32.6 percent for the Vermilion River at Vermilion and 90-percent duration flow of 0.01 cfs per square mile indicate that permeable deposits are less extensive in the Vermilion Basin than in the Huron Basin. Base flow of Beaver Creek at Amherst is relatively high with 90-percent duration flow of 0.05 cfs per square mile. However, low flows in Beaver Creek are significantly augmented by wastewater discharge at Amherst.

Base flows of the Black River at Elyria are moderately low with 90-percent duration flow of 0.03 cfs per square mile and 7-day, 2-year low-flow index of 0.02. East Branch has significantly lower base flow than the main stem and apparently derives little ground water from the moraine in headwater areas. Base flow of the Rocky River near Berea is similar to that of the Huron River at Milan with 90-percent duration flow of 0.04 cfs per square mile and 7-day, 2-year low-flow index of 0.03. East Branch Rocky River with 90-percent duration flow of 0.06 cfs per square mile is affected by water supply operations and wastewater discharge at Berea.

The 50-percent duration flows of streams tributary to Lake Erie between the Sandusky River and the Cuyahoga River are in the middle to lower range for streams in Ohio and consistent with the limited amounts of ground-water storage in the basins. The 50-percent duration flow for East Branch Black River of 0.12 cfs per square mile is exceptionally low indicating minimal amounts of ground-water storage exists in the basin.

The 10-percent duration flows for streams tributary to Lake Erie between the Sandusky River and the Cuyahoga River are comparatively low, but the 2-year-recurrence interval flood-peak discharges are moderately high due primary to the rolling topography and relatively steep stream gradients. The Rocky River originates in the Glaciated Allegheny Plateaus and has the steepest average gradient of the major tributaries. It also has the highest relative flood-peak discharge. Average stream gradient of the Black River is lowest of the major tributaries and flood peak discharge on a relative basis is also lowest.

TABLE 3

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Lake Erie Tributaries between Sandusky River and Cuyahoga River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
W. Branch Huron River near Monroeville 04198020	220	-	-	-	-	9.1 (0.041)	6.2	-
Norwalk Creek near Norwalk 04198100	4.92	-	-	-	-	-	-	346 (70.3)
E. Branch Huron River near Norwalk 04198500	85.5	68.1 (0.80) (10.9)	35.8	148 (1.73)	17 (0.20)	3.5 (0.041)	2.4 (0.035)	2670 (31.2)
Huron River at Milan 04199000	371	311 (0.84) (11.4)	35.5	717 (1.93)	84 (0.023)	16 (0.043)	11 (0.035)	8000 (21.6)
Old Woman Cr. at Berlin Road 04199155	22.1	-	32.4	-	-	0.2 (0.009)	0.1	-
Vermilion River near Fitchville 04199287	112	-	35.8	-	-	-	-	-
Vermilion River at Clarksfield 04199300	130	-	-	-	-	0.7 (0.005)	0.3	-
Vermilion River near Vermilion 04199500	262	258 (0.98) (13.3)	32.6	595 (2.27)	55 (0.21)	3.6 (0.014)	1.7 (0.007)	6170 (23.5)
Neff Run near Litchfield 04199800	0.76	-	-	-	-	-	-	70 (92.1)
Beaver Creek at Amherst 04199550	43.4	-	-	-	-	2.0 (0.046)	1.6 (0.037)	-
E. Branch Black River at Elyria 04200000	217	177 (0.82) (11.1)	26.4	450 (2.07)	25 (0.12)	1.1 (0.005)	0.4 (0.002)	4660 (21.5)

TABLE 3

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Lake Erie Tributaries between Sandusky River and Cuyahoga River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	50% cfs (cfs/sq. mi.)	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Plum Creek at Oberlin 04200100	4.83	-	-	-	-	-	-	298 (61.7)
Black River at Elyria 04200500	396	338 (0.85) (11.5)	-	836 (2.11)	75 (0.19)	11 (0.028)	7.7 (0.023)	7260 (18.3)
W. Branch Rocky River at West View 04201400	147	-	-	-	-	3.6 (0.024)	2.8	-
E. Branch Rocky River near Berea 04201498	76.9	-	-	-	-	5.0 (0.065)	4.0	-
Rocky River near Berea 04201500	267	284 (1.06) (14.4)	-	664 (2.49)	85 (0.32)	11 (0.041)	8.8 (0.031)	7820 (29.3)

CUYAHOGA RIVER BASIN

The Cuyahoga River originates in Geauga County in the extreme northern part of the Akron-Canton Interlobate Plateau. From its headwaters area, the river flows southwestward in a relatively long, narrow basin toward Akron. Downstream of Cuyahoga Falls, the river turns abruptly northward and flows in a wide, deep preglacial valley to Cleveland and its mouth in Lake Erie. The peculiar shape of the basin with its long eastern arm is the result of drainage changes brought about by glaciation. The map in figure 9 shows the outline of the basin and flow paths of the main watercourses.

In the upper part of the eastern basin near Burton, the East Branch, West Branch, and Bridge Creek converge to give the Cuyahoga River a drainage area of about 150 square miles. Downstream at Kent, Congress Lake Outlet adds about 79 square miles of drainage area. At Akron, the Little Cuyahoga joins the Cuyahoga River contributing 62 square miles of drainage area. North of Akron, a series of smaller tributaries drain into the Cuyahoga from both sides of the basin, the largest of these being, Mud Brook, Yellow Creek, Furnace Run, Brandywine Creek, and Chippewa Creek. Near Bedford, Tinkers Creek joins the Cuyahoga contributing 96 square miles of drainage area. Additional smaller tributaries flow into the Cuyahoga in Cleveland, the largest being Big Creek with 38 square miles of drainage area.

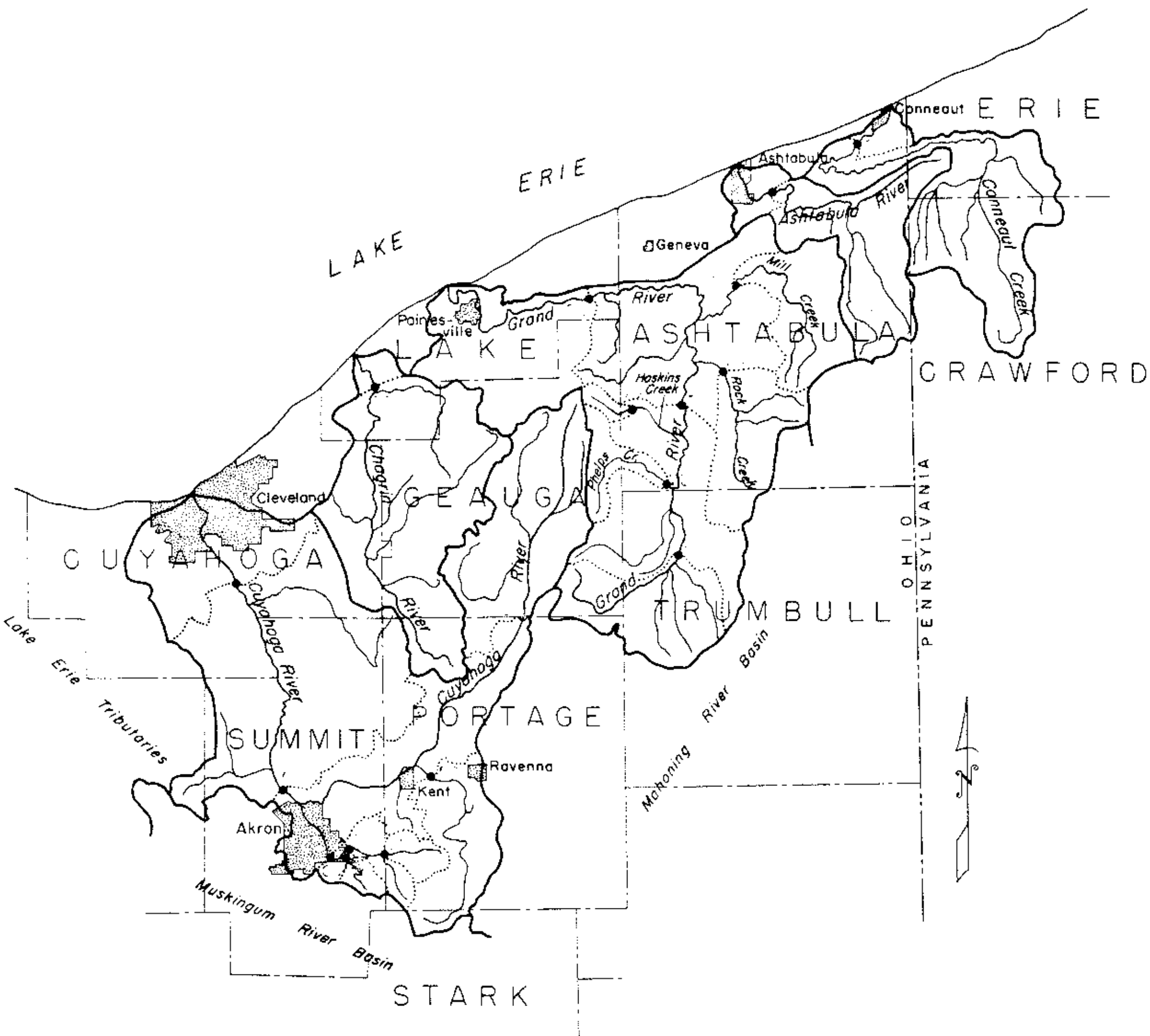
Physiography

The topography of the Cuyahoga River Basin varies from flat lake plain to relatively rough glaciated, dissected plateau. Most of the basin is in the Glaciated Allegheny Plateaus; only the extreme lower part lies in the Erie Lake Plain. Relief is generally moderate except where the river has cut a deep valley, and where there is local steepness created by smaller streams.

The northern part of the Akron-Canton Interlobate Plateau, where the eastern arm of the basin is located, is hummocky and dominated by kames, kame terraces, eskers, bogs, and natural lakes. The river flows in a relatively shallow channel cut in lacustrine deposits and drift at very low gradient of about 3 feet per mile. Kame terraces and outwash exist along most of the channel. The channel reach in Geauga County cuts through lacustrine deposits.

Congress Lake Outlet and the Little Cuyahoga River are in the central part of the interlobate area where considerable amounts of outwash material exists. The river flows north of the outwash area in a deep narrow gorge cut in Pennsylvanian-age sandstone dropping about 220 feet in 1.5 miles through a series of steep rapids and falls.

Along the northward course, the river flows in a wide, deep preglacial valley that contains Pleistocene lacustrine deposits and alluvium of more recent time. The river meanders at moderately low gradient of about 6 feet per mile. Upland areas draining to



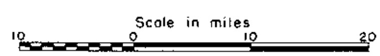


Figure 9. Map of Cuyahoga River Basin and Lake Erie Tributaries East of the Cuyahoga River.

the valley of the lower Cuyahoga are in areas of ground moraine and end moraine. Tinkers Creek gathers in lacustrine areas with extensive wetlands and flows northward along the Defiance End Moraine atop a buried valley before turning westward at Bedford and descending at steep gradient to the Cuyahoga River.

The Cuyahoga River flows across the Erie Lake Plain in a deep wide valley at Cleveland. Most of the lake plain tributary to the Cuyahoga on the west side of the river in Cleveland is drained by Big Creek.

Geology

The surface rocks in the Cuyahoga River Basin range in age from Devonian to Pennsylvanian. Devonian-age shales outcrop along the lower Cuyahoga Valley and lake plain area. Upland areas along the lower reach of the Cuyahoga are underlain with Mississippian sandstones and shales. Berea sandstone outcrops along Tinkers Creek just downstream of Bedford. Pennsylvanian-age sandstones and shales underlie much of the basin along the upper Cuyahoga. The narrow gorge at Cuyahoga Falls is cut in Sharon Conglomerate of Pennsylvanian age. As a whole, ground water from the rock strata has little effect on stream flow except locally where streams have cut through sandstone formations.

The glacial drift in the basin varies greatly in thickness and character, ranging from a few feet to as much as 200 feet in thickness and consisting of deep impermeable till in some places to highly permeable sand and gravel in other places. Deep buried valleys are present throughout the basin, but it is ground water from outwash material in high-level terraces, kames, and kame terraces that support the dry-weather flow of the Cuyahoga River.

The shales underlying the lake plain at Cleveland are thinly mantled with till and clayey lacustrine deposits. Uplands tributary to the lower reach of the Cuyahoga are generally covered with moderate amounts of clayey till except along the moraines where till thickness is greater and contains some permeable deposits. The Cuyahoga Valley is hundreds of feet deep to bedrock. The buried valley along the Cuyahoga between Newburg Heights and downtown Cleveland contains permeable deposits that yield substantial amounts of ground water to wells.

Pennsylvanian- and Mississippian-age sandstones and shales are covered with till and extensive amounts of sand and gravel deposits in the upper basin. Large deposits of permeable outwash material exist in the interlobate area between the Grand River and Killbuck Lobes of the Wisconsinan glaciation. Depths of these deposits vary from a few feet to as much as 100 feet in some places.

Soils

The Glaciated Allegheny Plateaus part of the Cuyahoga River Basin that comprises the vast majority of the basin is in Soil Region 6. The narrow Erie Lake Plain part of the basin at Cleveland is in Soil Region 2.

Soils on the Erie Lake Plain at Cleveland are largely urban land complexes wherein imperious surfaces constitute a large percentage of the complex. Mahoning urban complex dominates the lake plain with lesser amounts of Oshtemo urban complex. The Mahoning soil developed from clay loam and clayey till and is slowly permeable. Oshtemo developed on sandy beach ridges and has rapid permeability.

The ground moraine and end moraines in the Killbuck-Pittsburgh Glaciated Plateau part of the basin are dominated by Mahoning and Rittman soils. Rittman developed from medium to fine textured till and has a fragipan that is slowly permeable. Soils developed from lacustrine deposits amid the end moraines have slow permeability.

Chili-Canfield soil associations dominate the interlobate area in the upper basin. Chili soil developed from loamy outwash on kames, kames terraces, and outwash fans common in the interlobate area. Chili is underlain with sand and gravel and has rapid permeability. Canfield soil developed from medium-textured till and has a fragipan that is slowly permeable.

Soil developed in alluvium along the lower Cuyahoga and upper reaches of Tinkers Creek are mostly Chagrin silt loams with moderate permeability. Permeability of soils on high-level terraces along the lower Cuyahoga vary from rapid to slow depending on the texture of the sediments.

Permeable outwash soils in the Cuyahoga Basin are limited in extent but highly significant ground water recharge areas for the ground water aquifers of the Cuyahoga Basin. Overall, however, most of the soils in the basin are slowly permeable.

Land Use

The Cuyahoga River Basin contains the cities of Cleveland and Akron and is a very heavily industrialized area. Most of the undeveloped land in the lower basin is confined to areas of steep terrain along the Cuyahoga River and tributaries draining into it. The Cuyahoga Valley National Recreation Area is located between Cleveland and Akron. Many metropolitan parks occupy areas of steeper terrain in Cleveland. The upper eastern basin is much less intensely developed than the lower basin and contains several large reservoirs.

The lake plain at Cleveland is part of the Erie Fruit and Truck Resource Area. Most of the commercial vegetable production in the Cleveland area takes place in green houses, and there are a sustainable number of these enterprises. Open space accounts for a relatively small percentage of land use as most of the land is developed. Land in the

Glaciated Allegheny Plateaus part of the basin is in the Eastern Ohio Till Plain Resource Area. Although much of the basin has been developed, dairy and cash grain farms are still common in more rural parts especially in Portage and Geauga Counties. Development in the lower basin includes intensive industrial and commercial development from Bedford Heights to Solon and wide expanses of housing along the western side of the lower basin between Akron and Cleveland. Much of the land in the basin that was farmland is now urban or idle land being held for development.

Water Development

The City of Akron has several water supply reservoirs in the upper Cuyahoga River Basin. These include East Branch Reservoir, LaDue Reservoir, and Lake Rockwell. Water is released from East Branch and LaDue to maintain water levels in Lake Rockwell where the city water supply intakes are located. Wastewater return flows from Akron enter the Cuyahoga below Old Portage several miles downstream of the confluence with the Little Cuyahoga.

Kent and Cuyahoga Falls obtain water supply from well fields located in sand and gravel deposits along the upper Cuyahoga. Some smaller communities in the upper basin including Burton obtain water supply from wells, but most obtain supply from either Akron or Cuyahoga Falls. Individual supply is generally available from sandstones of the Pottsville Group, mainly the Sharon Conglomerate, and from permeable deposits in buried valleys.

The city of Cleveland obtains water from Lake Erie and distributes it throughout Cuyahoga County and to some communities in neighboring counties. All of the communities in Cuyahoga County except Berea obtain supply from Cleveland. Return flows enter the Cuyahoga though the Cleveland Southerly Wastewater Treatment Plant at Cuyahoga Heights.

Some water is diverted from the Tuscarawas River Basin to the Cuyahoga River Basin through the Ohio-Erie Canal system at Akron. Water from Portage Lakes is diverted to the Ohio Canal for industrial use and discharged through Summit Lake to the Little Cuyahoga River. Mogador Reservoir on the Little Cuyahoga River was built for industrial supply and recreation.

Flow Characteristics

Recent estimates of flow characteristics are available for 14 stream gaging stations in the Cuyahoga River Basin. Selected flow characteristics at these gaging sites are given in table 4.

Mean annual flows of streams in the Cuyahoga River Basin range from about 12 inches to 21 inches. Upper reaches of the Cuyahoga in Geauga County are in an area that receives some of the greatest amounts of mean annual precipitation in the state. This accounts for the relatively high mean annual flow of 20.2 inches at Hiram Rapids.

Tinkers Creek is also in an area receiving relatively high amounts of mean annual precipitation. This largely but not entirely accounts for the 21.7 inches of runoff recorded at Bedford. The flow of Tinkers Creek at the gage site is augmented by wastewater originating from wells and imported waters. The Little Cuyahoga River is in an area of lower mean annual precipitation averaging about 36 inches at Akron. Mean annual runoff of the Little Cuyahoga is correspondingly lower at about 12 inches. Mean annual flow of 14.9 inches for the Cuyahoga River at Old Portage excludes water diverted from Lake Rockwell for use at Akron and returned downstream of Old Portage. This diversion is partly offset by canal diversions from the Portage Lakes into the Cuyahoga River. On balance, mean annual flow at Old Portage without the diversions should be closer to 17 inches. Mean annual flow of the Cuyahoga at Independence of 16.4 inches represents the composite of mean annual flows of streams in the basin. The relatively high mean annual flow of Big Creek at Cleveland is due to industrial wastewater discharge and shorter, wetter period of record.

Base flows of the Cuyahoga River at all of the gaging stations are affected by regulation. Base flows at Hiram Rapids are affected by evaporative losses and releases from East Branch and LaDue. Base flows at Old Portage are largely a function of releases from Lake Rockwell and flows from Congress Lake Outlet and the Little Cuyahoga.

The gaging records for Yellow Creek give some insight to the affect of permeable deposits on base flows. The basin upstream of Ghent is situated in an area of kames and outwash deposits. This accounts for the relatively high mean base-flow index of 68 and 90-percent duration flow of 0.213 cfs per square mile for Yellow Creek at Ghent. North Fork at Bath Center includes areas of ground moraine containing much less permeable material. The mean base-flow index of 44 and 90-percent duration flow of 0.072 cfs per square mile reflects this difference in geology. Yellow Creek at Boltzum with 90-percent duration flow of 0.16 cfs per square mile and mean base-flow index of 54 represents a composite of basin characteristics.

Tinkers Creek with mean base-flow index of 48 and 90-percent duration flow of 0.24 cfs per square mile contains some permeable deposits along the Defiance End Moraine but not to the same degree as Yellow Creek. Base flows in Tinkers Creek are augmented significantly by wastewater discharges from municipal and industrial plants.

The base-flow record for Cuyahoga River at Independence excludes water diverted into the Ohio Canal upstream at Brecksville. The 90-percent duration flow of 0.184 cfs per square mile and the 7-day, 2-year low-flow index of 0.153 are lower than they would be if the diversions were included. The relatively high base-flow indices for Big Creek are due to industrial wastewater discharge upstream of the gaging station.

The median flow or 50-percent duration flow of 0.69 cfs per square mile for the Cuyahoga River at Independence is representative of flow conditions at gaging sites along the Cuyahoga and its major tributaries. This median flow rate is at the high end of the range for Ohio streams and reflects the combination of relatively large amounts of ground-water storage, substantial artificial and natural surface-water storage, and significant flow regulation from water supply and wastewater operations in the basin.

The 10-percent duration flows of streams in the Cuyahoga River Basin are at the high end of the range for streams in Ohio. This indicates that although significant storage exists in the basin, it is limited as far as attenuation of larger floods. Relatively low 2-year recurrence interval flood-peak discharges characteristic of the streams in the basin indicate that basin storage nevertheless provides some attenuation of flood flows. The 10-percent duration flows at stations along the Little Cuyahoga River are relatively low because of the large reservoirs located upstream of the gaging sites.

TABLE 4

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Cuyahoga River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Cuyahoga River at Hiram Rapids 04202000	151	225 (1.49) (20.2)	-	531 (3.52)	130 (0.86)	45 (0.298)	28 (0.124)	1620 (10.7)
Little Cuyahoga River at Mogadore 04204000	17.3	14.5 (0.84) (11.4)	-	32 (1.84)	10 (0.58)	2.0 (0.116)	1.6 (0.110)	-
Little Cuyahoga R. at Massillon Road 04204500	31.6	27.6 (0.87) (11.9)	-	57 (1.80)	19 (0.60)	7.0 (0.221)	6.3 (0.228)	-
Springfield Lake Outlet at Akron 04205000	9.72	4.87 (0.50) (6.8)	-	12 (1.23)	2.7 (0.28)	0.3 (0.031)	0.2 (0.041)	-
Cuyahoga River at Old Portage 04206000	404	442 (1.09) (14.9)	-	1040 (2.57)	270 (0.67)	79 (0.196)	74 (0.167)	-
Yellow Creek at Ghent 04206208	12.7	-	67.7	-	-	2.7 (0.213)	2.3	-
North Fork at Bath 04206210	2.81	-	41.4	-	-	0.1 (0.036)	0	-
Park Creek at Bath Center 04206211	0.83	-	-	-	-	0.1 (0.120)	0	-
North Fork at Bath Center 04206212	5.58	-	44.8	-	-	0.4 (0.072)	0.2	-
Bath Creek at Bath Center 04206215	3.52	-	46.8	-	-	0.3 (0.085)	0.3	-
Yellow Creek at Boltzum 04206220	30.7	-	54.1	-	-	4.9 (0.160)	4.2	-

TABLE 4

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Cuyahoga River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Tinkers Creek at Bedford 04207200	83.9	134 (1.60) (21.7)	48.0	327 (3.90)	63 (0.75)	20 (0.238)	18 (0.134)	2380 (28.4)
Cuyahoga River at Independence 04208000	707	855 (1.21) (16.4)	-	2050 (2.90)	486 (0.69)	130 (0.184)	131 (0.153)	8590 (12.1)
Big Creek at Cleveland 04208502	35.3	54.7 (1.55) (21.0)	-	123 (3.48)	25 (0.71)	12 (0.340)	9.1 (0.166)	-

LAKE ERIE TRIBUTARIES EAST OF THE CUYAHOGA RIVER

East of the Cuyahoga River, the main tributaries to Lake Erie from Cleveland to Conneaut are the Chagrin River, the Grand River, the Ashtabula River, and Conneaut Creek. Drainage areas of these streams are 264, 705, 137, and 189 square miles, respectively. Between the Cuyahoga River and Chagrin River smaller tributaries drain about 90 square miles to Lake Erie. These include Doan Brook and Euclid Creek. Between the Grand River and the Ashtabula River, smaller tributaries including Arcola Creek, Wheeler Creek, Cowles Creek, and Indian Creek drain about 115 square miles to the lake. The map in figure 9 shows the outlines of the basins and flow paths of the main watercourses.

The Chagrin River originates in Geauga County at Chardon and flows southwest to Chagrin Falls where its drainage area is 60.6 square miles. Just west of Chagrin Falls, Aurora Branch with 58.2 square miles of drainage area joins the river from the south. From the confluence with Aurora Branch, the Chagrin flows northward in a preglacial valley to Willoughby and its mouth in Lake Erie at Fairport Harbor. East Branch with drainage area of 51.1 square miles joins the river at Willoughby.

The Grand River gathers in morainal hills around the southern end of the Grand River Finger Lake Plain. The river meanders northward picking up drainage from relatively small tributaries to the west include Swine Creek, Phelps Creek, and Hoskins Creek with drainage areas of 30.9, 29.2, and 26.9 square miles, respectively. Larger tributaries join the Grand River from the east including Rock Creek with drainage area of 70.7 square miles and Mill Creek with drainage area of 103 square miles. At the north end of the Grand River Finger Lake Plain, the river turns west and meanders toward Painesville in a relatively deep, flat bottom valley in the Lake Escarpment. Paine Creek and Big Creek with drainage areas of 28.9 and 50.1 square miles flow into the river from the south along the Lake Escarpment. At Painesville, the river cuts north across the narrow Erie Lake Plain to its mouth in the lake.

The Ashtabula River gathers along the Defiance End Moraine and flows northward in two main branches, East Branch and West Branch. Drainage areas of the branches are 37.1 and 27.9 square miles, respectively. Just south of Kelloggsville, the river with 70.3 square miles of drainage area is joined from the east by Ashtabula Creek with 88.1 square miles of drainage area. At Kelloggsville, the river turns westward along the southern flank of the Lake Escarpment to Ashtabula. The river loops and meanders torturously in a relatively deep valley as it approaches Ashtabula and cuts through to the lake.

Conneaut Creek gathers in morainal hills south of Conneautville, Pennsylvania. The creek meanders along a highly sinuous course northward from Conneautville to Albion where it is joined first by West Branch with 33 square miles of drainage area and then by East Branch with 26 square miles of drainage area. Just north of Albion, the creek turns westward and meanders along a relatively deep, flat bottom valley cut in the Lake Escarpment. Along the Lake Escarpment, many small tributaries draining from the bordering ridges join the creek. At Kingsville, the creek loops back to the east and flows across the lake plain to its mouth in Lake Erie at Conneaut.

<u>Physiography</u>

The main tributaries to Lake Erie east of the Cuyahoga River lie mostly in the Glaciated Allegheny Plateaus with only the extreme lower reaches in the Erie Lake Plain. The Erie Lake Plain is separated from the Glaciated Allegheny Plateaus by the Portage Escarpment, an irregular slope 2 to 4 miles wide descending from elevation of about 1200 feet to 700 or 800 feet above mean sea level. The main tributaries have cut deep gorges in the Portage Escarpment. The smaller tributaries to the lake typically gather in and along the south side of the escarpment.

The Chagrin River Basin is mostly in the Killbuck Glaciated Pittsburgh Plateau and is rougher than that of the other main tributaries to the east. The terrain is rolling hills with moderate relief. The river flows on bedrock in some places and on valley fill of silts and clays in other places. Rock outcrops along the upper reaches of the Chagrin and its main tributaries are mainly that of Sharon Conglomerate. The upper reach between Chardon and Chagrin Falls flows at relatively steep gradient averaging about 25 feet per mile. At Chagrin Falls the river drops through a series of rapids about 100 feet over the course of a mile. Aurora Branch flows at average gradient of about 20 feet per mile and drops about 60 feet through a series of rapids near Chagrin Falls. The lower reach of the Chagrin River flows at relatively low gradient of about 4 feet per mile in a preglacial valley filled with silts and clays. The river flows in a deep gorge cut in Devonian-age shales at the Portage Escarpment. East Branch originates on the west side of Chardon and flows at relatively steep gradient averaging about 35 feet per mile to its confluence with the Chagrin River in the Portage Escarpment at Willoughby.

The Grand River Basin occupies nearly all of the Grand River Finger-Lake Plain located in the western part of the Grand River Low Plateau. The broad trough-like preglacial valley that the river flows north in is filled with surficial lacustrine deposits and till. Relief in the Finger-Lake Plain is very low as is the gradient of the river. Tributaries joining the Grand River from the west descend into the valley at relatively steep gradient while those flowing in from the east have more moderate gradient. The lower westward reach of the Grand River flows in a deep gorge along the Portage Escarpment to Painesville where it crosses the narrow Erie Lake Plain. Paine Creek and Big Creek that join the Grand River along its westward course, originate north of Chardon in the Killbuck Glaciated Pittsburgh Plateau.

The Ashtabula River Basin and Conneaut Creek Basin are mostly in the Grand River Low Plateau and geologically similar. Westward flowing reaches of the Ashtabula River and Ashtabula Creek flow parallel to the south side of the Portage Escarpment. Conneaut Creek flows westward along a relatively deep valley in the escarpment before looping back east across the lake plain. Upper reaches of Conneaut Creek flow through areas of extensive wetlands at very low gradient.

Geology

The surface rocks along the Erie Lake Plain are shales of Devonian age. These rocks continue at the surface south of the Portage Escarpment toward the midpoint of the basins. South and east, sandstone and shales of Mississippian age are at the surface. The Pennsylvanian-age Pottsville Group including the Sharon Conglomerate interfaces with the Mississippian-age rocks in upper parts of the Chagrin River Basin. The Berea sandstone of Mississippian age forms the falls at Chagrin Falls. A buried valley exists along the general course of Aurora Branch and the lower Chagrin River. Although the Berea sandstone yields some ground water to streams, it is the Sharon Conglomerate that yields large quantities. The shales yield little ground water to streams. The overburden of glacial drift covering the basin as a whole is relatively impermeable. Two recessional moraines cross the area, and there are some local deposits of outwash material.

Soils

Basins of the main tributaries to Lake Erie east of the Cuyahoga River are largely in Soil Region 6. Parts of the basin in the Erie Lake Plain and Portage Escarpment are in Soil Region 2.

Mahoning soil is dominant in the northern and eastern parts of the Grand River Low Plateau where the main tributaries east of the Cuyahoga River are located. Mahoning soil developed from clay loam and clayey till and has slow permeability. Platea soil is also common. It has a fragipan that is very slowly permeable. Soils in the Grand River Finger Lake Plain developed from medium- to fine-textured till and lacustrine deposits. They have slow permeability. Soils developed in loamy outwash at various places have rapid permeability. For the most part, however, soils in Grand River Low Plateau of the tributary basins have slow permeability that impeded ground water recharge.

Conneaut soil is dominant in the Erie Lake Plain eastward from Cleveland. This slowly permeable soil developed from lacustrine deposits of lacustrine silt loam and silty glacial till. Rapidly permeable soils are on beach ridges. Conotton soil formed on beach ridges along the Portage Escarpment. Conotton is rapidly permeable.

Land Use

Lake Erie tributaries east of the Cuyahoga River are in two major land resource areas, the Erie Fruit and Truck Area and the Eastern Ohio Till Plain. The Erie Lake Plain and Lake Escarpment from Cleveland to Conneaut are moderately to highly developed. Land southward of the Portage Escarpment in the Grand River Low Plateau is mainly rural.

The Erie Lake Plain from Euclid to Mentor is highly developed with open space confined mainly to metro parks along tributaries to the lake. From Painesville to Ashtabula and Conneaut the lake plain and escarpment are less intensely developed. Commercial horticulture and nurseries are common in the area.

The Chagrin Basin is the most developed of the main tributary basins. Much of the development in the basin south of Willoughby and Kirkland is in the form of rural residential. Considerable amounts of former dairy and general farmland have been developed or are idle land held for development. Dairy, pasture and cropland are common in the till areas of the main tributary basins east of the Chagrin. The Grand River Basin has extensive wetlands as does the upper Conneaut Creek Basin.

<u>Water Development</u>

Communities along Lake Erie from Cleveland to Conneaut are supplies with water from the lake. Source of supply for the communities distant from the lake includes both surface water and ground water. The Grand River is source of supply for Rock Creek. Roaming Rock Lake on Rock Creek serves as source of supply for Roaming Shores. Sand and gravel lens in glacial drift supply Orwell. Chardon has wells near Bass Lake at the head of the Chagrin River. Chagrin Falls obtains supply from Cleveland.

<u>Flow Characteristics</u>

Recent estimates of flow characteristics are available for 15 stream gaging stations along Lake Erie tributaries in Ohio east of the Cuyahoga River. Selected flow characteristics at these gaging sites are given in table 5.

Mean annual flows of the main tributaries to Lake Erie east of the Cuyahoga River range from about 17 to 21 inches. Mean annual runoff of these streams is among the highest in the state mainly due to relatively high mean annual precipitation and relatively low mean annual temperatures and water losses. Most of the Conneaut Creek Basin is in the area receiving the greatest amounts of mean annual precipitation therefore accounting for its 21.2 inches of runoff. The difference in mean annual runoff of the Grand River at Madison versus Painesville is explained in part by differences in period of record. The record at Painesville is for a shorter, wetter period; the record at Madison is for a longer, drier period. Actual mean annual runoff of the Grand River is likely around 18 inches.

The 90-percent duration flows and 7-day, 2-year low flows are probably better indicators of base-flow characteristics than the mean base-flow indices for Lake Erie tributaries east of the Cuyahoga. Areas with large amounts of snow pack and extensive wetlands present limitations for the hydrograph separation techniques used to derive mean base-flow indices.

Streams with the lowest base flows in the area include the Ashtabula River at Ashtabula and Mill Creek near Jefferson. Both these streams have 7-day, 2-year low flows of zero. These streams flow from basins with black shales overlain with thin to thick silty clay till containing limited sand lens. The Chagrin River at Willoughby and Aurora Branch near Chagrin Falls have relatively high base flow largely due to discharges from the Sharon Conglomerate and some outwash deposits. Big Creek and Painsville Creek gather in outwash near Chardon like the Chagrin and have relatively high base flows. East Branch of the Chagrin River is characterized as cold-water habitat and likely has high base flow similar to the Chagrin River. The Grand River and Conneaut Creek have relatively low base flow but somewhat higher than the Ashtabula River. The higher base flow of the Grand River at Painesville versus Madison partly reflects contributions of Paine Creek and Big Creek. Outwash deposits in the Lake Escarpment where Conneaut Creek flows westward may contribute significant amounts of ground water to sustain stream flows. Median flows of the tributaries mirror the pattern of base flow indices.

The 10-percent duration flows of streams in the area are relatively high indicating that high water is not uncommon. The relatively low 2-year recurrence interval flood-peak discharge of 15 cfs per square mile for Grand River at Madison reflects the attenuating effects of the Finger Lake Plain. The watershed of Hoskins Creek upstream of Hartsgrove is a relatively flat till plain with extensive wetlands. This explains the 37.6 cfs per square mile peak discharge of Hoskins Creek versus 69.5 cfs per square mile for nearby Phelps Creek that gathers in the end moraine where the terrain is hilly and the relief is greater.

TABLE 5

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Lake Erie Tributaries East of the Cuyahoga River

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Aurora Branch near Chagrin Falls 04208900	57.4	-	-	-	-	12 (0.209)	9.9	-
Chagrin River at Willoughby 04209000	246	340 (1.38) (18.7)	-	782 (3.18)	152 (0.62)	36 (0.146)	29 (0.085)	8790 (35.7)
Grand River near North Bristol 04209500	89.7	-	33.2	-	-	2.8 (0.031)	1.7	-
Phelps Creek near Windsor 04210000	25.6	36.1 (1.41) (19.1)	29.1	85 (3.32)	6.0 (0.23)	0.7 (0.027)	0.5 (0.020)	1780 (69.5)
Montville Ditch at Montville 04210100	0.29	-	-	-	-	-	-	31 (107)
Grand River near Rome 04210500	276	-	39.9	-	-	8.9 (0.032)	5.4	-
Hoskins Creek at Hartsgrove 04210100	5.42	-	-	-	-	-	-	204 (37.6)
Rock Creek near Rock Creek 04211000	69.2	-	-	-	-	-	-	2490 (36.0)
Mill Creek near Jefferson 04211500	78.3	108 (1.38) (18.7)	-	285 (3.64)	20 (0.26)	0.1 (0.001)	0	3300 (42.1)
Grand River near Madison 04211000	581	660 (1.14) (15.4)	41.0	2020 (3.48)	170 (0.29)	11 (0.019)	5.4 (0.008)	8770 (15.1)
Big Creek at Painesville 04212085	36.4	-	-	-	-	5.9 (0.162)	4.1	-

TABLE 5

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Lake Erie Tributaries East of the Cuyahoga River

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Grand River near Painesville 04212500	685	1060 (1.55) (21.0)	39.3	2920 (4.26)	445 (0.65)	42 (0.061)	24 (0.023)	-
Ashtabula River near Ashtabula 04212500	121	154 (1.27) (17.3)	31.3	409 (3.38)	40 (0.33)	0.4 (0.003)	0	4500 (37.2)
Hubbard Run Trib. to Ashtabula R. 04212600	0.88	-	-	-	-	-	-	103 (117)
Conneaut Creek at Conneaut 04213000	175	274 (1.56) (21.2)	38.4	713 (4.07)	102 (0.58)	11 (0.063)	7.1 (0.026)	6300 (36.0)

OHIO RIVER BASIN

About 70 percent of the land in Ohio is in the Ohio River Basin. Land draining to the Ohio River in the eastern half of the state is in the Allegheny Plateaus and Glaciated Allegheny Plateaus. Land draining to the Ohio River in the western half of the state is mainly in the Till Plains. All of the land in the state beyond the glacial margin drains to the Ohio River.

The larger streams in the Allegheny Plateaus flow at relatively low gradient in flat bottom valleys confined by steep hillsides. Lower reaches of these streams are affected by high stages of the Ohio River. Tributaries originating in the Allegheny Plateaus rise at relatively steep gradient in narrow valleys. These tributaries are prone to flash floods that descend rapidly from the hills filling the flat-bottom valleys of the larger streams with deep flood waters.

The largest streams tributary to the Ohio River in the state originate in either the Glaciated Allegheny Plateaus or the Till Plains. All the streams originating in the Glaciated Allegheny Plateaus flow through the unglaciated Allegheny Plateaus to join the Ohio River. Some of the streams originating in the Till Plains flow through the Allegheny Plateaus while others flow directly to the Ohio River.

Headwater areas in the Glaciated Allegheny Plateaus where larger streams originate contain vast quantities of permeable outwash material particularly in interlobate areas. Ground water discharges from these permeable deposits in substantial quantities to sustain base flows of these streams. The outwash materials extend into the Allegheny Plateaus along the courses of the larger streams.

Streams originating in the Till Plains generally receive little ground water contribution from the till but may receive substantial contributions from outwash fans and valley trains along their courses. Massive quantities of permeable materials exist in interlobate areas of the Till Plains. The Till Plains contain streams with some of the highest sustained base flows and some with the lowest sustained base flows of any in the state. Some streams originating in the Till Plains have unusual profiles where the flattest gradients are in upper channel reaches while the steepest gradients are along middle channel reaches. This reverse profile is due to glaciation; headwaters are in flat lying glacial moraine deposits, downstream reaches are in areas of greater of relief.

The basin descriptions given in this section are essentially those given in Division of Water, Bulletin 31 with minor edits and updates to make the information current. The tables include recent estimates of flow characteristics at stream gaging stations in the basins.

MAHONING RIVER BASIN

The Mahoning River drains a total area of 1,133 square miles, 55 of which are in Pennsylvania. The source is southeast of Alliance, and the river flows northeasterly to near Warren where it turns sharply to the southeast, flowing 41 miles to its mouth, which is the head of Beaver River. The Mahoning River meanders somewhat in a wide valley below Warren. The stream width varies from about 150 feet near Warren to about 200 feet at the mouth. Below Niles the river has cut a gorge in the bedrock. The basin map in figure 10 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The basin is entirely within the Glaciated Plateau. The Plateau is well dissected in the southeastern part, and is relatively flat toward the north, merging with the glacial plains.

Geology

The rocks exposed in the Mahoning River Basin dip gently toward the south, so that the formations crop out in east-west belts with successively younger formations toward the south. The Berea sandstone of Mississippian age occurs at the surface north of Warren. For several miles south of Warren interbedded shales and sandstones of Mississippian age prevail at or near the surface. The surface of the southern part of the Mahoning River Basin is underlain by the Pottsville and Allegheny rocks of Pennsylvanian age. Several of the sandstones and conglomerates are water bearing, but the Pennsylvanian strata are predominantly shale and clay with thin beds of coal and limestone. The effect of the rock aquifers on streamflow is probably negligible.

Of relatively greater importance from the hydrologic standpoint is the covering of glacial drift. This is erratic in thickness and variable in character. The drift is mostly of late Wisconsin age, largely till, and is generally thin, averaging about 25 feet in thickness. The valleys, except those that are buried, have little water storage in their glacial deposits. The buried valley deposits are generally of clay and fine sand that provide only limited storage. The western part of the area has a thicker drift, associated with the end moraines. There is a buried valley extending south to north across Portage County with a drift 200 feet thick and a similar one extending northward to the Mahoning-Grand River valley. The glaciers blocked the northward-flowing streams, and filled the ancient valleys with drift, rearranging the drainage pattern, and causing such reversals in direction as the bend in the Mahoning River near Warren. The most abundant water supplies are generally in the underlying rocks, indicating that there is little natural ground-water storage affecting streamflow. This is confirmed by the duration curves, which show relatively low sustained flows. Locally there are small areas of sands and gravels, and some variation in the thickness and permeability of the drift, which accounts for the small variations in the duration curves.

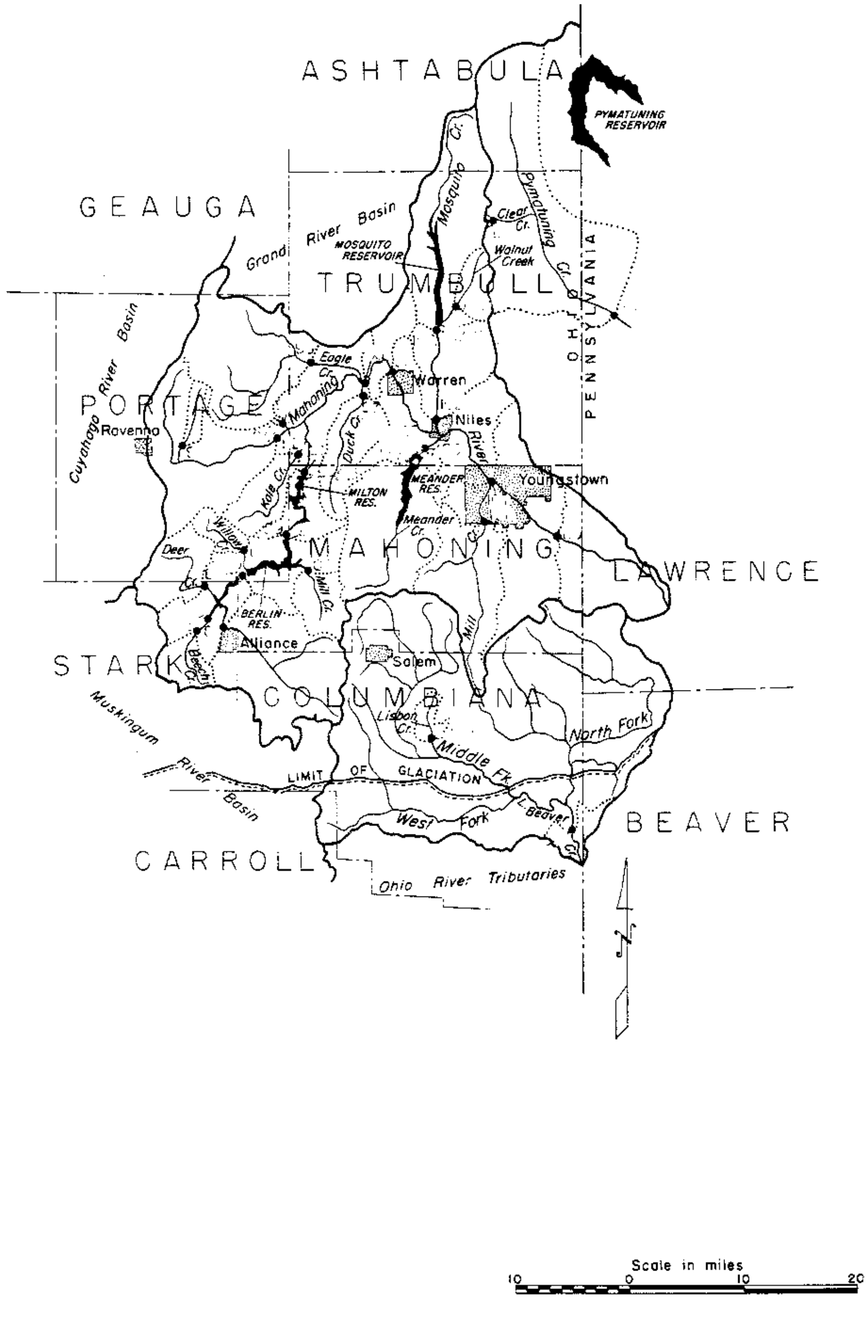


Figure 10. Map of Mahoning River Basin and Little Beaver Creek.

Soils

The soils in this area developed generally from late Wisconsin till deposited on sandstone and shale. The Mahoning and Ellsworth series of loams and silt loams are mapped over wide areas of the upland. These soils developed from fine- to moderately-fine-textured glacial till and are somewhat poorly drained. South and west of Youngstown there are moderately large areas of Ravenna silt loam soils developed from medium-textured glacial till with fair to good surface drainage, but with restricted internal drainage. Wooster and Canfield soils, developed from medium-textured glacial till, also occur. They have a fragipan with restricted internal drainage. Locally there are small areas of well-drained permeable terrace and alluvial soils, such as Chili and Chagrin, but generally the soils are slowly to very slowly permeable.

Water Development

Milton Reservoir was built in 1916 about 22 miles above Warren to provide water for industrial use; it now serves recreation, fish and wildlife purposes. Meander Creek Dam was built in 1929 to provide water supply for Niles and Youngstown. Berlin Dam was built in 1942 above Milton Reservoir to provide partial flood control and water supply. Mosquito Creek Dam was completed in 1943 for the same purpose. Kirwan Reservoir was built in 1966 on West Branch of Mahoning River for multiple purposes. Walborn Reservoir was built on Deer Creek in 1971 for water supply at Alliance.

Flow Characteristics

Recent estimates of flow characteristics are available for 33 stream gaging stations in the Mahoning River Basin. Selected flow characteristics at these gaging sites are given in table 6.

The indices of dry-weather flow show a wide range of variation. The relatively high indices at stations along the Mahoning River reflect flow regulation from water supply and wastewater operations. During the dry weather periods, Eagle Creek at Phalanx Station has a relatively high sustained flow as compared with the other unregulated tributaries in the basin. Eagle Creek drains an area in which the surface formations consist of relatively porous and permeable glacial deposits and sandstone bedrock; thus the ground-water contribution to streamflow is high.

The median- and low-flow indices for unregulated streams in the Mahoning River Basin are generally low in comparison with those for many other basins in the state, but they are not the lowest. The indices for flow 10 percent of the time are about average, indicating that high-water flows are not uncommon.

TABLE 6

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Mahoning River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Mahoning River at Alliance 03086500	89.2	94.6 (1.06) (14.4)	-	225 (2.52)	38 (0.43)	6.9 (0.077)	5.6 (0.059)	2250 (23.8)
Beech Creek near Bolton 03087000	17.4	-	31.3	-	-	0.9 (0.052)	0.6	1040 (59.8)
Beech Creek near Lexington 03087500	30.5	-	18.7	-	-	-	-	-
Deer Creek at Limaville 03088000	31.9	-	38.1	-	-	3.3 (0.103)	2.6	1060 (33.2)
Mahoning River near Deerfield 03088500	175	-	32.9	-	-	-	-	-
Willow Creek near Deerfield 03089000	11.6	-	20.6	-	-	-	-	-
Mill Creek near Berlin Center 03089500	19.1	16.7 (0.87) (11.9)	31.1	37 (1.94)	2.9 (0.15)	0.4 (0.021)	0.2 (0.012)	953 (49.9)
Mahoning River below Berlin Dam 03090500	248	252 (1.02) (13.8)	-	616 (2.48)	169 (0.68)	33 (0.133)	25 (0.099)	5510 (22.2)
Mahoning River at Pricetown 03091500	273	283 (1.04) (14.1)	-	723 (2.65)	181 (0.66)	61 (0.223)	40 (0.141)	-
Kale Creek at Pricetown 03092000	21.9	23.4 (1.06) (14.5)	25.2	52 (2.31)	4.0 (0.18)	0.3 (0.014)	0.1 (0.004)	1100 (50.2)

TABLE 6

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Mahoning River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	 50% cfs (cfs/sq. mi.)	 90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
West Branch Mahoning River near Ravenna 03092090	21.8	28.3 (1.30) (17.6)	42.9	66 (3.03)	12 (0.55)	2.3 (0.106)	1.5 (0.053)	883 (40.5)
Hinkley Creek near Berlin Center 03092099	7.85	-	-	-	-	0.4 (0.051)	0.3	341 (43.4)
West Branch Mahoning River below Kirwan Dam 03092460	81.7	106 (1.30) (17.6)	-	224 (2.74)	78 (0.95)	23 (0.281)	22 (0.208)	-
West Branch Mahoning River near Newton Falls 03092500	96.3	111 (1.15) (15.6)	37.3	225 (2.34)	83 (0.86)	24 (0.249)	23 (0.207)	2550 (26.5)
Ordinance Creek near Newton Falls 03092600	0.16	-	-	-	-	-	-	36 (221)
Eagle Creek at Phalanx Station 03093000	97.6	115 (1.18) (16.0)	45.5	268 (2.74)	45 (0.46)	14 (0.143)	11 (0.096)	2610 (26.7)
Duck Creek at Leavittsburg 03093500	35.2	-	28.6	-	-	0.7 (0.020)	0.4	-
Mahoning River at Leavittsburg 03094000	575	602 (1.05) (14.2)	-	1430 (2.49)	331 (0.58)	173 (0.301)	159 (0.264)	-
Walnut Creek at Cortland 03094900	8.75	-	-	-	-	-	-	481 (56.9)
Mosquito Cr. below Mosquito Cr. Dam 03095500	97.5	83.9 (0.86) (11.7)	26.7	206 (2.11)	35 (0.36)	5.1 (0.052)	5.5 (0.063)	-

TABLE 6

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Mahoning River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	 **50%** cfs (cfs/sq. mi.)	 **90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Mosquito Creek at Niles 03096000	138	-	38.0	-	-	-	-	1610 (11.7)
Meander Creek at Ohlstown 03096500	78.4	-	26.1	-	-	-	-	-
Meander Creek At Mineral Ridge 03097500	84.3	43.8 (0.52) (7.05)	-	103 (1.22)	1.8 (0.02)	0.6 (0.007)	0.6 (0.014)	-
Mahoning River at Youngstown 03098000	898	1000 (1.11) (15.1)	-	2300 (2.56)	570 (0.63)	311 (0.346)	258 (0.258)	-
Mill Creek at Youngstown 03098500	66.3	58.1 (0.88) (11.9)	-	148 (2.23)	19 (0.29)	2.5 (0.038)	0.9 (0.015)	1490 (22.4)
Crab Creek at Youngstown 03098700	14.0	-	-	-	-	-	-	673 (48.1)
Mahoning River at Lowellville 03099500	1073	1340 (1.25) (17.0)	-	2900 (2.70)	846 (0.79)	467 (0.435)	370 (0.276)	-
Clear Creek at Dillworth 03102900	1.13	-	-	-	-	-	-	66 (58.4)
Pymatuning Cr. at Kinsman 03102950	96.7	129 (1.33) (18.1)	51.0	358 (3.70)	57 (0.59)	5.5 (0.057)	2.0 (0.016)	1580 (16.3)

OHIO RIVER TRIBUTARIES BETWEEN MAHONING RIVER AND MUSKINGUM RIVER

Between the Mahoning River and the Muskingum River in southeastern Ohio is an area of about 2,500 square miles drained by several small tributaries of the Ohio River. The largest stream is Little Beaver Creek, with an area of 510 square miles. The basin maps in figures 10 and 11 show the outlines of the basins and flow paths of the main watercourses.

Physiography

Most of the Little Beaver Creek Basin is glaciated but the remainder of the area is part of the unglaciated Allegheny Plateau. The plateau is well dissected and the topography is rough, with the steepest slopes near the Ohio River. The northern part of Columbiana County, in the Little Beaver Creek drainage, is a broken glacial plain. South of this area is a belt of terminal moraines, with generally thin till but with occasional hills and lobes of thick drift.

The unglaciated plateau is decidedly hilly, with deep valleys, and in the lower ends of several streams, narrow gorges. The thick sandstone formations are resistant and form steep cliffs, particularly toward the Ohio River. The lower courses of Short Creek and Yellow Creek, for example, are entrenched, narrow and sinuous. The upland areas are flatter, but rough terrain predominates.

Geology

The rocks exposed in this area dip toward the southeast and consist of sandstones, shales, coal, and clay with occasional thin calcareous formations. The rocks are of Pennsylvanian and Permian age.

The glacial drift and outwash has some appreciable effect on the flow characteristics of Little Beaver Creek. South of the glacial boundary the soils are thin, and there is relatively little natural storage in the bedrock. Some of the streams south of the glacial limit flow over deep permeable alluvial deposits, for example, Yellow Creek. The sandstones are permeable and contribute toward sustained dry-weather flow of streams, but generally storage is small. Many of the coarser sandstone units are well above stream drainage. There are large areas denuded by strip mining.

Soils

The soils of the glaciated part of this area are predominantly the well-drained, moderately permeable Wooster and the moderately well drained, slowly permeable Canfield soils series. These soils developed from Wisconsin medium-textured glacial till on sandstone

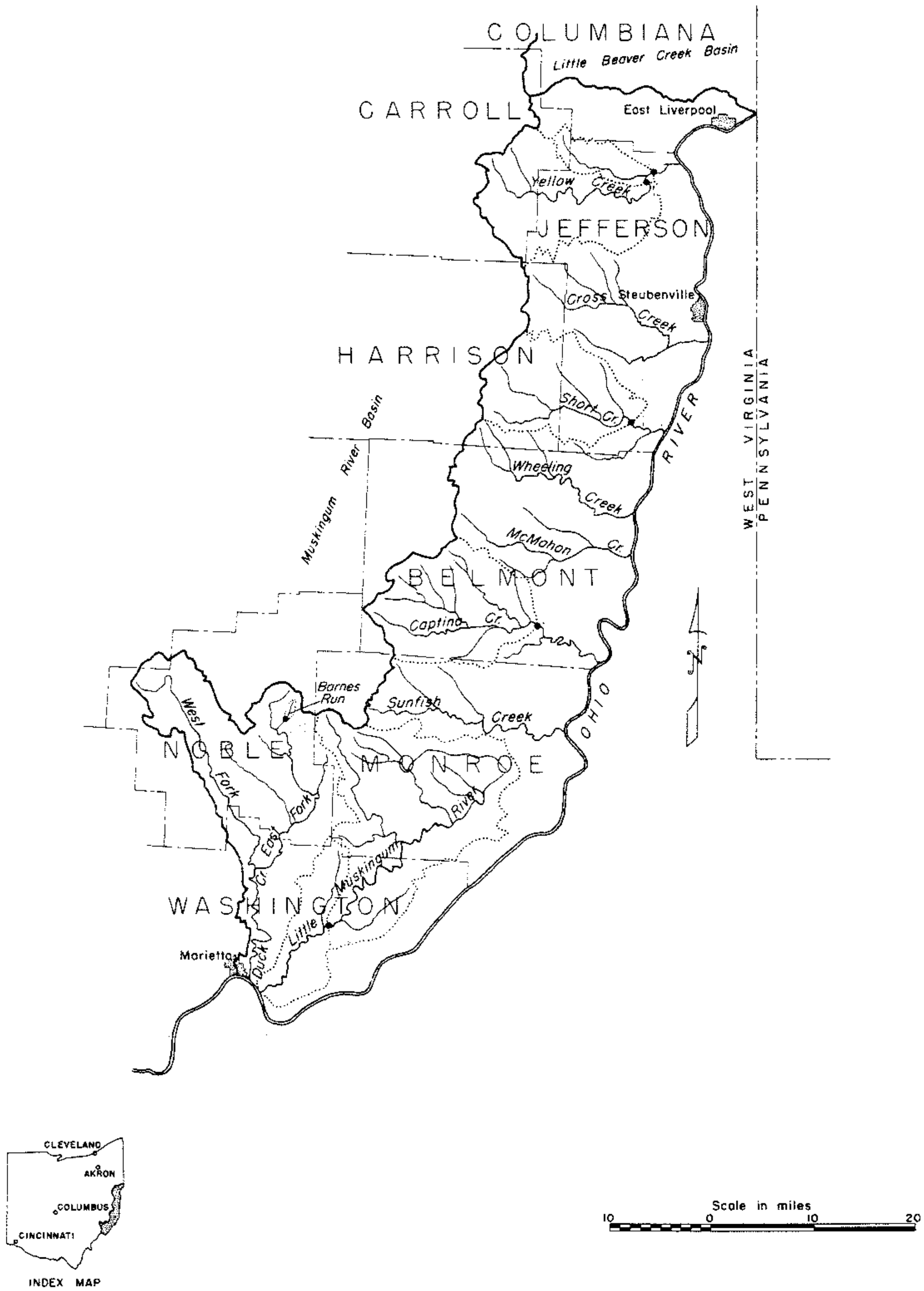


Figure 11. Map of Ohio River Tributaries between Little Beaver Creek and Muskingum River.

and shale. South of the glacial boundary the soils are shallow, with thin fill even in the valleys. Steep topography and erosion have prevented the normal development of soil profiles. Over large areas the soils are classified as the Gilpin, Berks, Hazleton, Westmoreland, Lowell, and Upshur series, with surface textures ranging from gravelly loam to silty clay loam. These are residual soils, and differences in their profile characteristics are due almost entirely to the underlying rock on which they developed. Permeability of the soils is generally moderate to slow.

Water Development

Several state lakes (Guilford Lake, Highlandtown Reservoir, and Monroe Lake) serving recreation, fish, and wildlife purposes and some municipal water supply reservoirs exist in the area. These impoundments have localized effects on stream flows.

Flow Characteristics

Recent estimates of flow characteristics are available for 41 stream gaging stations along tributaries to the Ohio River between the Mahoning River and Muskingum River. Selected flow characteristics at these gaging sites are given in table 7.

Study of these data reveals that generally the streams in the northern part of the area have greater sustained flows than those to the south. The low-flow index for Short Creek is abnormal because of mine drainage. Under normal conditions of flow, its index would be similar to that of Captina Creek.

In the northern part of the area the streams are affected somewhat by glacial deposits. The higher low-flow index for Little Beaver Creek indicates the additional increment of ground water furnished by the glacial deposits. North Fork and Middle Fork contribute the major portion of the dry-weather flow of Little Beaver Creek. These tributaries extend into the glaciated area and their main channels are underlain with glacial outwash deposits.

The flow of Yellow Creek is intermediate between that of Little Beaver Creek and the streams to the south. Well-drilling records show that the flood plain of Yellow Creek, throughout a large portion of its course, is underlain by deep alluvium that is quite permeable.

The dry-weather flow indices are low, but not as low as for some other areas in Ohio. The median flows are relatively high, indicating that there is limited storage in the basins that is exhausted after short droughts. The high-flow indices are high, particularly for the Little Muskingum River, and high water is not uncommon in the area.

TABLE 7

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Mahoning River and Muskingum River

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Middle Fork Little Beaver Cr. near Salem 03108980	35.7	-	-	-	-	5.5 (0.15)	4.5	-
Cherry Valley Run at Leetonia 03108985	11.9	-	-	-	-	1.5 (0.04)	1.2	-
East Branch M.F. Little Beaver Cr. at Leetonia 03108990	28.0	-	-	-	-	1.7 (0.06)	1.3	-
Middle Fork Little Beaver Cr. at Teegarden 03108996	90.2	-	-	-	-	11 (0.12)	8.6	-
Lisbon Creek at Lisbon 03109000	6.19	5.84 (0.94) (12.8)	53.3	14 (2.26)	2.2 (0.36)	0.4 (0.06)	0.2 (0.03)	377 (60.9)
Middle Fork Litttle Beaver Cr. near Rogers 03109100	149	-	-	-	-	20 (0.13)	-	-
West Fork Little Beaver Cr. at West Point 03109200	99.9	-	-	-	-	6.2 (0.06)	4.3	-
Bull Creek at Negley 03109395	55.4	-	-	-	-	5.7 (0.10)	4.1	-
North Fork Little Beaver Cr. near Negley 03109400	166	-	-	-	-	22 (0.13)	17	-

TABLE 7

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Mahoning River and Muskingum River

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Little Beaver Cr. Near East Liverpool 03109500	496	523 (1.05) (14.3)	55.4	1240 (2.50)	248 (0.50)	51 (0.10)	37 (0.07)	9290 (18.7)
Yellow Creek near Hammondville 03110000	147	162 (1.10) (15.0)	60.5	394 (2.68)	76 (0.52)	11 (0.07)	6.4 (0.04)	3180 (21.6)
Yellow Creek at Hammondville 03110500	164	-	52.2	-	-	-	-	-
North Fork Yellow Creek at Hammondville 03110600	59.4	-	-	-	-	3.1 (0.05)	2.1	-
Island Creek Near Toronto 03110850	26.4	-	-	-	-	2.6 (0.10)	1.6	-
Consol Run at Bloomingdale 03110980	0.04	-	-	-	-	-	-	7 (175)
Cross Creek at Mingo Junction 03111000	125	-	-	-	-	10 (0.08)	7.0	-
Branson Run at Georgetown 03111450	1.31	-	-	-	-	-	-	58 (44.6)
South Fork Short Cr. at Georgetown	10.9	-	-	-	-	-	-	215 (19.7)
Short Creek at Adena 03111465	63.9	-	-	-	-	12 (0.19)	10	-

TABLE 7

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Mahoning River and Muskingum River

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Little Piney Fork at Parlett 03111470	1.57	-	-	-	-	-	-	65 (41.4)
Piney Fork Trib. near Piney Fork 03111490	0.44	-	-	-	-	-	-	17 (38.6)
Short Creek near Dillonvale 03111500	123	130 (1.06) (14.3)	71.4	273 (2.21)	80 (0.65)	23 (0.19)	19 (0.15)	2940 (23.9)
Sloan Run Trib. near Harrisville 03111540	0.34	-	-	-	-	-	-	52 (153)
Wheeling Creek below Blaine 03111548	97.7	111 (1.14)	69.6	229 (2.34)	72 (0.74)	27 (0.28)	20 (0.18)	-
Wheeling Creek at Brookside 03111550	149	-	-	-	-	16 (0.16)	13	-
McMahon Creek at Glencoe 03112820	50.7	-	-	-	-	2.8 (0.06)	1.1	-
McMahon Creek at Bellaire 03113550	90.2	-	-	-	-	7.3 (0.08)	3.4	-
Captina Creek at Armstrong Mills 03114000	134	165 (1.23) (16.7)	49.8	384 (2.87)	66 (0.49)	4.5 (0.030)	1.5 (0.01)	6190 (46.2)
Wood Run near Woodsfield 03114240	0.53	-	-	-	-	-	-	69 (130)

TABLE 7

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Mahoning River and Muskingum River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Sunfish Creek at Cameron 03114250	99.6	-	-	-	-	2.2 (0.02)	1.0	-
Trail Run near Antioch 03115280	5.45	-	-	-	-	-	-	593 (109)
Little Muskingum near Rinard Mills 03115300	130	-	-	-	-	2.7 (0.02)	0.9	-
Little Muskingum River at Bloomfield 03115400	210	272 (1.30) (17.6)	41.5	656 (3.12)	98 (0.47)	4.8 (0.02)	1.6 (0.01)	7000 (33.3)
Graham Run near Bloomfield 03115410	0.13	-	-	-	-	-	-	22 (169)
Little Muskingum River at Fay 03115500	259	340 (1.31) (17.8)	41.0	774 (3.0)	106 (0.41)	5.9 (0.02)	3.7 (0.01)	-
Moss Run near Wingett 03115510	1.52	-	-	-	-	-	-	209 (138)
Barnes Run near Summerfield 03115600	3.46	-	-	-	-	-	-	520 (150)
East Fork Duck Cr. at Lower Salem 03115650	111	-	-	-	-	5.6 (0.05)	2.3	-
West Fork Duck near Dexter City 03115700	75.4	-	-	-	-	2.4 (0.03)	1.0	-

TABLE 7

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Mahoning River and Muskingum River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Buffalo Run Trib. near Dexter City 03115710	0.19	-	-	-	-	-	-	43 (226)
Duck Creek at Stanleyville 03115800	267	-	-	-	-	5.1 (0.02)	3.9	-

MUSKINGUM RIVER BASIN

The Muskingum River is the largest stream in the state and drains 8,038 square miles, or about one-fifth of Ohio. Within the basin, the physiographic, geologic, and soil conditions vary greatly. The Muskingum River forms at the junction of the Walhonding and Tuscarawas rivers near Coshocton, and flows 109 miles to the south and east to enter the Ohio River at Marietta. The northern and western edges of the basin are glaciated. The map in figure 12 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The basin is entirely within the Allegheny Plateaus province. The line of glaciation marking the farthest southward advance of the ice sheets extends west from northern Tuscarawas County to the vicinity of Loudonville, thence almost directly south, leaving the basin in Perry County. The glaciated area is generally gently rolling with some flat topography, and the unglaciated plateau is generally rough and well dissected.

Geology

The bedrock formations dip generally to the southeast about 20 to 40 feet to the mile. The rocks are of Mississippian, Pennsylvanian, and Permian ages, and consist of interbedded sandstones and shales, with some coal and clay beds and occasional thin limestone formations. Several of the sandstone beds are important sources of ground water, but generally the rocks have little direct influence upon streamflow. The productive sandstones are at depth below stream drainage.

The glacial deposits vary from thin and relatively impermeable till to thick sand and gravel beds. The melt water deposits, such as valley train deposits, kames and kame terraces are generally well sorted and permeable. Such beds, where extensive, have a profound influence on streamflow particularly in buried valleys filled with permeable material with a present-day stream flowing over the top of the ancient valley.

The valleys of Sandy Creek and Nimishillen Creek in the vicinity of Canton, for example, have enormous ground-water storage in the thick permeable gravels and are one of the best areas in the state from this standpoint. In nearby areas the till is thin and impervious, and there is little natural storage in the ground. Every county that is in the glaciated part of the Muskingum River Basin has some thick valley deposits, but detailed surveys are required to determine the extent of such fills.

Soils

The soils in the glaciated area of this basin are generally developed from late Wisconsin drift. Over large areas of the upland in the north the soils are predominantly the well

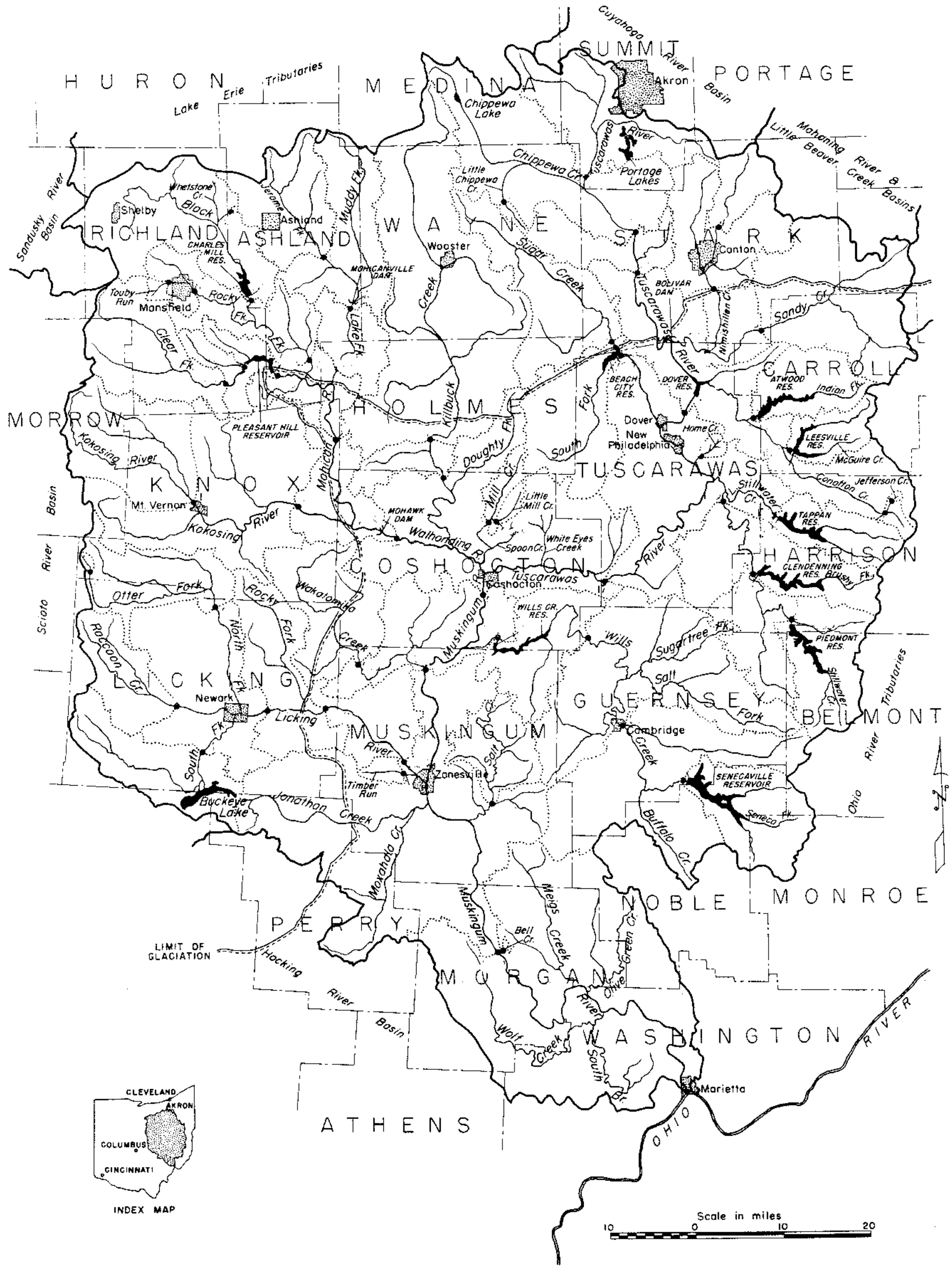


Figure 12. Map of the Muskingum River Basin.

drained and moderately permeable Wooster and the moderately well drained, slowly permeable Canfield. Moderately large areas of slowly permeable Rittman and Wadsworth silt loams occur in the northern part of the glaciated area. Amanda and Alexandria silt loams and associated soils are prevalent along the western part of the glaciated area. The permeability of these soils varies from moderate to slow. More permeable soils are found in the valleys. Chili, Chagrin, and Tioga loams and silt loams are the more important soils there. Below the glacial boundary, the principal upland soils are the Gilpin, Brownsville, Berks, Westmoreland, Coshocton, Keene, and Wellston loams and silt loams, with Upshur in some areas of reddish clay shale in the southern part of the basin. These are moderately deep or deep residual soils developed on a variety of contrasting bedrock. Their profile characteristics depend almost entirely on the kind of parent rock on which the soils developed. Generally these soils are moderately to slowly permeable. In the broader valleys, there are areas of alluvial and terrace soils which are well drained and permeable.

Water Development

In 1938, the Corps of Engineers completed 14 flood control reservoirs in the Muskingum River Basin for the Muskingum Conservancy District. This system of reservoirs is the most important water development in the basin. In 1960, the Corps of Engineers completed Dillon Reservoir on the Licking River for flood protection at Zanesville.

Canal Era locks and dams on the Muskingum River facilitated commercial navigation as far as Dresden, 91 miles above the mouth, but now serve recreational watercraft needs.

Some flow from the upper reaches of the Tuscarawas River (Portage Lakes) is diverted into the Cuyahoga River by a feeder canal. Buckeye Lake, in Licking River drainage, was formed to provide water for the summit level of the old Ohio Canal, but it is now used for recreational purposes only.

Flow Characteristics

Recent estimates of flow characteristics are available for 125 stream gaging stations in the Muskingum River Basin. Selected flow characteristics at these gaging sites are given in table 8.

The gaging stations on the Tuscarawas River at Clinton and Massillon have high indices of dry-weather flow. The effect of the Portage Lakes during the low-flow period is probably small. The effect of the Barberton Reservoir on Wolf Creek is negligible on the overall flow of Tuscarawas River above Massillon. It is believed that the high sustained flow in this part of the basin is derived from the kame moraine area east of the Portage Lakes. The morainal material is highly permeable and absorbs large quantities of rainfall. Associated with the morainal material are buried valley deposits and high-level outwash material. Discharge of ground water in this area supports the dry-weather flow in the Tuscarawas River. As a whole the Tuscarawas River flows over relatively thick glacial deposits. A buried valley that contains about 200 feet of fill underlies the flood plain between Clinton and Massillon. This valley extends to the northwest under Chippewa Creek. Although Chippewa Creek may contribute some flow to the sustained flow of the Tuscarawas, it is quite likely that the high index of flow of the Tuscarawas is the result of ground-water contribution from glacial deposits associated with the Tuscarawas valley in Summit and Stark counties.

Analysis of flow in Sandy Creek reveals the effect of the sands and gravels on dry-weather flow. For the most part the Sandy Creek basin lies below the glacial boundary; only the extreme upper part drains the terminal moraine area. However, the floodplain of Sandy Creek and several of its tributaries such as Little Sandy Creek, Hugle Run, and Middle Branch are underlain by sand and gravel deposits of outwash origin. The gaging stations at Waynesburg and Sandyville show indices of dry-weather flow well above average.

There is a wide difference in the indices of flow between Middle Branch of Nimishillen Creek at Canton and Nimishillen Creek at North Industry. The entire area is glaciated, the drift consisting of end moraine that varies from tight till to gravel, ground moraine of varying character, kames and kame terraces and outwash and valley train gravel. With such surface features, high sustained flows should be expected. The discrepancy between the two stations is the result of ground-water pumpage at the Canton northeast well field where up to 11 million gallons per day has been pumped from the gravel formation underlying the flood plain of Middle Branch. Field studies have shown that recharge to the well field is derived from river infiltration.

Below Massillon, the gaging stations on the Tuscarawas River are affected by regulation of the Muskingum Watershed Conservancy District reservoirs. Prior to the regulation, however, records indicate a high sustained flow. Throughout most of its course, the Tuscarawas River flows on extensive valley train gravels.

The record on Home Creek near New Philadelphia is significant in that it shows the small influence of ground-water storage in bedrock on streamflow in the basin. Home Creek is in the unglaciated area and flows on bedrock of Pennsylvanian age.

Stillwater Creek at Uhrichsville, although regulated at present, has a low index of dry-weather flow as determined by the record from 1923 to 1936, prior to regulation. Ground-water contribution from the rock strata is almost negligible in this basin. Underlying the floodplain of Stillwater Creek is 100 feet or more of valley fill. This material is largely silt, clay, or fine sand and thus adds little to streamflow. Similar conditions prevail in Wills Creek.

The Walhonding River and all of its major tributaries have high indices of dry-weather flow. The tributary system in this basin follows essentially the Deep Stage drainage system, which was inaugurated in interglacial times. Thus, the Walhonding and its principal tributaries flow through valleys that are underlain by deep valley fill. Headwaters of the Kokosing River, Mohican River, and Killbuck Creek extend well into the glaciated area where a variety of surface conditions prevail. End moraines of Wisconsin and Illinoian glacial stages are present and the material ranges from tight till to porous gravel. The ground moraine is chiefly till although locally it may be sandy or gravelly. High-level outwash gravels are present locally and some areas have extensive kame and kame terrace deposits. As a whole the Walhonding Basin has a high percent of permeable glacial deposits capable of absorbing and releasing large quantities of water. Furthermore, the extensive sandstone of the Blackhand formation of Mississippian age lies at or near the surface in places in Knox and Richland counties and undoubtedly contributes ground water to the flow of the Kokosing and Mohican tributaries.

Of the records available in the Walhonding Basin, two streams, Mill Creek near Coshocton and Jerome Fork at Jeromesville, show relatively low indices compared with other streams in the basin. Mill Creek is cut into impermeable Pennsylvanian strata except in the lower three miles of its course where it flows on unconsolidated valley fill. Above Jeromesville, Jerome Fork drains an area in which the surface materials are chiefly dense ground moraine.

The moderately sustained flow of Wakatomika Creek near Frazeysburg is influenced by conditions in both glacial deposits and bedrock. Wakatomika Creek had its inception during Illinoian glaciation and it has not changed greatly since that time. The stream in places flows over deep valley fill and over bedrock in other portions of its course. It drains an area partly occupied by the terminal moraine of Illinoian age. The morainal material varies from dense till to loose porous gravel. Additional sand and gravel deposits are present in the form of valley train and high-level outwash. Underlying the drift cover in the headwater area is the sandstone of the Blackhand formation that has a large ground-water storage capacity and undoubtedly contributes somewhat to the flow of Wakatomika Creek.

The Licking River is formed by the confluence of North Fork, Raccoon Creek, and South Fork at Newark. The flows equaled or exceeded 90 percent of the time in North Fork at Utica and Raccoon Creek at Granville are both about 0.05 cubic feet per second per square mile. Flow equaled or exceeded 90 percent of the time in South Fork near Millersport is about 0.06 cubic feet per second per square mile. Flow equaled or exceeded 90 percent of the time in the Licking River at Newark, however, is about 0.13 cubic feet per second per square mile. Miscellaneous measurements at low water indicate varying rates of increase in flow below the North Fork gage at Utica, and the 90 percent of the time flow in North Fork near Newark is about 0.12 cubic feet per second per square mile.

Study of glacial geology in the Newark area, aided by soil maps, provides an explanation for the streamflow characteristics. The tributaries forming the Licking River flow through areas of ground moraine and end moraine largely composed of till. The lower part of North Fork and the main stem of the Licking River at Newark flow through an area of kame terraces, valley train, and outwash plains. A marked increase in flow at Vanatta north of Newark is explained by the presence of a low outwash fan upon the main valley train.

On average, the dry-weather flow of streams in the Muskingum River Basin is higher than that of any other large area in the state, equaling the Miami River average. Median-flow indices are also relatively high. High-flow indices are correspondingly low, on average, but large floods have occurred at intervals in the basin. The reservoir system significantly attenuates floods on the major streams, but tends to increase the 10-percent duration flow indices, by increasing the duration of medium high flows.

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Tuscarawas River At Uniontown 03115890	8.26	-	-	-	-	2.7 (0.327)	2.8	-
Tuscarawas River at East Liberty 03115900	33.1	-	-	-	-	16 (0.482)	17	-
Tuscarawas River at Barberton 03115920	72.5	-	-	-	-	25 (0.345)	26	-
Wolf Creek near Barberton 03115990	53.9	-	-	-	-	4.0 (0.074)	4.2	-
Tuscarawas River at Clinton 03116000	174	157 (0.90) (12.2)	-	343 (1.97)	87 (0.50)	49 (0.282)	50 (0.318)	1340 (7.7)
Chippewa Creek at Seville 03116075	44.0	-	-	-	-	1.4 (0.032)	1.2	-
Chippewa Creek at Sterling 03116080	64.4	-	-	-	-	2.5 (0.039)	2.2	-
Little Chippewa Cr. near Smithville 03116100	16.4	-	-	-	-	2.6 (0.159)	2.4	726 (44.3)
Chippewa Creek at Easton 03116200	146	136 (0.93) (12.6)	-	356 (2.44)	49 (0.34)	12 (0.082)	10 (0.074)	1820 (12.5)
Nimisila Creek near Canal Fulton 03116410	23.1	-	-	-	-	4.7 (0.203)	4.8	-
Newman Creek near Massillon 03116950	38.2	-	-	-	-	1.5 (0.039)	1.2	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Tuscarawas River at Massillon 03117000	518	458 (0.88) (12.0)	-	1080 (2.08)	233 (0.45)	102 (0.197)	93 (0.203)	4070 (7.9)
Sandy Creek at Minerva 03117150	61.9	-	-	-	-	6.4 (0.103)	5.7	-
Still Fork near Minerva 03117160	36.2	-	-	-	-	1.8 (0.050)	1.6	-
Hugle Run near Malvern 03117280	21.3	-	51.4	-	-	2.1 (0.100)	1.9	-
Sandy Creek at Malvern 03117300	163	-	-	-	-	26 (0.160)	24	-
Pipe Run at Malvern 03117310	27.7	-	-	-	-	0.4 (0.014)	0.4	-
Little Sandy Creek near Robertsville 03117450	29.7	-	-	-	-	4.5 (0.152)	4.1	-
Sandy Creek at Waynesburg 03117500	253	272 (1.05) (14.6)	63.0	638 (2.52)	138 (0.55)	35 (0.138)	31 (0.114)	3450 (13.6)
Middle Branch Nimishillen Creek at Canton 03118000	43.1	37.9 (0.88) (11.9)	-	85 (1.97)	20 (0.46)	4.2 (0.097)	4.4 (0.116)	659 (15.3)
East Branch Nimishillen Creek near Canton 03118100	33.4	-	-	-	-	4.8 (0.144)	4.5	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
West Branch Nimishillen Creek at Canton 03118300	43.9	-	-	-	-	8.6 (0.196)	8.0	-
Nimishillen Creek at North Industry 03118500	175	194 (1.11) (15.0)	-	379 (2.17)	123 (0.70)	54 (0.309)	57 (0.294)	3140 (17.9)
Sandy Creek at Sandyville 03119000	481	-	58.9	-	-	-	-	7190 (14.9)
Tuscarawas River at Zoar 03119580	1102	-	-	-	-	226 (0.205)	199	-
Conotton Creek at Jewett 03119700	14.3	-	-	-	-	0.6 (0.042)	0.4	488 (34.1)
Conotton Creek at Leesville 03119900	87.1	-	-	-	-	8.3 (0.095)	5.3	-
McGuire Creek below Leesville Dam 03120500	48.3	53.8 (1.11) (15.1)	-	159	20	1.9 (0.039)	1.6	-
Huff Run At Mineral City 03121850	12.3	-	69.5	-	-	-	-	-
Tuscarawas River below Dover Dam 03122500	1405	1450 (1.03) (14.0)	-	3880 (2.76)	844 (0.60)	313 (0.223)	290 (0.200)	14900 (10.6)
Sugar Creek near Orville 03122850	47.2	-	-	-	-	2.0 (0.042)	1.4	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	50%	90% (cfs) (cfs/sq. mi.)	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Sugar Creek near West Lebanon 03122900	69.8	-	-	-	-	3.3 (0.047)	2.3	-
Sugar Creek above Beach City Dam 03123000	160	140 (0.88) (11.9)	-	350 (2.19)	51 (0.32)	10 (0.062)	7.4 (0.053)	-
South Fork Sugar Cr. at Dundee 03123300	124	-	-	-	-	6.0 (0.048)	4.2	-
Dundee Creek at Dundee 03123400	0.74	-	-	-	-	-	-	130 (176)
Sugar Creek below Beach City Dam 03124000	300	276 (0.92) (12.5)	-	760 (2.53)	116 (0.39)	20 (0.067)	16 (0.053)	-
Sugar Creek at Strasburg 03124500	311	301 (0.97) (13.1)	-	821 (2.64)	138 (0.44)	25 (0.080)	23 (0.076)	-
Sugar Creek at Dover 03124520	348	-	-	-	-	32 (0.092)	24	-
Home Creek near New Philadelphia 03125000	1.64	1.31 (0.80) (10.8)	48.2	3.0 (1.83)	0.4 (0.24)	0	0	121 (73.8)
W. Branch Spencer Creek at Hendrysburg 03125300	2.26	-	-	-	-	-	-	194 (85.8)
Robinson Run near Hendrysburg 03125450	1.97	-	-	-	-	-	-	104 (52.8)
Boggs Fork at Piedmont 03125900	36.6	-	-	-	-	0.9 (0.025)	0.5	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Stillwater Creek at Piedmont 03126000	122	139 (1.14) (15.5)	-	373 (3.06)	77 (0.63)	7.7 (0.063)	5.5 (0.045)	-
Skull Fork at Freeport 03126170	45.9	-	-	-	-	0.6 (0.013)	0.2	-
Stillwater Creek at Tippecanoe 03127000	282	325 (1.15) (15.6)	-	934 (3.31)	162 (0.57)	17 (0.060)	13 (0.040)	-
Crooked Creek near Stillwater 03127100	47.5	-	-	-	-	1.5 (0.032)	0.7	-
Stillwater Creek at Uhrichsville 03127500	367	426 (1.16) (15.8)	-	1200 (3.27)	216 (0.59)	24 (0.065)	15 (0.035)	-
Clear Fork near Jewett 03127950	5.45	-	-	-	-	-	-	194 (35.6)
Clear Fork Trib. near Hanover 03127970	0.68	-	-	-	-	0.1 (0.147)	0.1	-
Little Stillwater Cr. below Tappan Dam 03128500	71.1	77.5 (1.09) (14.8)	-	237 (3.33)	27 (0.38)	2.2 (0.031)	1.7 (0.022)	-
Little Stillwater Cr. near Dennison 03128600	96.4	-	-	-	-	3.6 (0.037)	2.9	-
Mud Run Trib. at Wainwright 03128650	0.55	-	-	-	-	-	-	15 (27.3)
Tuscarawas River at Tuscarawas 03128700	2367	-	-	-	-	461 (0.195)	406	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	 **50%** cfs (cfs/sq. mi.)	 **90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Tuscarawas River at Newcomerstown 03129000	2443	2580 (1.06) (14.3)	-	6760 (2.77)	1530 (0.63)	443 (0.181)	384 (0.149)	21300 (8.7)
White Eyes Creek Trib. near Coshocton 03129012	0.012	-	-	-	-	-	-	3 (250)
White Eyes Creek Trib. near Coshocton 03129014	0.441	-	-	-	-	-	-	707 (243)
White Eyes Creek Trib. near Coshocton 03129016	0.116	-	-	-	-	-	-	29 (250)
White Eyes Creek near Fresno 03129100	52.1	-	-	-	-	2.5 (0.048)	1.1	-
Tuscarawas River at Coshocton 03129150	2596	-	-	-	-	483 (0.186)	418	-
Whetstone Creek Trib. near Olivesburg 03129300	0.24	-	-	-	-	-	-	42 (175)
Black Fork above Charles Mill Dam 03129400	193	-	-	-	-	6.8 (0.035)	6.2	-
Black Fork below Charles Mill Dam 03130000	217	206 (0.95) (12.9)	-	591 (2.72)	92 (0.42)	19 (0.09)	16 (0.078)	-
Touby Run at Mansfield 03130500	5.44	5.12 (0.94) (12.8)	39.5	12 (2.21)	1.6 (0.29)	0.4 (0.074)	0.3 (0.058)	403 (74.1)
Black Fork at Loudonville 03131500	349	368 (1.05) (14.3)	-	932 (2.67)	207 (0.59)	77 (0.221)	73 (0.198)	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Killbuck Creek at Wooster 03138800	128	-	-	-	-	5.7 (0.045)	5.2	-
Apple Creek at Wooster 13138820	33.7	-	58.6	-	-	4.9 (0.145)	4.6	-
Jennings Ditch Trib. at Wooster 03138900	0.9	-	-	-	-	-	-	79 (87.8)
Salt Creek at Homesville 03138910	42.6	-	40.4	-	-	1.7 (0.040)	1.6	-
Killbuck Creek at Killbuck 03139000	464	427 (0.92) (12.5)	65.0	-	-	-	-	-
Killbuck Creek at Layland 03139500	503	-	57.5	-	-	-	-	-
Little Mill Creek Trib. near Coshocton 03139930	0.54	-	-	-	-	-	-	65 (120)
Little Mill Creek near Coshocton 03139940	1.44	-	-	-	-	-	-	156 (108)
Little Mill Creek near Coshocton 03139960	2.38	-	-	-	-	-	-	296 (124)
Little Mill Creek Trib. near Coshocton 03139970	0.19	-	-	-	-	-	-	27 (142)
Little Mill Creek near Coshocton 03139980	4.02	-	-	-	-	-	-	409 (102)

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Little Mill Creek near Coshocton 03139990	7.16	-	-	-	-	-	-	690 (96.4)
Mill Creek near Coshocton 03134000	27.2	28.4 (1.04) (14.2)	54.8	65 (2.39)	11 (0.40)	1.1 (0.040)	0.5 (0.018)	1330 (48.9)
Spoon Creek Trib. near Coshocton 03140010	0.12	-	-	-	-	-	-	22 (183)
Spoon Creek Trib. near Coshocton 03140020	0.07	-	-	-	-	-	-	10 (143)
Spoon Creek Trib. near Coshocton 03140030	0.05	-	-	-	-	-	-	14 (280)
Muskingum River near Coshocton 03140500	4859	5020 (1.03) (14.0)	-	13000 (2.68)	2970 (0.61)	859 (0.177)	746 (0.149)	-
Buffalo Fork at Pleasant City 03140700	71.1	-	-	-	-	5.7 (0.080)	1.2	-
Seneca Fork below Senecaville Dam 03141500	118	132 (1.12) (15.2)	-	451 (3.82)	39 (0.33)	2.6 (0.022)	2.5 (0.019)	-
Leatherwood Creek near Cambridge 03141900	88.3	-	-	-	-	3.2 (0.036)	0.8	-
Wills Creek at Cambridge 03142000	406	438 (1.08) (14.6)	-	1220 (3.00)	183 (0.45)	18 (0.044)	10 (0.023)	-
Salt Fork near Cambridge 03142200	55.6	-	41.8	-	-	-	-	1740 (31.3)

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Wills Creek at Birds Run 03142500	730	-	40.3	-	-	-	-	-
Wills Creek below Wills Creek Dam 03143550	842	935 (1.11) (15.1)	-	2650	452	53	38	-
Wakatomika Creek near Perryton 03143760	58.3	-	-	-	-	4.9 (0.084)	3.6	-
Wakatomika Creek near Frazeysburg 03144000	140	154 (1.10) (14.9)	54.5	347 (2.48)	64 (0.46)	11 (0.079)	8.1 (0.052)	4060 (29.0)
Sand Fork near Wakatomika 03144400	1.3	-	63.8	-	-	-	-	-
Opossum Run Trib. near Wakatomika 03144450	1.3	-	56.3	-	-	0.1 (0.077)	0.1	-
Muskingum River at Dresden 03144500	5993	6470 (1.08) (14.7)	-	16900 (2.82)	3810 (0.64)	1030 (0.172)	950 (0.147)	46200 (7.7)
Etna Creek at Etna 03144800	1.1	-	-	-	-	-	-	99 (90)
South Fork Licking River near Millersport 03144830	62.9	-	-	-	-	2.7 (0.043)	2.4	-
South Fork Licking River near Hebron 03145000	133	160 (1.20) (16.3)	-	444 (3.34)	49 (0.37)	8.4 (0.063)	6.5 (0.041)	-
Raccoon Creek at Granville 03145500	83.0	-	31.1	-	-	4.2 (0.051)	3.7	3850 (46.4)

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Otter Fork near Centerburg 03145600	3.17	-	-	-	-	-	-	1.27 (40.1)
North Fork Licking River at Utica 03146000	116	138 (1.19) (16.1)	36.8	322 (2.78)	44 (0.38)	5.9 (0.051)	4.5 (0.033)	4750 (40.9)
North Fork Licking River above Newark 03146250	224	-	-	-	-	27 (0.121)	25	-
Licking River near Newark 03146500	537	621 (1.16) (15.7)	49.9	1470 (2.74)	257 (0.48)	68 (0.127)	63 (0.101)	11300 (21.0)
Licking River at Toboso 03147000	672	-	47.8	-	-	-	-	12800 (19.0)
Licking River below Dillon Dam 03147500	742	889 (1.20) (16.3)	-	2700 (3.64)	396 (0.53)	98 (0.132)	84 (0.113)	-
Timber Run near Zanesville 03147900	10.1	-	-	-	-	-	-	782 (77.4)
Moxahala Creek at Roseville	80.6	-	-	-	-	11 (0.136)	8.5	2300 (28.5)
Moxahala Creek at Roberts 03148400	98.1	-	-	-	-	8.8 (0.090)	7.0	-
Jonathan Creek at East Fultonham 03148450	125	-	-	-	-	5.8 (0.046)	5.2	-
Moxahala Creek near Zanesville 03148600	300	-	-	-	-	20 (0.067)	16	-

TABLE 8

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Muskingum River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Salt Creek near Chandlersville 03149500	75.7	89.2 (1.18) (16.0)	44.5	199 (2.63)	30 (0.40)	2.8 (0.037)	0.7 (0.008)	3200 (42.3)
Muskingum River at McConnelsville 03150000	7422	7780 (1.05) (14.2)		20500 (2.76)	4550 (0.61)	1200 (0.162)	1020 (0.131)	55800 (7.5)
Meigs Creek near Beverly 03150250	136	-	-	-	-	8.4 (0.062)	3.7	-
West Branch Wolf Creek near Waterford 03150480	144	-	-	-	-	1.6 (0.011)	1.2	-
South Branch Wolf Creek near Waterford 03150490	79.3	-	-	-	-	1.0 (0.013)	0.4	-
Tupper Creek at Devola 031506	1.0	-	-	-	-	-	-	135 (135)

HOCKING RIVER BASIN

The Hocking River drains an area of 1,200 square miles. Its source is about 35 miles southeast of Columbus, and it flows southeasterly about 100 miles to the Ohio River at Hockingport. The river follows a winding course and flows in a channel usually about 100 feet wide, except near the mouth. The banks are low, and the flat bottomlands, averaging about one-half mile in width, are often inundated. The gradient is flat, averaging about 2.8 feet per mile. The map in figure 13 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The glaciated portion of the basin, largely in Fairfield County, is part of the Glaciated Allegheny plateau. The topography is moderately hilly, with wide, flat valley. A portion of the area is swampy. South of this area is the unglaciated plateau, with rougher terrain, steep slopes and in some valleys picturesque sandstone cliffs.

Geology

The surface rocks are of Mississippian and Pennsylvanian age, and are mostly of interbedded sandstones and shales. The dip is almost directly east. The outcrops of the Black Hand formation, massive conglomeratic sandstone, are particularly impressive. In some areas the sandstones are important sources of ground water, but their effect on stream flow is not apparent. The best-sustained stream flows are in the glaciated region, where the thick drift store in buried valleys and high-level terraces large quantities of water. South of the glacial boundary the main valley is filled with deep outwash sand and gravel, but the effect on stream flow is negligible because the permeable material lie below drainage.

Soils

The soils in the glaciated region (northwestern part of the basin) are generally of sandstone and shale origin. Principal soils include the Amanda, Alexandria, Centerburg, and Cardington silt loams in the Wisconsin drift area and the Homewood and Cincinnati silt loams in the Illinoian drift area. Loudonville soils, which are formed from moderately deep till over sandstone, occur in both Wisconsin and Illinoian glaciated areas. Permeability of these soils is moderate to slow. South of the glacial boundary, the upland soils are of the Gilpin, Westmoreland, Upshur, Guernsey, Steinsburg, and Wellston soils series. Steep topography and erosion have slowed the development of mature soils throughout most of the upland area. Permeability is moderate to slow. Terrace and alluvial soils in the valleys are thicker and more productive; the important soils series include the Chagrin, Nolin, Glenford, and Otwell, which are well drained or moderately well drained and permeable.

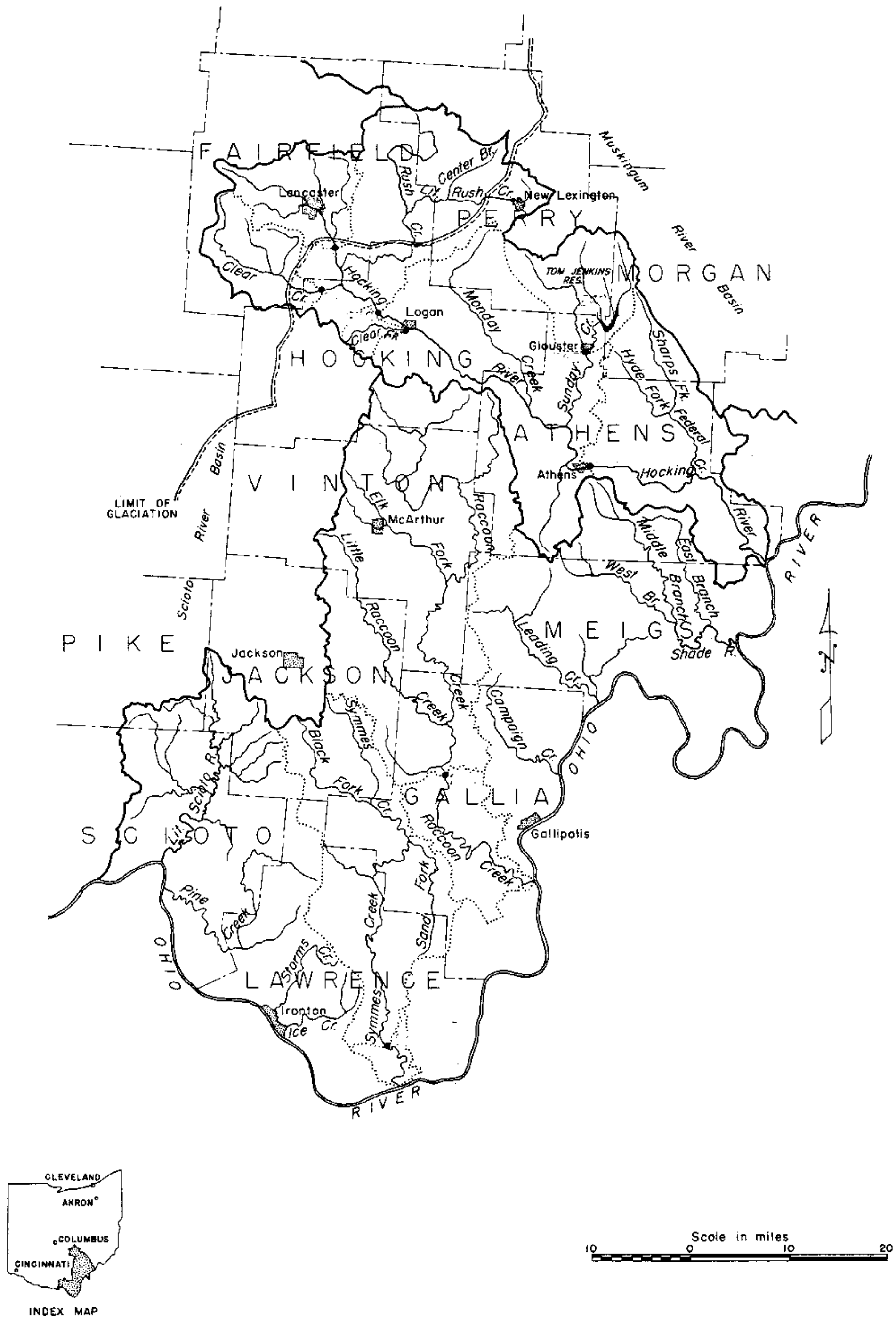


Figure 13. Map of Hocking River Basin and Ohio River Tributaries between Hocking River and Scioto River.

Water Development

Bur Oak Reservoir, completed in 1952 by the Corps of Engineers on Sunday Creek, provides flood protection to Glouster and other villages in the vicinity. Many smaller flood control structures constructed by the Natural Resources Conservation Service exist in the Hunters Run and Rush Creek watersheds.

Flow Characteristics

Recent estimates of flow characteristics are available for 17 stream gaging stations in the Hocking River Basin. Selected flow characteristics at these gaging sites are given in table 9.

The relatively high dry-weather flow in Clear Creek near Rockbridge and in the Upper Hocking River indicates the effects of glacial deposits. Both streams originate in the end moraine deposits of Wisconsin and Illinoian age in Fairfield County. Streamflow of the Hocking River at Enterprise, which lies beyond the glacial border, still reflects the influence of the sustained contribution from the headwater areas. Flow from Rush Creek, which enters the Hocking River at Sugar Grove, may add somewhat to the sustained flow of the Hocking River but not in the same proportion as the Hocking River above Sugar Grove. The record on Clear Fork near Logan is of short duration and offers little data for interpretation but it appears that the ground-water contribution to streamflow is relatively small. Clear Fork is in the unglaciated area and flows through rock valleys over a major portion of its course, but locally it traverses a buried valley containing outwash material.

The low-flow index for the Hocking River at Athens, which is a measure of average conditions in the Hocking Valley, is about the average for the state. The median-flow index is relatively high, and the 10-percent-of-time flow is about average. It is apparent that the sustained flows south of the line of glaciation are of about the same magnitude as for other areas in southeastern Ohio.

TABLE 9

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Hocking River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** 10%	50%	90%	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
				cfs (cfs/sq. mi.)				
Little Hocking R. near Little Hocking 03155800	47.9	-	-	-	-	0.2 (0.004)	0.1	-
Hocking River at Union St. at Lancaster 03155895	36.2	-	55.0	-	-	4.3 (0.119)	3.9	-
Hunters Run at Lancaster 03156000	10.0	10.5 (1.05) (14.3)	-	20 (2.00)	4.9 (0.49)	1.3 (0.130)	1.0 (0.095)	-
Hocking River At Lancaster 03156400	48.2	40.9 (0.85) (11.5)	-	83 (1.72)	21 (0.44)	6.2 (0.129)	5.1 (1.125)	-
Center Branch Rush Creek near Junction City 03156549	24.9	-	37.7	-	-	0.6 (0.024)	0.5	-
Rush Creek near Junction City 03156550	71.0	-	43.2	-	-	3.8 (0.054)	3.3	-
Rush Creek near Sugar Grove 03156700	229	-	-	-	-	13 (0.057)	12	-
Clear Creek at Clearport 03156900	47.3	-	55.0	-	-	5.5 (0.116)	4.5	-
Clear Creek near Rockbridge 03157000	89.0	90.5 (1.02) (13.8)	59.8	188 (2.11)	45 (0.51)	16 (0.180)	14 (0.155)	-
Hocking River at Enterprise 03157500	459	471 (1.03) (13.9)	53.5	1080 (2.35)	212 (0.46)	58 (0.126)	53 (0.113)	6920 (15.1)

TABLE 9

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Hocking River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Clear Fork at Logan 03158000	14.8	-	42.2	-	-	1.3 (0.088)	1.0	-
Hayden Run near Haydenville 03158100	1.04	-	-	-	-	-	-	86 (82.7)
Glen Run near Doanville 03158220	1.09	-	-	-	-	-	-	106 (97.2)
Sunday Creek at Glouster 03159000	104	112 (1.08) (14.6)	-	300 (2.88)	30 (0.29)	5.1 (0.049)	5.0 (0.048)	-
Mill Creek near Chauncy 03159450	1.48	-	-	-	-	-	-	123 (83.1)
Hocking River at Athens 03159500	943	1020 (1.08) (14.7)	-	2470 (2.62)	431 (0.46)	89 (0.094)	78 (0.083)	12400 (13.1)
Hocking River below Athens 03159510	957	1110 (1.16) (15.7)	-	2750 (2.87)	532 (0.56)	109 (0.114)	97 (0.101)	-

OHIO RIVER TRIBUTARIES BETWEEN HOCKING RIVER AND SCIOTO RIVER

This area includes 2,374 square miles, of which 684 square miles are drained by Raccoon Creek. With the exception of Raccoon Creek and Symmes Creek, relatively small streams with short steep courses drain the area. Raccoon Creek, which is about 50 miles long, has a relatively flat gradient despite the rough terrain. The map in figure 13 shows the outlines of the basins and flow paths of the main watercourses.

Physiography

The entire area is in the unglaciated Allegheny Plateau, and is characterized by rugged topography. The tops of hills are at about the same elevation, showing that the area was once a plain, but the ridges are narrow to sharp, and the slopes generally steep, with occasional cliffs. Tributary valleys are generally narrow, but a few of the principal streams flow through wide valleys of preglacial origin.

Geology

The rocks occurring at the surface are of Mississippian and Pennsylvanian age and are largely of sandstone and shale. In areas where shale is the dominant lithologic type, the valleys tend to be wide, particularly where large preglacial streams carved them. The rock strata are not important sources of water and have little influence on stream flow. The wide deep valleys are filled with glacial outwash and alluvium, but mostly with clays and other fine-grained materials. There are some light, well-drained valley soils, but the sustained dry-weather flows of streams are low.

Soils

The soils in this area are residual, having been derived largely from sandstone and shale. In scattered areas the soils are derived from mixed limestone, sandstone, and shale. Over large areas of the uplands the soils are classified as Gilpin, Shelocta, Latham, Steinsburg and associated series. Areas of reddish clay soils, classified with the Upshur and Vandalia soils series, and soils from mixed limestone, sandstone, and shale are found in the eastern part of the basin. Generally, soil development has been slowed because of erosion and steepness of slope. These soils are moderately to slowly permeable. Alluvial and terrace soils in the valleys range from coarse-textured and well drained, to fine-textures and poorly drained. Generally they are moderately to slowly permeable. Slopes in this area are generally too steep for cultivation except in bottomlands.

Water Development

There are several relatively large impoundments in this area that have localized effects on stream flows including Lake Hope, Lake Rupert, Jackson Lake, and Lake Vesuvius.

Flow Characteristics

Recent estimates of flow characteristics are available for 20 stream gaging stations in this area. Selected flow characteristics at these gaging sites are given in table 10.

The low indices of flow of streams in this area are typical of the Ohio River tributaries that do not extend into and drain the glaciated part of the state. The sustained flows are comparable to those of the Little Muskingum River and Captina Creek, although in other aspects of flow they vary considerably. Raccoon Creek, which has a low gradient, flows south from Ewington through a wide preglacial valley, which is swampy in places. These factors explain in part the large channel and overbank storage in the Raccoon Creek valley. The large amount of storage reduces flood peaks but prolongs inundation. Raccoon Creek has as much channel storage effect per square mile as any stream in the state.

Symmes Creek is situated in a geologic environment similar to that of Raccoon Creek. However, the channel of Symmes Creek is markedly less sinuous than that of Raccoon Creek, and the floodplains are narrower, especially in the upper reaches of the basin. These features tend to increase flood peaks and shorten the retention period.

The median-flow indices are relatively low for streams in the area, indicating relatively rapid runoff. The 10-percent duration flow indices are about average, and the duration curves are steep, with frequent floods.

TABLE 10

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Hocking River and Scioto River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
W. Branch Shade River near Burlington 03159534	22.2	-	50.4	-	-	-	-	-
W. Branch Shade River at Chester 03159536	71.1	-	41.3	-	-	1.8 (0.025)	1.1	-
Middle Branch Shade R. at Chester 03159538	57.5	-	40.7	-	-	1.3 (0.023)	0.7	-
Shade River near Chester 03159540	156	171 (1.10) (14.9)	36.8	400 (2.56)	61 (0.39)	4.3 (0.028)	2.5 (0.015)	3480 (22.3)
E. Branch Shade R. near Tupper Plains 03159555	37.5	-	50.9	-	-	0.5 (0.013)	0.2	-
Leading Creek near Middleport 03160050	117	-	-	-	-	1.9 (0.016)	1.0	-
Campaign Creek near Gallipolis 03160105	35.5	-	-	-	-	0.4 (0.011)	0.2	-
Starr Run near New Plymouth 03201550	0.30	-	-	-	-	-	-	50 (167)
Sandy Run above Big Four Hollow Cr. 03201600	0.98	1.11 (1.13) (15.4)	50.3	2.5 (2.55)	0.4 (0.41)	0.1 (0.102)	0	111 (113)
Big Four Hollow Creek near Lake Hope 03201700	1.01	1.17 (1.16) (15.7)	46.0	2.7 (2.67)	0.3 (0.30)	0	0	119 (118)
Sandy Run near Lake Hope 03201800	4.99	5.73 (1.15) (15.6)	-	14 (2.81)	1.4 (0.28)	0	0	-

TABLE 10

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Hocking River and Scioto River

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	50%	90% cfs (cfs/sq. mi.)	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Raccoon Creek near Prattsville 03201900	200	-	-	-	-	1.9 (0.010)	1.0	-
Strongs Run near Ewington 03201947	15.8	-	30.8	-	-	-	-	-
Little Raccoon Cr. near Vinton 03201990	154	-	-	-	-	7.7 (0.050)	5.4	-
Raccoon Creek at Adamsville 03202000	585	630 (1.08) (14.6)	-	1720 (2.94)	233 (0.40)	24 (0.041)	16 (0.025)	6070 (10.4)
Indian Guyan Cr. near Bradrick 03205210	67.5	-	-	-	-	1.4 (0.021)	0.9	-
Symmes Creek at Getaway 03205500	333	-	35.4	-	-	7.2 (0.022)	4.7	-
Sandusky Creek near Burlington 03205995	0.73	-	-	-	-	-	-	100 (137)
Ice Creek at Ironton 03216050	37.2	-	35.1	-	-	0.5 (0.013)	0.3	-
Pine Creek near Wheelersburg 03216640	152	-	-	-	-	3.8 (0.025)	2.6 (0.017)	-

SCIOTO RIVER BASIN

The Scioto River drains 6,510 square miles and has the third largest drainage basin in the state. It is about 240 miles in length. The topography of the basin is extremely varied, from flat swamplands near the source to the rugged terrain of the unglaciated plateau near the mouth. The map in figure 14 shows the outline of the basin and flow paths of the main watercourses.

Physiography

Three physiographic sections are represented in the basin. About 65 percent of the area is in the Till Plains Section of the Central Lowlands Province. This northern part of the basin varies from an almost level plain to gently rolling terrain with thick glacial drift mantling the bedrock and filling the preglacial valleys. The streams flow in wide valleys, and a part of the area is swampy. The eastern margin of the basin from Chillicothe north is in the Glaciated Allegheny Plateaus Section of the Appalachian Plateaus Province. Here the topography is more rolling, with rounded hills and with valleys filled with glacial deposits. The southern and southeastern quarter of the basin is in the unglaciated Allegheny Plateaus Section with steep slopes and rugged topography.

The profile of the river is peculiar because of glaciation. The upper reaches are swampy and flat. From Marion County to Columbus the gradient is steeper, averaging 4 feet fall per mile, and the river is confined in a narrow gorge. South of Columbus the river flows in a wide preglacial or interglacial valley, and the gradient averages 1.7 feet per mile. The valley width in this lower section is about 1.5 miles.

Geology

The rock strata underlying the Scioto Basin ranges in age from Silurian to Pennsylvanian. East of an approximate north-south line through Columbus, the bedrock is predominantly dense, impervious shale. West of this line the rocks are dolomite and limestone that contain relatively large quantities of ground water in solution channels and joint systems. South of the Pickaway-Ross county line the dominant rock types become interbedded Mississippian and Pennsylvanian shales, siltstones, and sandstones.

Despite the fact that the underlying rocks store appreciable quantities of ground water in most of the basin, the effect of the bedrock character on streamflow is relatively unimportant. The glacial drift, particularly the melt-water deposits such as outwash, valley train, kame, and esker sands and gravels, store huge quantities of water and markedly affect low-water streamflow. The greatest influences occur where a present day stream flows in a preglacial valley over deep sand and gravel. Some of the till plain drift is relatively impermeable, and in these areas there is little sustained flow in streams.

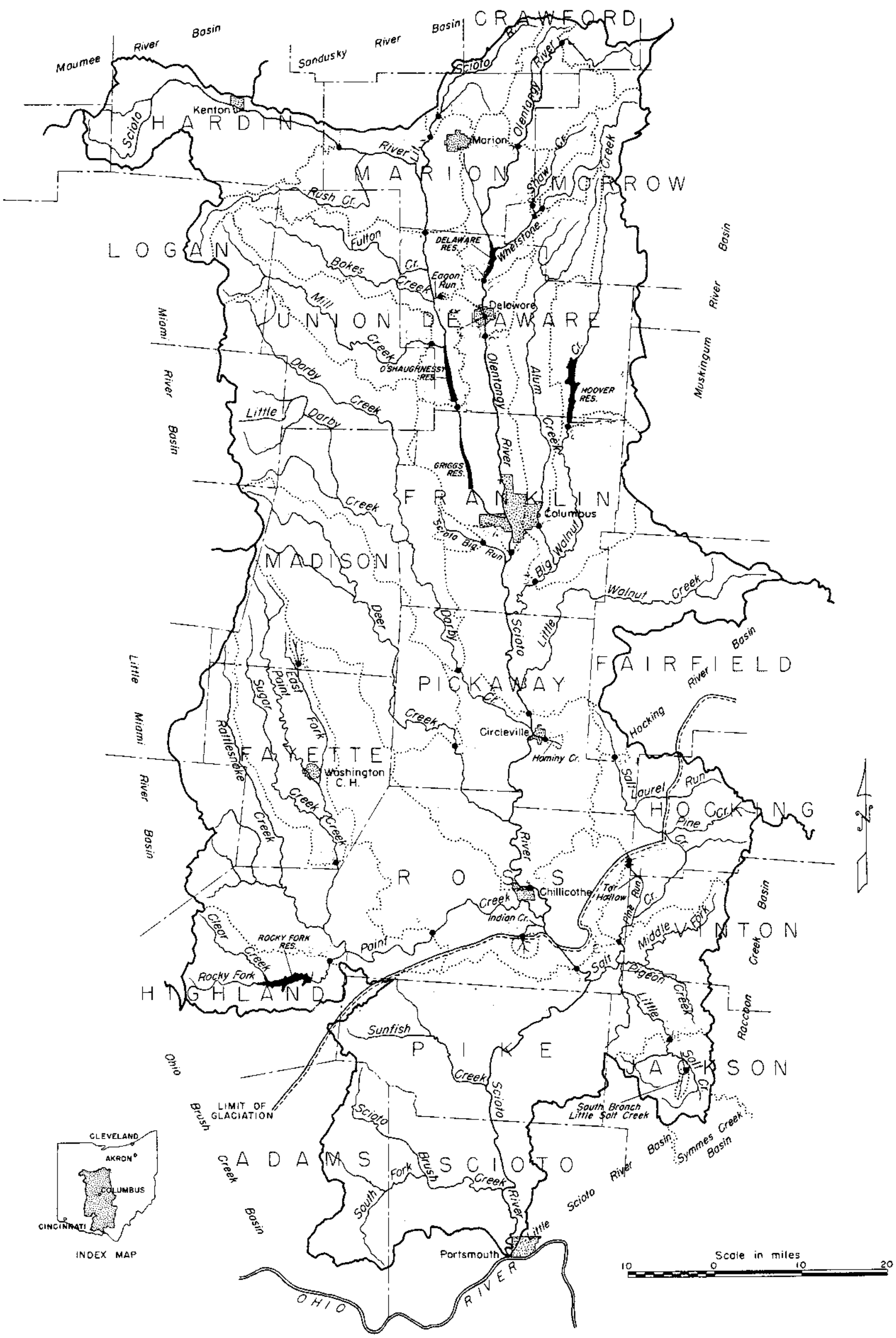


Figure 14. Map of Scioto River Basin.

Soils

Soils of glacial origin cover most of this area. The principal soils are those of the Miamian and Blount catenas in the glacial limestone area, and the Bennington catena of soils in the glacial sandstone and shale area. Generally, the till soils are moderately slow to slowly permeable; however, some moderately permeable soils occur. Terrace and alluvial soils are generally more permeable. The predominant soils are the Eldean and Genesee. There are some muck soils in the basin. South of the glacial boundary the soils are residual. The dominant soils include the Shelocta, Brownsville, and Latham soil series. Alluvial and terrace soils in this area include some well-drained permeable soils, but generally, permeability of the soils in the basin is moderate to slow.

Water Development

The City of Columbus has two water supply reservoirs on the Scioto River, Griggs Reservoir built in 1905 and O'Shaughnesy Reservoir built in 1925. Hoover Reservoir on Big Walnut Creek was added to the municipal supply system in 1954.

The Corps of Engineers completed construction of Delaware Reservoir on the Olentangy River near Delaware in 1951, Deer Creek Reservoir on Deer Creek in 1968, Paint Creek Reservoir on Paint Creek in 1971, and Alum Creek Reservoir on Alum Creek in 1973.

Flow Characteristics

Recent estimates of flow characteristics are available for 84 stream gaging stations in the Scioto River Basin. Selected flow characteristics at these gaging sites are given in table 11.

There are wide differences in streamflow characteristics in adjacent areas, or even within the same subbasin. For example, Big Walnut Creek has about four times the sustained flow, in cubic feet per second per square mile, at the downstream station as compared with the upstream station. This is caused apparently by the presence of thick and permeable glacial deposits in the lower reach of the stream, the upper station being in an area of predominantly shallow till overlying dense shale. Alum Creek at Columbus is similarly affected by the heavy overburden of glacial drift east and northeast of Columbus. Another anomaly is the sustained flow of Rocky Fork, that is much greater that of adjacent areas of equal size. A major portion of this flow is derived from its tributary, Clear Creek, which has its headwater in the Cuba Moraine, and flows on glacial outwash material throughout most of its course.

Generally, the streams in the northern part of the Scioto River Basin above Columbus have lower sustained flows than those in the southern part. There is a remarkable consistency in the sustained flows at stations in the upper half of the basin. The bedrock in the above areas contributes a negligible amount of ground water to streamflow, and the overburden of glacial drift consists mainly of impervious till.

The Scioto River above Prospect is an ice-front stream in origin and derives its low flow from morainal masses both to the north and south. Rock exposures are few in this area. The channel is in glacial drift throughout practically its entire course and the morainal hills rise from 50 to 100 feet above the valley floor. Although the sustained flow above Prospect is not great, it clearly shows the effect of the relatively permeable morainal hills in contrast with flow of streams in strictly till areas.

Darby Creek and Deer Creek drain areas that have very similar surface features. Both streams flow through areas in which the glacial drift is relatively thick but variable in its physical characteristics. Deer Creek is influenced somewhat by the moraine south and west of Marysville.

The dry-weather flow index of Paint Creek at Bourneville prior to completion of Paint Creek Reservoir was three times that at Greenfield and remains about the same. Above Greenfield the stream drains an area of thin till that yields little ground water to sustain streamflow. Ground-water discharge from the buried valley deposits that underlie the floodplain of Paint Creek in the area between Bainbridge and Bourneville and contributions made by Rocky Fork apparently account for the higher dry-weather flow at Bourneville.

At first glance, the low-flow index for Rocky Fork at Barretts Mills appears abnormally high. As mentioned above, the high sustained flow is attributable to storage in the glacial deposits, particularly on Clear Creek, but it appears probable that storage in the cavernous limestone and dolomite may be a contributing factor. Also, the average annual precipitation in Highland and Clinton counties is greater than any other place in the state.

The low-flow index of Salt Creek at Londonderry is slightly greater than that of Little Salt Creek at Richmond. A considerable volume of permeable outwash material may be present along Salt Creek in the vicinity of Laurelville and south of the Pine Cottage col where a drainage reversal occurred during glacial times. Little Salt Creek drains an area underlain by lower Pennsylvanian strata that as a whole are quite impermeable. Mine drainage may contribute somewhat to the flow.

In the Scioto River Basin there are areas of both relatively high and relatively low dry-weather flow indices. On the average, the indices are lower than those of other large tributaries to the Ohio River, but higher than those of most Lake Erie tributaries. The median-flow indices and the high-flow indices are below the average for the state. The Scioto River is not as much of a flood-producing stream as some others, although large floods have occurred at intervals.

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	 **50%** cfs (cfs/sq. mi.)	 **90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Scioto River near Kenton 03217400	130	-	-	-	-	4.1 (0.032)	3.3	-
Scioto River at La Rue 03217500	257 (0.83) (11.3)	214	33.3	530 (2.06)	48 (0.19)	6.9 (0.027)	5.3 (0.025)	5300 (20.6)
Little Scioto R. above Marion 03218000	72.4	50.2 (0.69) (9.4)	43.3	130 (1.80)	11 (0.15)	0.2 (0.003)	0.1 (0.002)	1110 (15.3)
Little Scioto R. at Sewage Plant 03218500	85.8	73.0 (0.85) (11.5)	-	189 (2.20)	16 (0.19)	1.2 (0.014)	1.2 (0.016)	-
Scioto River near Prospect 03219500	567	469 (0.83) (11.2)	38.2	1330 (2.35)	131 (0.23)	20 (0.035)	15 (0.032)	6100 (10.8)
Fulton Creek near Radnor 03219520	46.9	-	33.2	-	-	0.3 (0.006)	0.2	-
Bokes Creek Near Warrensburg 03219590	83.2	71.6 (0.86) (11.7)	31.8	179 (2.15)	19 (0.23)	0	0	-
Eagon Run near Warrensburg 03219600	0.123	0.09 (0.73) (9.9)	-	0.2 (1.63)	0	0	0	-
Mill Creek near Broadway 03219770	66.1	-	35.9	-	-	1.4 (0.021)	0.9	-
Mill Creek near Bellpoint 03220000	178	161 (0.90) (12.3)	25.4	372 (2.09)	29 (0.16)	4.1 (0.023)	2.7 (0.017)	4480 (25.2)
Scioto River below O'Shaughnessy Dam 03221000	980	820 (0.84) (11.4)	-	2320 (2.37)	206 (0.21)	43 (0.044)	22 (0.027)	12700 (13.0)

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Olentangy River near New Winchester 03222500	49.7	-	29.1	-	-	0.5 (0.010)	0.4	-
Mud Run near Caledonia 03222700	16.1	-	37.9	-	-	0.5 (0.031)	0.4	-
Flat Run near Caledonia 03222800	29.9	-	36.7	-	-	0.7 (0.023)	0.4	-
Olentangy River at Claridon 03223000	157	158 (1.01) (13.7)	35.8	412 (2.62)	44 (0.28)	4.5 (0.029)	2.8 (0.018)	3200 (20.4)
Whetstone Creek near Shawtown 03223500	61.7	-	-	-	-	2.8 (0.045)	1.9	-
Shaw Creek at Shawtown 03224000	25.2	-	35.4	-	-	1.0 (0.040)	0.6	822 (32.6)
Whetstone Creek near Ashley 03224500	98.7	97.9 (0.99) (13.5)	36.8	221 (2.24)	29 (0.29)	3.7 (0.037)	2.5 (0.026)	2820 (28.6)
Olentangy River near Delaware 03225500	393	367 (0.93) (12.7)	31.9	1040 (2.65)	94 (0.24)	19 (0.048)	13 (0.035)	7360 (18.7)
Delaware Run near Delaware 03226200	5.84	-	-	-	-	-	-	338 (57.9)
Olentangy River at Stratford 03226500	445	-	31.3	-	-	-	-	-
Olentangy River near Worthington 03226800	497	459 (0.92) (12.5)	-	1310 (2.64)	144 (0.29)	26 (0.052)	18 (0.039)	-

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Linworth Run near Linworth 03226850	0.474	-	-	-	-	-	-	75 (158)
Linworth Road Creek at Columbus 03226870	2.0	-	43.8	-	-	-	-	-
Scioto River at Columbus 03227500	1629	1490 (0.91) (12.4)	-	4240 (2.60)	525 (0.32)	149 (0.091)	142 (0.095)	-
Scioto Big Run at Briggsdale 03228000	11.0	10.7 (0.97) (13.2)	31.7	24 (2.18)	1.2 (0.11)	0	0	1160 (105)
Big Walnut Creek above Sunbury 03228200	77.8	-	-	-	-	0.2 (0.003)	0.1	-
Big Walnut Creek at Central College 03228500	190	202 (1.06) (14.4)	26.0	314 (1.65)	120 (0.63)	68 (0.358)	83	6900 (36.3)
Blacklick Creek near Brice 03228690	51.6	-	54.1	-	-	5.7 (0.097)	5.3	-
Blacklick Creek near Groveport 03228700	57.4	-	-	-	-	3.2 (0.056)	2.6	-
Alum Creek at Kilbourne 03228750	64.9	-	36.5	-	-	-	-	-
Alum Creek at Africa 03228805	122	111 (0.91) (12.4)	31.0	326 (2.67)	18 (0.15)	5.5 (0.045)	4.9 (0.044)	4260 (34.9)
Alum Creek at Columbus 03229000	189	198 (1.05) (14.2)	31.8	560 (2.96)	66 (0.35)	16 (0.085)	11 (0.056)	4560 (24.1)

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10%	 50% cfs (cfs/sq. mi.)	 90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Big Walnut Creek at Reese 03229500	544	492 (0.90) (12.3)	30.6	1280 (2.35)	195 (0.36)	58 (0.107)	43 (0.087)	11900
Walnut Creek near Carrol 03229750	69.2	-	40.6	-	-	3.6 (0.052)	3.3	-
Walnut Creek near Groveport 03229770	198	-	52.1	-	-	20 (0.101)	18	-
Walnut Creek near Ashville 03229800	285	-	-	-	-	29 (0.102)	25	-
Big Darby Creek at Plain City 03230200	151	-	-	-	-	3.9 (0.026)	3.0	-
Big Darby Creek near West Jefferson 03230230	239	-	39.4	-	-	8.5 (0.036)	6.6	-
Little Darby Creek near Irwin 03230250	29.4	-	58.9	-	-	4.4 (0.150)	3.7	-
Little Darby Creek at Chuckery 03230300	71.4	-	-	-	-	4.9 (0.069)	3.8	-
Little Darby Creek at West Jefferson 03230310	162	-	39.5	-	-	6.0 (0.037)	4.5	-
Big Darby Creek at Darbydale 03230400	449	-	-	-	-	18 (0.040)	14	-
Hellbranch Run near Harrisburg 03230450	37.0	-	41.2	-	-	-	-	-

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Big Darby Creek at Darbyville 03230500	534	465 (0.87) (11.8)	46.2	1150 (2.15)	157 (0.29)	25 (0.047)	20 (0.043)	8260 (15.5)
Hominy Creek at Circleville 03230600	5.66	-	-	-	-	0.3 (0.053)	0.3	596
Deer Creek at US 142 near London 03230745	50.7	-	-	-	-	2.8 (0.055)	1.8	-
Deer Creek at Mount Sterling 03230800	228	250 (1.10) (14.9)	52.2	564 (2.47)	100 (0.44)	20 (0.088)	14 (0.056)	5460 (23.9)
Deer Creek near Pancoastburg 03230900	277	273 (0.99) (13.4)	-	740 (2.67)	123 (0.44)	14 (0.050)	11 (0.040)	-
Deer Creek at Williamsport 03231000	333	348 (1.05) (14.2)	44.6	990 (2.97)	158 (0.47)	20 (0.060)	14 (0.040)	8430 (25.3)
Kinnikinnick Cr. near Kinnikinnick 03231300	36.2	-	-	-	-	9.2 (0.254)	8.2	-
Scioto River at Chillicothe 03231500	3849	3570 (0.93) (12.6)	-	9280 (2.41)	1490 (0.39)	368 (0.100)	356 (0.100)	41500 (10.8)
Paint Creek at Washington C. H. 03231550	62.3	-	-	-	-	0.5 (0.008)	0.2	-
E. Fork Paint Cr. near Sedalia 03231600	3.82	-	-	-	-	-	-	214 (56.0)
E. Fork Paint Cr. near Bloomingburg 03231620	36.8	-	-	-	-	0.8 (0.022)	0.5	-

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Sugar Creek near Rock Mills 03231800	78.3	-	33.2	-	-	0.4 (0.005)	0.2	-
Paint Creek near Greenfield 03232000	249	242 (0.97) (13.2)	48.5	606 (2.43)	77 (0.31)	4.4 (0.012)	2.6 (0.011)	5190 (20.8)
Rattlesnake Creek at Centerfield 03232300	209	-	46.4	-	-	-	-	5110 (24.4)
Paint Creek below Paint Creek Dam 03232470	570	591 (1.04) (14.1)	-	1580 (2.77)	246 (0.43)	27 (0.047)	16 (0.027)	-
Clear Creek near Hillsboro 03232480	35.4	-	49.6	-	-	2.9 (0.082)	2.2	-
Rocky Fork near Barretts Mills 03232500	140	151 (1.08) (14.6)	-	352 (2.51)	62 (0.44)	8.7 (0.062)	7.5 (0.050)	6140 (43.9)
Paint Creek near Bourneville 03234000	807	927 (1.15) (15.6)	-	2650 (3.28)	394 (0.49)	59 (0.073)	46 (0.050)	19800 (24.5)
Paint Creek at Chillicothe 03234300	1136	1320 (1.16) (15.8)	-	3720 (3.27)	529 (0.47)	74 (0.065)	60 (0.045)	-
Indian Creek at Massieville 03234100	9.6	-	-	-	-	-	-	1290 (134)
Scioto River at Higby 03234500	5131	4740 (0.92) (12.5)	-	12400 (2.42)	2110 (0.41)	539 (0.105)	508 (0.107)	47900 (9.3)
Salt Creek At Tarlton 03235000	11.5	10.4 (0.90) (12.3)	35.1	22 (1.91)	2.2 (0.19)	0.1 (0.001)	0	977 (85.0)

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	50%	90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Bull Creek near Adelphi 03235080	3.13	-	-	-	-	-	-	334 (107)
Salt Creek at Adelphi 03235090	47.8	-	38.0	-	-	1.4 (0.029)	1.2	-
Little Blackjack Branch 03235200	0.89	-	-	-	-	-	-	163 (183)
W. Branch Tar Hollow Creek 03235400	0.30	-	-	-	-	-	-	21 (70.0)
Tar Hollow Cr. at Tar Hollow S. P. 03235500	1.35	1.24 (0.92) (12.5)	46.4	3.1 (2.30)	0.2 (0.15)	0	0	113 (83.7)
Salt Creek near Londonderry 03235995	268	-	-	-	-	-	-	10600 (39.6)
Salt Creek near Londonderry 03236000	286	299 (1.05) (14.2)	44.4	715 (2.50)	85 (0.30)	14 (0.049)	8.7 (0.029)	-
Middle Fork Salt Cr. near Richmond Dale 03236055	109	-	-	-	-	2.6 (0.024)	2.2	-
S. Branch Little Salt Creek near Jackson 03236090	1.98	-	-	-	-	-	-	171 (86.4)
S. Branch Little Salt Creek at Jackson 03236100	3.76	-	-	-	-	-	-	624 (166)

TABLE 11

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Scioto River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	 **50%** cfs (cfs/sq. mi.)	 **90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Little Salt Creek at Jackson 03236200	33.6	-	-	-	-	0.5 (0.015)	0.4	-
Little Salt Creek near Jackson 03236500	76.1	-	37.7	-	-	-	-	-
Little Salt Creek near Richmond Dale 03236600	133	-	-	-	-	5.0 (0.038)	4.2	-
Salt Creek at Richmond Dale 03236800	552	-	-	-	-	15 (0.027)	13	-
Big Beaver Creek near Piketon 03237040	62.0	-	-	-	-	0.4 (0.006)	0.2	-
Devers Run at Lucasville 03237095	1.22	-	-	-	-	-	-	176 (144)
Scioto Brush Cr. at Otway 03237130	94.4	-	-	-	-	1.3 (0.014)	0.7	-
Rose Run near Portsmouth 03237210	1.04	-	-	-	-	-	-	102 (98.1)

OHIO RIVER TRIBUTARIES BETWEEN SCIOTO RIVER AND LITTLE MIAMI RIVER

There are 1,336 square miles contributing to the Ohio River drainage between the Scioto and Little Miami rivers. Of this area, Ohio Brush Creek drains 435 square miles and Whiteoak Creek drains 234 square miles. The map in figure 15 shows the outlines of the basins and flow paths of the main watercourses.

Physiography

Most of Adams County is an unglaciated limestone area, considered physiographically to be part of the Bluegrass Section of the Interior Low Plateau Province, but the soils are thin, the topography rough, and there is little resemblance to the fertile Kentucky Bluegrass region. North and west of Adams County the area is in the Till Plains, but the terrain is rugged and the drift relatively thin.

Geology

The surface rocks are extremely variable, ranging from sandstone and shale in the eastern part to dolomite and limestone in the central part and to calcareous shale in the western sector. The western part of the area is covered with Illinoian drift, generally thin, but with some local areas of thick and relatively impermeable deposits. The glaciated area has lower dry-weather streamflow than the unglaciated, but not as low as in the Little Miami River Basin.

Soils

The soils of this area may be placed in three groups according to their parent materials and physiographic relationship: (1) those derived from limestone and shale that are generally shallow and occur on steep, hilly topography; (2) those derived from relatively shallow Illinoian glacial till on undulating to gently rolling relief; and (3) soils derived from sandstone and shale on steep, hilly topography. Principal soils in the first group are the Eden, Bratton, Brushcreek, and Cedarville. The permeability of these soils is generally moderate to slow. Soils of the second group include the moderately slow to slowly permeable Jessup, Bonnell, and Rossmoyne soils series. In the third group, the principal soils are the steep phases of Shelocta, Latham, and Rarden.

There are some alluvial soils, but the valleys are narrow and of limited extent, except along the Ohio River where there are areas of moderately permeable soils.

Water Development

There are no large inland water developments in the area.

Flow Characteristics

Recent estimates of flow characteristics are available for 11 stream gaging stations in the area. Selected flow characteristics at these gaging sites are given in table 12.

Ohio Brush Creek and Whiteoak Creek have relatively low sustained flow. With the exception of a small area in the headwaters, Ohio Brush Creek drains an unglaciated area. Some alluvium and glacial outwash is present under the valley floor. The Brassfield limestone of Silurian age, which is a notable spring horizon, is exposed along the valley of Ohio Brush Creek throughout a large portion of its course. The spring water and possibly some discharge from the alluvium support the rather low dry-weather flow.

Whiteoak Creek drains an area in which the surface material is dense glacial till of Illinoian age. The underlying bedrock, which is exposed at many places in the valley, is the impervious shale and limestone of Ordovician age. With such a geologic environment, it is reasonable to expect extremely low dry-weather flows in the streams.

The median-flow indices are below the average for the state, indicating limited storage at all stages. The high-flow indices are slightly above average, because high flows are relatively frequent.

TABLE 12

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Ohio River Tributaries between Scioto River and Little Miami River

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Upper Twin Cr. at McGaw 03237280	12.2	13.8 (1.13) (15.4)	44.6	33 (2.70)	3.4 (0.28)	0.1 (0.008)	0	1120 (91.8)
W. Branch Turkey Run near Winchester 03237300	0.89	-	-	-	-	-	-	195 (219)
Ohio Brush Creek near West Union 03237500	387	458 (1.18) (16.1)	26.0	1030 (2.66)	108 (0.28)	5.3 (0.014)	2.6 (0.006)	20600 (53.2)
Big Threemile Cr. near Aberdeen 03238020	19.7	-	-	-	-	0	0	-
Eagle Creek near Ripley 03238200	137	-	-	-	-	0.6 (0.004)	0.3	-
Straight Creek near Higginsport 03238250	57.3	-	-	-	-	0.1 (0.002)	0	-
E. Fork White Oak Creek near Sardinia 03238370	60.1	-	-	-	-	1.7 (0.028)	1.1	-
Harwood Creek near Fayetteville 03238400	0.88	-	-	-	-	-	-	135 (153)
White Oak Creek near Georgetown 03238500	218	263 (1.21) (16.4)	17.7	554 (2.54)	45 (0.21)	2.6 (0.012)	0.8 (0.003)	10000 (45.9)
Bullskin Creek near Felicity 03238650	47.7	-	-	-	-	0.1 (0.002)	0	-
Big Indian Cr. at Point Pleasant 03238730	38.7	-	-	-	-	0.2 (0.005)	0.1	-

LITTLE MIAMI RIVER BASIN

The Little Miami River Basin drains an area of 1,755 square miles. The source of the main stream is a few miles southeast of Springfield, and the mouth is just east of Cincinnati. The length of the stream is slightly less than 100 miles. East Fork, its principal tributary, originates near Hillsboro and joins the main stream about 12 miles above the mouth. East Fork drains 501 square miles of the total area comprising the Little Miami Basin. The map in figure 15 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The entire basin lies within the Till Plains. The northern part of the area is flat to gently rolling but with occasional deep gorges, such as Clifton Gorge near Yellow Springs. Generally to the south the relief is greater, although a large area in the East Fork drainage is flat swampland. The valleys are generally relatively narrow and bordered by rock buffs. At places where the streams traverse preglacial drainage lines, the valleys are broad and flat-bottomed.

Geology

Dense calcareous shale, dolomite, and limestones of Ordovician and Silurian age underlie the basin. There is minor karst sinkhole terrain in the Silurian limestone, but it is poorly developed. Although there are springs and spring lines where a relatively permeable limestone outcrops over an impermeable shale, their effect on streamflow is negligible. Glacial deposits of two ice advances occupy the area of the Little Miami Basin. Approximately the upper half of the basin is covered by drift of Wisconsinan age and the lower half by Illinoian deposits.

Soils

The soils in this basin vary widely. In areas of late Wisconsin drift are Miamian, Celina, Crosby, Kokomo, Birkbeck, Reesville, and Ragsdale soils. They range from very poorly drained to well drained and are for the most part slowly permeable. The moderately to slowly permeable Russell, Xenia, and Fincastle are the important soils series in areas of early Wisconsin drift. Rossmoyne, Clermont, and Avonburg are the dominant soils in the Illinoian drift area. The well-drained Bonnell and Jessup soils are common in areas in the southern part of the basin where the Illinoian till deposits are thin. These soils are slowly permeable. There are also terrace and alluvial soils with good drainage but these are rather limited in extent.

Water Development

The Corps of Engineers completed Caesar Creek Reservoir on Caesar Creek in 1973 and East Fork Reservoir on East Fork Little Miami River in 1977.

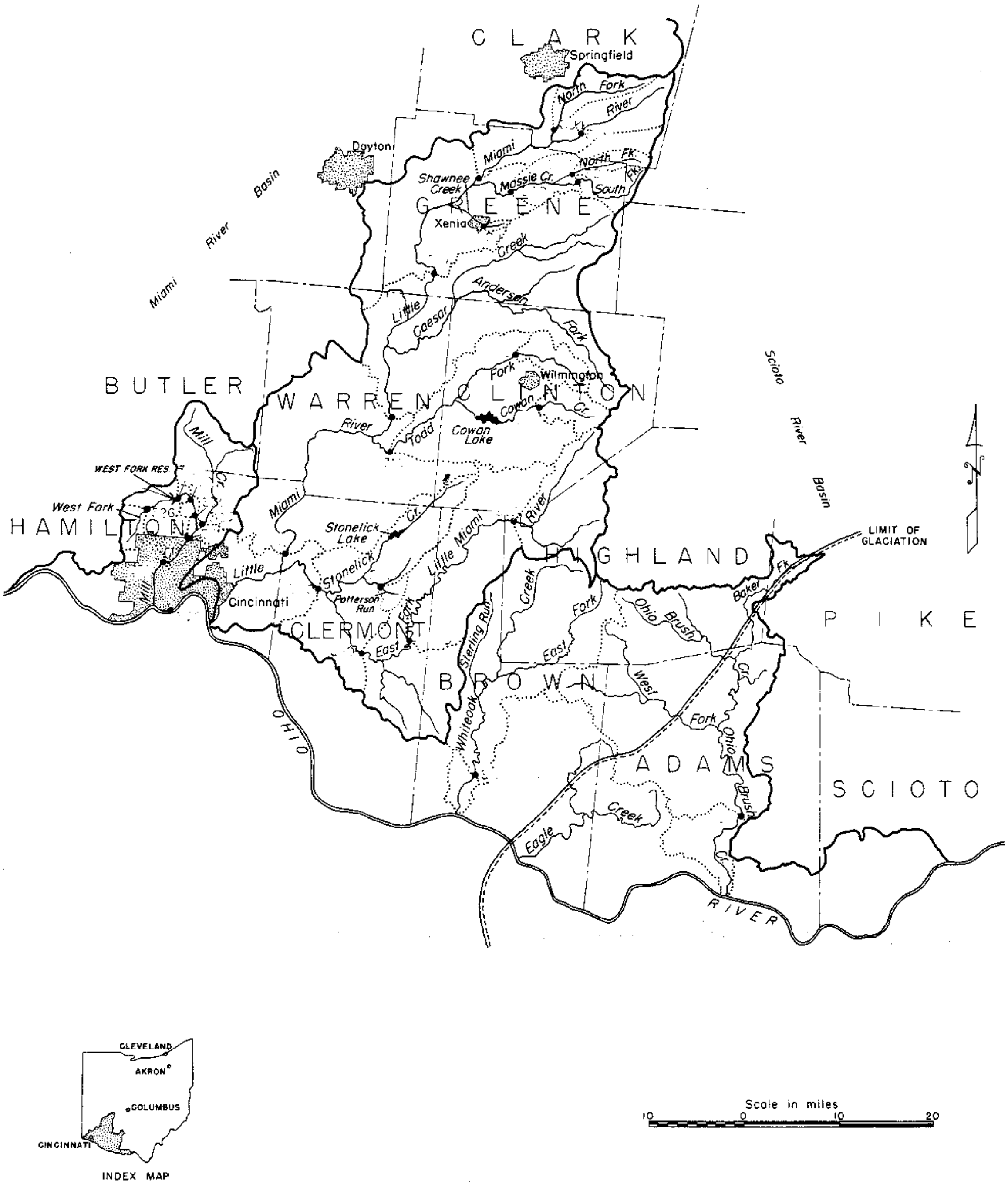


Figure 15. Map of Little Miami River and Ohio River Tributaries between Scioto River and Miami River.

Flow Characteristics

Recent estimates of flow characteristics are available for 22 stream gaging stations in the Little Miami River Basin. Selected flow characteristics at these gaging sites are given in table 13.

There is a wide range of difference in the flow characteristics of the streams in this basin. The effects of glacial material on flow characteristics are manifest in this area. As the drift thins toward the south and changes from dominantly gravel terrain to till cover, the dry-weather flow decreases in relative magnitude from the source to the mouth.

The gaging station on the Little Miami at Spring Valley shows an exceptionally high sustained flow as a result of the widespread gravel deposits that lie above drainage in the headwater area of the basin. High-level outwash materials in the form of valley fill, terraces, and kame terraces are present in northern Greene county and southern Clark County. These materials, which are highly permeable, absorb large quantities of rainfall and release it rather uniformly throughout the year. In addition to the ground water contribution from the glacial deposits, a minor amount is contributed by the limestone and dolomite formations.

The record of flow at the Oldtown gage on the Little Miami River indicates a relatively high index of median flow in the upper part of the Little Miami valley. Fifty percent of the time the flow exceeded about 0.5 cubic feet per second per square mile which is above average for an uncontrolled stream. The record at the Spring Valley station has an even higher median-flow index although augmented by wastewater discharges. Between Spring Valley and Fort Ancient, the Little Miami follows the course of a preglacial valley in which more than 100 feet of unconsolidated valley fill is present. However, there are no high-level glaciofluvial deposits that greatly affect streamflow. The relatively high base-flow index at the Fort Ancient is a reflection of the influence of ground-water discharge in the headwater area above Spring Valley and flow augmentation from wastewater discharges. Caesar Creek that is the principal tributary above Fort Ancient is cut into the shale bedrock throughout much of its course and the unregulated flow relatively low during dry periods.

The record of flow at the Milford gaging station shows a high dry-weather flow index. This is still a reflection of the influence of conditions in the headwater area, although some additional flow is contributed by terrace deposits in the valley north of Milford and releases from Caesar Creek Reservoir.

Cowan Creek drains an area in which impervious shale and dense till predominate. This accounts for the very low indices of flow indicated by the records near Wilmington and at Clinton County Air Force Base.

The index of flow of East Fork of Little Miami River should be similar to that of Whiteoak Creek because of the similarity of geologic conditions in the two basins. East Fork drains an area in which the surface material is almost entirely glacial till of Illinoian age. This material as a whole is very dense and impermeable with only local, rather restricted, bodies of sand and gravel. The bedrock in this basin, which occurs at the surface in many ravines, is shale of Ordovician age and is too dense to allow for significant ground-water storage. Only a very small percentage of the rainfall finds its way into the ground, most of it becomes direct runoff or is lost to evapotranspiration.

Within the Little Miami River Basin are areas with the lowest dry-weather flow indices in the state, and areas with indices approaching the highest in the state. Median-flow indices are relatively low, and south of Spring Valley produces frequent floods, particularly on the East Fork.

TABLE 13

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Little Miami River Basin

Stream Name and Location sta. no.	drainage area sq. mi.	mean annual runoff cfs (cfs/sq. mi.) (inches)	mean base-flow index percent	discharge equaled or exceeded percent of time 10% cfs (cfs/sq. mi.)	 50%	 90%	7-day, 2-yr low flow cfs (ratio to mean annual flow)	2-yr. R.I. flood-peak discharge cfs (cfs/sq.mi.)
Little Miami R. near S. Charleston 03238950	9.76	-	-	-	-	0.2 (0.020)	0.2	-
Little Miami R. near Selma 03239000	48.9	-	61.3	-	-	-	-	1410 (28.8)
N. F. Little Miami River near Pitchin 03239500	28.9	-	72.1	-	-	-	-	405 (140)
Little Miami R. near Oldtown 03240000	129	121 (0.93) (12.7)	65.1	262 (2.03)	63 (0.49)	18 (0.140)	16 (0.132)	2770 (21.5)
N. Fork Massies Creek at Cedarville 03240500	28.9	25.7 (0.89) (12.1)	61.9	65 (2.25)	9.9 (0.34)	1.4 (0.048)	0.9 (0.035)	733 (25.4)
S. Fork Massies Creek near Cedarville 03241000	17.1	17.7 (1.04) (14.0)	52.1	44 (2.57)	5.3 (0.31)	0.3 (0.018)	0.2 (0.011)	718 (42.0)
Massies Creek at Wilberforce 03241500	63.2	64.3 (1.02) (13.8)	59.6	150 (2.37)	29 (0.46)	4.8 (0.076)	4.2 (0.065)	1570 (24.8)
Shawnee Creek at Xenia 03241600	4.21	-	-	-	-	-	-	378 (89.8)
Little Miami R. near Spring Valley 03242050	366	390 (1.07) (14.5)	65.9	849 (2.32)	266 (0.73)	102 (0.279)	69 (0.177)	7360 (20.1)
Caesar Creek near Xenia 03242150	71.4	79.3 (1.11) (15.1)	-	180 (2.52)	32 (1.45)	2.8 (0.039)	1.8 (0.023)	2990 (41.9)
Anderson Fork near New Burlington 03242200	77.8	83.0 (1.07) (14.5)	45.9	196 (2.52)	31 (0.40)	2.1 (0.027)	1.5 (0.018)	2500 (32.1)

TABLE 13

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Little Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Little Miami R. near Fort Ancient 03242500	680	-	47.6	-	-	-	-	19400 (28.5)
Todd Fork near Wilmington 03243000	22.2	-	46.5	-	-	-	-	-
Cowan Creek at Clinton Co. A. F. B. 03243400	29.7	-	-	-	-	0.1 (0.003)	0.1	-
Todd Fork near Roachester 03244000	219	-	-	-	-	-	-	10300 (47.0)
Turtle Creek at South Lebanon 03244570	58.2	-	-	-	-	1.6 (0.027)	0.7	-
Little Miami R. at Milford 03245500	1203	1370 (1.14) (15.5)	-	3450 (2.87)	609 (0.51)	178 (0.148)	141 (0.103)	30200 (25.1)
E. F. Little Miami River near Marathon 03246200	195	241 (1.24) (16.8)	24.4	578 (2.96)	61 (0.31)	5.9 (0.030)	3.0 (0.012)	-
E. F. Little Miami River at Williamsburg 03246500	237	273 (1.15) (15.6)	18.7	608 (2.57)	47 (0.20)	1.7 (0.007)	0.8 (0.003)	10400 (43.9)
E. F. Little Miami River near Batavia 03247050	352	427 (1.21) (16.5)	22.8	1360 (3.86)	111 (0.32)	31 (0.088)	22 (0.052)	-
Patterson Run near Owensville 03247100	3.34	-	-	-	-	-	-	571 (171)
E. F. Little Miami River at Perintown 03247500	476	629 (1.32)	17.0	2090 (4.39)	166 (0.35)	39 (0.082)	32 (0.051)	19600 (41.2)

MILL CREEK BASIN

Mill Creek drains 164 square miles to the Ohio River in the vicinity of Cincinnati. West Fork of Mill Creek with 36.4 square miles of drainage area is the largest subbasin. The map in figure 15 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The Mill Creek Basin is in the Till Plains, but has relatively rough topography, except for the broad flat-bottomed preglacial valley through which Mill Creek flows. Outside the valley the slopes are steep, and tributaries have cut deep ravines.

Geology

The exposed rocks are shales and limestones of Upper Ordovician age, so dense that they contain little water. The Illinoian glacier covered the entire area but only Butler County was reached by the Wisconsin glaciation. The till is relatively thin on the uplands and is to compact to absorb much water. The main stem of Mill Creek is underlain by 150 to 200 feet of buried valley deposits consisting of sand and gravel interbedded with till and clay. The sand and gravel deposits furnish large quantities of ground water for industrial and municipal use in the valley. The dry-weather flows of Mill Creek are low, but it seems probable that this is partly caused by the large amount of pumpage of ground water.

Soils

Soils in the Mill Creek Basin developed generally from thin Illinoian glacial till. The principal soils are the moderately deep Eden and the deep Pate, Switzerland, and Rossmoyne. These soils all have relatively low permeability. The soils of the valley are classified as Martinsville, Fox, and Genesee. They have good drainage and relatively high permeability, thus permitting recharge to ground water bodies.

Water Development

The major water developments in this area are the ground-water well fields, the diversion by pipeline from wells near the Miami River, and the construction of West Fork Mill Creek Reservoir in 1953 by the Corps of Engineers for flood control purposes.

Flow Characteristics

Recent estimates of flow characteristics are available for 5 stream gaging stations in the Mill Creek Basin. Selected flow characteristics at these gaging sites are given in table 14.

Only one record for the basin, a short one for West Fork Mill Creek at Mount Healthy, gives a measure of natural runoff. All other records are affected by ground-water pumpage, by diversion, or by regulation.

Sustained flow in Mill Creek is low because of the absence of extensive permeable surface material and because of the extremely low ground-water levels in the valley. This valley is underlain by 150 to 200 feet of outwash material, but below the Lockland-Reading area, a considerable thickness of clay and till lies at the surface. Above Lockland the surface materials tend to be more open and permeable. Studies of Mill Creek valley show that the principal recharge to the deeper gravel aquifer occurs above Lockland. The intense ground-water pumpage and the resultant lowering of the water table eliminate ground-water discharge to the stream. The low-flow index is also vitiated by diversion into the basin. The median- and high-flow indices are quite low.

TABLE 14

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Mill Creek Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Mill Creek at Reading 03255500	73.0	75.4 (1.03) (14.0)	-	159 (2.18)	26 (0.36)	8.2 (0.112)	7.5 (0.099)	3310 (45.3)
W. F. Mill Creek at Mount Healthy 03256000	7.9	-	16.7	-	-	-	-	-
W. F. Mill Creek At Woodlawn 03257500	32.2	33.7 (1.05) (14.2)	-	81 (2.52)	6.3 (0.20)	0.1 (0.003)	0	-
W. F. Mill Creek at Lockland 03258000	35.6	-	-	-	-	-	-	3270 (91.9)
Mill Creek at Carthage 03259000	115	116 (1.01) (13.7)	-	277 (2.41)	37 (0.32)	10 (0.087)	8.6 (0.074)	-

MIAMI RIVER BASIN

The Miami River drains 5,385 square miles, of which 1,437 square miles are in Indiana, mainly in the Whitewater River Basin. The highest point in Ohio (1,550 feet above mean sea level) is in the Miami River drainage near Bellefontaine, and the lowest point in the state (about 430 feet above mean sea level, low water level in the Ohio River at the Indiana line) is just below the mouth of the Miami River. The map in figure 16 shows the outline of the basin and flow paths of the main watercourses.

Physiography

The entire basin is in the Till Plains. The level to gently rolling plain is broken by the wide valleys of the major streams. Toward Cincinnati the topography is hilly and more dissected, but is not as rugged as some other parts of southern and southeastern Ohio. The principal terrain features north of Middletown are the kames, eskers, and end moraines left by the glaciers.

Geology

The bedrock units exposed in the basin consist of limestone, dolomite, and shale of Ordovician and Silurian age. These strata are relatively dense and do not allow for the storage of large volumes of ground water. In the northern part of the basin, where the Silurian dolomites prevail, ground-water storage may influence streamflow to a minor degree.

The glacial drift is deep over the upper part of the basin, exceeding 300 feet in places, but thinning toward the south. The glaciers left extensive deposits of washed material, particularly outwash, valley-train deposits, kames, eskers, and kame moraines. Many deep preglacial or interglacial stream valleys are filled with permeable sands and gravels.

Soils

The soils in the basin are derived from glacial deposits of both early and late Wisconsin age. Miamian, Celina, Crosby, and Kokomo are the dominant soils of the late Wisconsin till area, and Russell, Xenia, and Fincastle are the principal soils of the early Wisconsin area. Classification of these soils depends on the drainage condition under which they developed. The less well-drained soils are relatively impermeable. Rather extensive terrace and alluvial soils occur, generally with good drainage and high permeability. Eldean, Ockley, and associated soils are prevalent on the terraces. Genesee soils are the dominant alluvial soils.

Water Development

Flood-control works of the Miami Conservancy District include five detention dams (dry reservoirs except during flood periods) that have automatic outlets. The dams provide

Figure 16. Map of Miami River Basin.

flood protection for Dayton and other cities along the Miami River. In 1972, the Corps of Engineers completed Buck Creek Reservoir on Buck Creek at Springfield.

The City of Dayton obtains its water supply from large well fields along the Miami River and Mad River.

Flow Characteristics

Recent estimates of flow characteristics are available for 58 stream gaging stations in the Miami River Basin and 2 stations in the upper Wabash River Basin. Selected flow characteristics at these gaging sites are given in table 15.

The amount of ground-water storage, the controlling factor influencing the low-flow characteristics of streams, is greatest in the upper part of the Miami River Basin, and diminishes toward the south. It is of interest to note that as early as 1896, a geologist with the U. S. Geological Survey (Leverett) recognized the influence of ground-water discharge on streamflow. Leverett states (U. S. Geological Survey, Monogram 41, 1902) that "The streams in this basin (Miami River Basin) seldom reach a very low stage in seasons of drouth, for the valleys are usually filled with gravelly or sandy deposits which furnish strong springs. Even in the small tributaries, water bearing beds outcrop along the banks or bluffs."

Above Dayton three principal streams, Stillwater River, Miami River, and Mad River, all of which converge at Dayton to form the main valley, drain the basin. Of the three branches, Stillwater River has the lowest index of dry-weather flow and Mad River the highest. Throughout most of its course, Stillwater River follows a preglacial valley containing moderately permeable outwash deposits. Above Covington the Stillwater lies between two moraines, and although it flows through a till plain, its tributaries extend into the morainal areas to the north and south. The morainal material is largely till but sufficiently extensive sand and gravel deposits are present to support the fairly good sustained flow in the Stillwater River.

The effects of morainal deposits are clearly shown on Greenville Creek. This stream is of ice-front origin and parallels the southern edge of the Union Moraine from Covington to the Indiana line. The dry-weather flow index at Bradford is double that of the Stillwater River above the mouth of Greenville Creek.

Below Covington the chief source of the sustained flow in the Stillwater River is the outwash and valley train deposits in the valley. Ground-water contribution from the limestone and dolomite that form the valley walls is relatively small.

Above Dayton the sustained flow in the Miami River is relatively high. With the exception of a short reach above Piqua, the channel is cut into valley fill of glacial origin. At the col above Piqua, the channel is cut into the bedrock. The sustained flow is maintained largely from ground-water flow originating in the extensive kame moraine, end moraine, and kame terrace deposits above Quincy in Logan County. Downstream from Piqua the chief source is form high-level terrace deposits.

The tributary, Loramie Creek, has a poor sustained flow. The area drained is till plain in which most of the surface materials are dense and impermeable. It is believed that Loramie Reservoir has little effect on the flow of Loramie Creek. The same holds true for Indian Lake at the head of the Miami River.

The greatest contribution to the sustained flow of the Miami River is received from the Mad River. The Mad River occupies a broad trough-like valley of preglacial and interglacial origin and most of its course lies between the morainal ridges deposited by the Miami and Scioto lobes of the Wisconsin glacier. The surface material in the interlobate area consists of extensive permeable drift such as kames, kame terraces and end moraines accompanied by high-level outwash in the uplands and valley train in the main valleys. At no other place in the state is there such an accumulation of permeable material and, as a result, the Mad River has some of the highest median- and low-flow indices of all the streams in Ohio. Similar conditions prevail in the area drained by Buck Creek and Beaver Creek although glacial drift in this area is less gravelly in nature and tends to be more dominantly till. Regional discharge from limestone contributes some ground water to sustain base flows of the Mad River.

Analyses of the gaging records for the Mad River show that the greatest influx of ground water occurs between Urbana and Springfield. This is due mainly to flow from Buck Creek and partly from greater ground-water influx along the river between Urbana and Springfield. The Mad River (similar to the Miami River at Piqua) has a short reach where it is shallow to limestone just west of Springfield. Between Springfield and Dayton there is a decrease in the index of flow. Miscellaneous discharge measurements made in this area in 1948 revealed that many of the tributary streams are dry during dry-weather periods.

From Dayton to Hamilton there is a general decrease in the dry-weather flow indices of the Miami River except at Miamisburg where the effects of municipal and industrial wastewater return flows from Dayton are noticeable. Municipal and industrial water supplies are derived from gravel deposits along the Miami River and Mad River in Dayton and discharged as wastewater upstream of the Miamisburg gage. Part of the water supply is diverted to the Little Miami River through the wastewater system. Tributaries such as Wolf Creek and Twin Creek have moderate sustained flows and tend to maintain the low flow in the Miami River.

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
S. F. Miami R. near Huntsville 03260450	47.5	-	-	-	-	1.6 (0.034)	1.9	-
Miami River at Russells Point 03260600	133	-	-	-	-	5.7 (0.043)	5.1	-
Muchinippi Cr. near Russels Point 03260620	86.2	-	-	-	-	1.7 (0.020)	1.4	-
Bokengehalas Cr. near DeGraff 03260700	36.3	34.0 (0.94) (12.7)	69.1	72 (1.98)	19 (0.52)	6.2 (0.171)	6.2 (0.182)	753 (20.7)
Stoney Creek near DeGraff 03260800	59.1	53.1 (0.90) (12.2)	66.8	108 (1.83)	28 (0.47)	10 (0.169)	11 (0.207)	1110 (18.8)
Miami River at Sidney 03261500	541	491 (0.91) (12.3)	-	1280 (2.37)	182 (0.34)	45 (0.083)	40 (0.081)	6800 (12.6)
Loramie Creek near Newport 03261950	152	139 (0.91) (12.4)	-	363 (2.39)	25 (0.16)	1.7 (0.011)	1.1 (0.008)	-
Loramie Creek at Lockington 03262000	257	215 (0.84) (11.4)	-	551 (2.14)	44 (0.17)	7.3 (0.028)	6.0 (0.028)	-
Miami River at Piqua 03262500	866	-	-	-	-	48 (0.055)	43	-
Miami River at Troy 03262700	926	851 (0.92) (12.5)	-	2260 (2.44)	313 (0.34)	72 (0.078)	67 (0.079)	-
Millers Ditch at Tipp City 03262750	0.83	-	-	-	-	-	-	107 (129)

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location **sta. no.**	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%** cfs (cfs/sq. mi.)	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Lost Creek near Troy 03262800	55.3	-	-	-	-	2.4 (0.043)	2.1	-
Honey Creek near New Carlisle 03262900	72.8	-	-	-	-	9.0 (0.124)	8.0	-
Miami River at Taylorsville 03263000	1149	1020 (0.89) (12.0)	-	2480 (2.16)	394 (0.34)	95 (0.083)	87 (0.085)	-
Popular Creek near Vandalia 03263100	3.11	-	-	-	-	-	-	390 (125)
Swamp Creek at Versailles 03263195	58.8	-	-	-	-	1.3 (0.022)	1.1	-
Greenville Creek near Coletown 03263390	69.2	-	-	-	-	6.2 (0.090)	5.6	-
Greenville Creek near Bradford 03264000	193	179 (0.93) (12.6)	52.9	403 (2.09)	75 (0.39)	22 (0.114)	19 (0.106)	3150 (16.3)
Stillwater River at Pleasant Hill 03265000	503	454 (0.90) (12.3)	39.9	1040 (2.07)	148 (0.29)	34 (0.068)	27 (0.059)	9910 (19.7)
Hog Run Trib. at Laura 03265100	0.46	-	-	-	-	-	-	36 (28.3)
Ludlow Creek at Ludlow Falls 03265395	62.9	-	-	-	-	2.0 (0.032)	1.6	-
Stillwater River at Englewood 03266000	650	593 (0.91) (12.4)	-	1440 (2.22)	198 (0.30)	43 (0.066)	37 (0.062)	-

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Mad River at Zanesfield 03266500	7.31	7.70 (1.05) (14.3)	65.0	17 (2.33)	3.6 (0.49)	1.3 (0.178)	1.2 (0.156)	415 (56.8)
Mad River at Lippincott 03266647	68.4	-	-	-	-	24 (0.351)	26	-
Kings Creek near Urbana 03266897	43.6	-	-	-	-	14 (0.321)	15	-
Mad River near Urbana 03267000	162	151 (0.93) (12.7)	81.1	273 (1.69)	111 (0.69)	52 (0.321)	57 (0.377)	2510 (15.5)
Cedar Run near Tremont City 03267400	2.08	-	-	-	-	3.8 (1.827)	4.1	-
Chapman Creek at Tremont City 03267600	24.0	-	-	-	-	0.7 (0.029)	0.9	-
Mad River at St. Paris Pike 03267900	310	315 (1.02) (13.8)	-	473 (1.53)	201 (0.65)	113 (0.365)	121 (0.384)	5350 (17.3)
Buck Creek near New Moorefield 03267950	30.5	-	83.4	-	-	-	-	-
E. F. Buck Creek near New Moorefield 03267960	28.7	-	75.6	-	-	-	-	-
Buck Creek at New Moorefield 03268000	65.3	65.6 (1.0) (13.6)	75.2	112 (1.72)	44 (0.67)	23 (0.352)	24 (0.366)	1880 (28.8)
Beaver Creek at Brighton 03268300	3.33	-	-	-	-	-	-	250 (75.1)

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Beaver Creek near Springfield 03268500	39.2	-	58.8	-	-	-	-	1830 (46.7)
Buck Creek at Springfield 03269000	139	-	-	-	-	-	-	3210 (23.1)
Mad River near Springfield 03269500	490	500 (1.02) (13.9)	-	916 (1.87)	338 (0.69)	174 (0.355)	177 (0.354)	7800 (15.9)
Mad River near Dayton 03270000	635	639 (1.01) (13.7)	-	1200 (1.89)	429 (0.68)	203 (0.320)	208 (0.326)	-
Miami River at Dayton 03270500	2511	2290 (0.91) (12.4)	-	5290 (2.11)	1060 (0.42)	329 (0.131)	320 (0.140)	36600 (14.6)
Wolf Creek at Trotwood 03270800	22.7	23.2 (1.02) (13.9)	40.4	52 (2.29)	7.1 (0.31)	0.7 (0.031)	0.5 (0.022)	1590 (70.0)
Wolf Creek at Dayton 03271000	68.7	65.2 (0.95) (12.9)	42.2	126 (1.83)	20 (0.29)	4.9 (0.071)	4.0 (0.061)	4680 (68.1)
Holes Creek near Kettering 03271300	18.7	-	-	-	-	1.6 (0.086)	1.4	-
Bear Creek at Ellerton 03271400	38.9	-	-	-	-	1.7 (0.044)	1.4	-
Miami River at Miamisburg 03271500	2711	2490 (0.92) (12.5)	-	5690 (2.10)	1280 (0.47)	438 (0.162)	433 (0.174)	-
Miami River at Franklin 03271620	2727	-	-	-	-	419 (0.154)	414	-

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%** cfs (cfs/sq. mi.)	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
Clear Creek at Franklin 03271700	51.6	-	-	-	-	1.5 (0.029)	1.2	-
Twin Creek at Lewisburg 03271736	68.4	-	-	-	-	2.9 (0.042)	2.3	-
Twin Creek at Ingomar 03271800	197	200 (1.00) (13.8)	39.7	449 (2.28)	64 (0.32)	10 (0.051)	8.3 (0.041)	7500 (38.1)
Twin Creek near Germantown 03272000	275	271 (0.99) (13.4)	-	611 (2.22)	85 (0.31)	14 (0.051)	11 (0.041)	-
Elk Creek at Miltonville 03272200	46.2	-	-	-	-	1.3 (0.028)	1.1	-
Dicks Creek near Excello 03272300	44.7	-	-	-	-	2.6 (0.049)	2.2	-
Trippetts Branch at Camden 03272695	0.33	-	-	-	-	-	-	95 (288)
Seven Mile Cr. at Camden 03272700	69.0	72.5 (1.05) (14.3)	47.4	167 (2.42)	27 (0.39)	4.0 (0.058)	3.0 (0.041)	3270 (47.4)
Seven Mile Cr. at Collinsville 03272800	120	101 (0.84) (11.4)	45.9	213 (1.78)	32 (0.27)	5.2 (0.043)	4.0 (0.040)	6140 (51.2)
Collins Creek at Collinsville 03272900	0.94	-	-	-	-	-	-	234 (249)
Fourmile Creek near Hamilton 03273500	307	-	40.1	-	-	-	-	14400 (46.9)

TABLE 15

FLOW CHARACTERISTICS AT STREAM GAGING STATIONS
Miami River Basin

Stream Name and Location sta. no.	**drainage area** sq. mi.	**mean annual runoff** cfs (cfs/sq. mi.) (inches)	**mean base-flow index** percent	**discharge equaled or exceeded percent of time** **10%**	**50%**	**90%**	**7-day, 2-yr low flow** cfs (ratio to mean annual flow)	**2-yr. R.I. flood-peak discharge** cfs (cfs/sq.mi.)
				cfs (cfs/sq. mi.)				
Miami River at Hamilton 03274000	3630	3350 (0.92) (12.5)	-	7720 (2.13)	1600 (0.44)	502 (0.138)	497 (0.148)	44300 (12.2)
Indian Creek near Millville 03274200	102	-	-	-	-	1.1 (0.011)	0.7	-
Miami River at New Baltimore 03274600	3814	-	-	-	-	510 (0.134)	504	-
Wabash River above Beaver Cr. 03322480	119	-	-	-	-	1.9 (0.016)	1.6	-
Wabash River near New Corydon 03322500	262	-	-	-	-	-	-	4160 (15.9)

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