In cooperation with the
U.S. Army Corps of Engineers and the
U.S. Department of Agriculture, Natural Resources Conservation Service

Status and Trends in Suspended-Sediment Discharges, Soil Erosion, and Conservation Tillage in the Maumee River Basin–Ohio, Michigan, and Indiana

Water-Resources Investigations Report 00-4091

U.S. Department of the Interior
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By Donna N. Myers and Kevin D. Metzker, U.S. Geological Survey, and
Steven Davis, U.S. Department of Agriculture, Natural Resources Conservation
Service

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U.S. Department of the Interior
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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile	2.590	square kilometer
acre	0.4047	square hectometer (hectare)
ton	0.4536	kilogram
gallon per minute (gal/min)	3.785	liter per minute
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Vertical datum: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Temperature: Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8 (°C) + 32$$

Concentrations of suspended sediment are given in miligrams per liter (mg/L), which is the same as parts per million.

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Status and Trends in Suspended-Sediment Discharges, Soil Erosion, and Conservation Tillage in the Maumee River Basin—Ohio, Michigan, and Indiana

By Donna N. Myers, Kevin D. Metzker, and Steven Davis[1]

Abstract

The relation of suspended-sediment discharges to conservation-tillage practices and soil loss were analyzed for the Maumee River Basin in Ohio, Michigan, and Indiana as part of the U.S. Geological Survey's National Water-Quality Assessment Program. Cropland in the basin is the largest contributor to soil erosion and suspended-sediment discharge to the Maumee River and the river is the largest source of suspended sediments to Lake Erie. Retrospective and recently-collected data from 1970–98 were used to demonstrate that increases in conservation tillage and decreases in soil loss can be related to decreases in suspended-sediment discharge from streams.

Average annual water and suspended-sediment budgets computed for the Maumee River Basin and its principal tributaries indicate that soil drainage and runoff potential, stream slope, and agricultural land use are the major human and natural factors related to suspended-sediment discharge. The Tiffin and St. Joseph Rivers drain areas of moderately to somewhat poorly drained soils with moderate runoff potential. Expressed as a percentage of the total for the Maumee River Basin, the St. Joseph and Tiffin Rivers represent 29.0 percent of the basin area, 30.7 percent of the average-annual streamflow, and 9.31 percent of the average annual suspended-sediment discharge. The Auglaize and St. Marys Rivers drain areas of poorly to very poorly drained soils with high runoff potential. Expressed as a percentage of the total for the Maumee River Basin, the Auglaize and St. Marys Rivers represent 48.7 percent of the total basin area, 53.5 percent of the average annual streamflow, and 46.5 percent of the average annual suspended-sediment discharge. Areas of poorly drained soils with high runoff potential appear to be the major source areas of suspended sediment discharge in the Maumee River Basin.

Although conservation tillage differed in the degree of use throughout the basin, on average, it was used on 55.4 percent of all crop fields in the Maumee River Basin from 1993–98. Conservation tillage was used at relatively higher rates in areas draining to the lower main stem from Defiance to Waterville, Ohio and at relatively lower rates in the St. Marys and Auglaize River Basins, and in areas draining to the main stem between New Haven, Ind. and Defiance, Ohio. The areas that were identified as the most important sediment-source areas in the basin were characterized by some of the lowest rates of conservation tillage.

The increased use of conservation tillage was found to correspond to decreases in suspended-sediment discharge over time at two loca-

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[1] U.S. Department of Agriculture, Natural Resources Conservation Service, Lima, Ohio.

tions in the Maumee River Basin. A 49.8 percent decrease in suspended-sediment discharge was detected when data from 1970–74 were compared to data from 1996–98 for the Auglaize River near Ft. Jennings, Ohio. A decrease in suspended-sediment discharge of 11.2 percent was detected from 1970–98 for the Maumee River at Waterville, Ohio. No trends in streamflow at either site were detected over the period 1970–98. The lower rate of decline in suspended-sediment discharge for the Maumee River at Waterville, Ohio compared to the Auglaize River near Ft. Jennings, may be due to resuspension and export of stored sediments from drainage ditches, stream channels, and flood plains in the large drainage basin upstream from Waterville. Similar findings by other investigators about the capacity of drainage networks to store sediment are supported by this investigation. These findings go undetected when soil loss estimates are used alone to evaluate the effectiveness of conservation tillage. Water-quality data in combination with soil-loss estimates were needed to draw these conclusions. These findings provide information to farmers and soil conservation agents about the ability of conservation tillage to reduce soil erosion and suspended-sediment discharge from the Maumee River Basin.

Introduction

Soil loss and soil erosion are among the most important economic and water-resource issues in the Lake Erie Basin. Excessive sediment degrades water quality, carries contaminants, and when deposited within water-conveyance structures, reduces their capacity. But because soil loss is within the tolerable range in most areas of the Maumee River Basin, reduction of cropland productivity is not considered to be as great a concern as are effects on water quality and navigation (Wager, 1996). Tolerable soil loss is the upper limit of permissible soil loss over an extended period of time that results in no net loss of productivity (Kimberlin and Moldenhauer, 1977).

The Maumee River discharges more tons of suspended sediment per year than any other tributary to the Great Lakes (Baker, 1993). Agricultural land in the Maumee River Basin, which is 70 percent cropland, is the primary source of sediment (U.S. Department of Agriculture, 1998). As a result of intensive agricultural activities, runoff to streamwaters in the Maumee Basin contains elevated amounts of suspended sediments, fertilizers, and pesticides (Baker, 1993; Baker and others, 1998). Conventional tillage associated with row crop farming results in an accelerated loss of soil from fields, and as a consequence, sedimentation of stream channels. Stream channel and riparian habitats are affected by sediment dredging, ditching, and removing of streambank vegetation to maximize acres of cultivated land and to rapidly move water off and away from the land surface. Some of the most greatly modified stream channels and impacted fish and aquatic invertebrate communities in Ohio are found in selected areas of the Maumee River Basin. These negative effects are attributed to habitat modification by agriculture (Ohio Environmental Protection Agency, 1989, 1992a,b; 1993a,b; 1994, 1995).

Industrialization of the lower main stem of the Maumee River, from Toledo to the mouth at Lake Erie, has resulted in impairments to water and sediment quality from contaminants. Sediments coming from the watershed upstream from Toledo become contaminated by trace metals and PCBs (polychlorinated biphenyls) as they pass through the Toledo area. Impairments from contaminated sediments include restrictions on human consumption of contaminated fish and documented impairments to benthic aquatic life (Ohio Environmental Protection Agency, 1989). Unlike clean sediments, contaminated sediments, once dredged, must be placed in CDFs (confined disposal facilities) rather than disposed of in the open waters of the lake. The restriction on the disposal of dredged sediment is considered an impairment to the beneficial use of the material. The lower main stem of the Maumee River has been identified by the International Joint Commission as an AOC (Area of Concern)—a waterway where beneficial uses of the water resources have been impaired by human activities. The Maumee River AOC is 1 of 43 in the Great Lakes Basin (International Joint Commission, 1987).

Economic effects on the Port of Toledo result from the need to dredge and dispose of 870,000 yd^3 (cubic yards) of sediment per year from the Maumee River and the Maumee Bay of Lake Erie at an average annual cost of about $2.2 million. To maintain the federal navigation channel at an adequate depth, approximately 300,000 yd^3 are dredged each year from the lower 7 mi (miles) of the Maumee River and 570,000 yd^3 are dredged from Maumee Bay. Dredging and disposal in CDFs incurs an economic cost on shipping through fees levied on users of the Port of Toledo. Because no new CDFs are being licensed for the federal navigation channel of the Maumee River, and existing CDFs are being filled to capacity, alternatives are needed.

The effects of suspended-sediment deposition from the Maumee River on the economy of the Port of Toledo and on the aquatic resources of the basin rank near the top of regional environmental concerns (U.S. Department of Agriculture, 1998; Ohio Lake Erie Commission, 1998). The Ohio Lake Erie Commission has set a goal of reducing the annual discharges of suspended sediment from Lake Erie tributaries in Ohio by 67 percent to improve water clarity and restore wetlands along Lake Erie (Ohio Lake Erie Commission, 1998, p. 22). Recent changes in regulations governing the disposal of dredged sediments and the desire to improve aquatic resources of the Maumee River Basin have resulted in the adoption of basinwide programs to improve the management of land, soil, water, and sediments. The long-term goal of the USACE (U.S. Army Corps of Engineers) is to reduce the amount of sediment dredged from the Maumee River and Maumee Bay in Lake Erie by 15 percent, an equivalent of 130,000 yd^3 each year (U.S. Department of Agriculture, 1998, p. 4).

Conservation tillage, a practice that reduces cultivation and retains the residue from the previous year's crop at the soil surface, is being implemented as a means to decrease the amount of soil that is eroded and the amount of suspended sediment that is transported, deposited, and dredged annually from the lower Maumee River and Maumee Bay. Natural-resource conservation programs such as the Conservation Reserve Program and conservation tillage have been used since the mid-1980s to reduce sediment and phosphorus discharges in the Maumee River Basin and to improve aquatic habitat for fish and wildlife. Although conservation tillage is estimated to have reduced soil loss and soil erosion (U.S. Department of Agriculture, 1998), the response of the Maumee River and its tributaries to conservation tillage may be variable from location to location in the basin. Without direct evidence of improving water quality, farmers and others may become indifferent to the voluntary use of these practices and programs. This, in turn, could negate the apparent success of these programs and the investments made by federal, State, and local natural-resource managers. Natural-resource managers need better information on where and how conservation practices are improving water quality to make the best use of limited resources available for implementation programs.

In 1994, The USGS (U.S. Geological Survey) began an intensive water-quality investigation in the Lake Erie-Lake St. Clair Basin as part of its NAWQA (National Water-Quality Assessment) Program. As part of this investigation, a study of the relation of suspended-sediment discharge to conservation-tillage practices was begun in the Maumee River Basin (fig. 1) in cooperation with the NRCS (Natural Resources Conservation Service) and the USACE. Conservation-tillage practices have been systematically used on more than 50 percent of the 3.1 million acres of cropland in the Maumee River Basin as a method to reduce soil erosion from cropland, to reduce the amount of dredging required in the Port of Toledo, and to improve the water quality and aquatic habitat.

Purpose and scope

The purposes of this report are to (1) identify the major source areas of sediment discharge in the Maumee River Basin, (2) quantify the suspended-sediment discharge delivered to the main stem from major tributaries and from the upper main stem to the lower main stem, (3) relate natural factors such as soil drainage, soil texture, and stream slope to discharges of suspended sediment, (4) examine whether conservation tillage has contributed to changes over time in suspended-sediment discharges, and (5) discuss the implications for management of soil erosion from cropland in the Maumee River Basin.

Data analyzed for this report include retrospective and recent data collected at eight sites in the Maumee River Basin at frequencies from daily to monthly, over a wide range of streamflows, and for different time periods between 1970–98. These sites represent the four largest tributaries to the Maumee River and three sites at key locations on the main stem. These data were used to answer questions about the role of natural and human factors in controlling soil erosion and suspended-sediment discharge in the Maumee River Basin.

Data were further extrapolated to provide an average annual sediment budget for the Maumee River Basin for 1996–98. Data on crop type, tillage practices, and soil-loss estimates were used to document

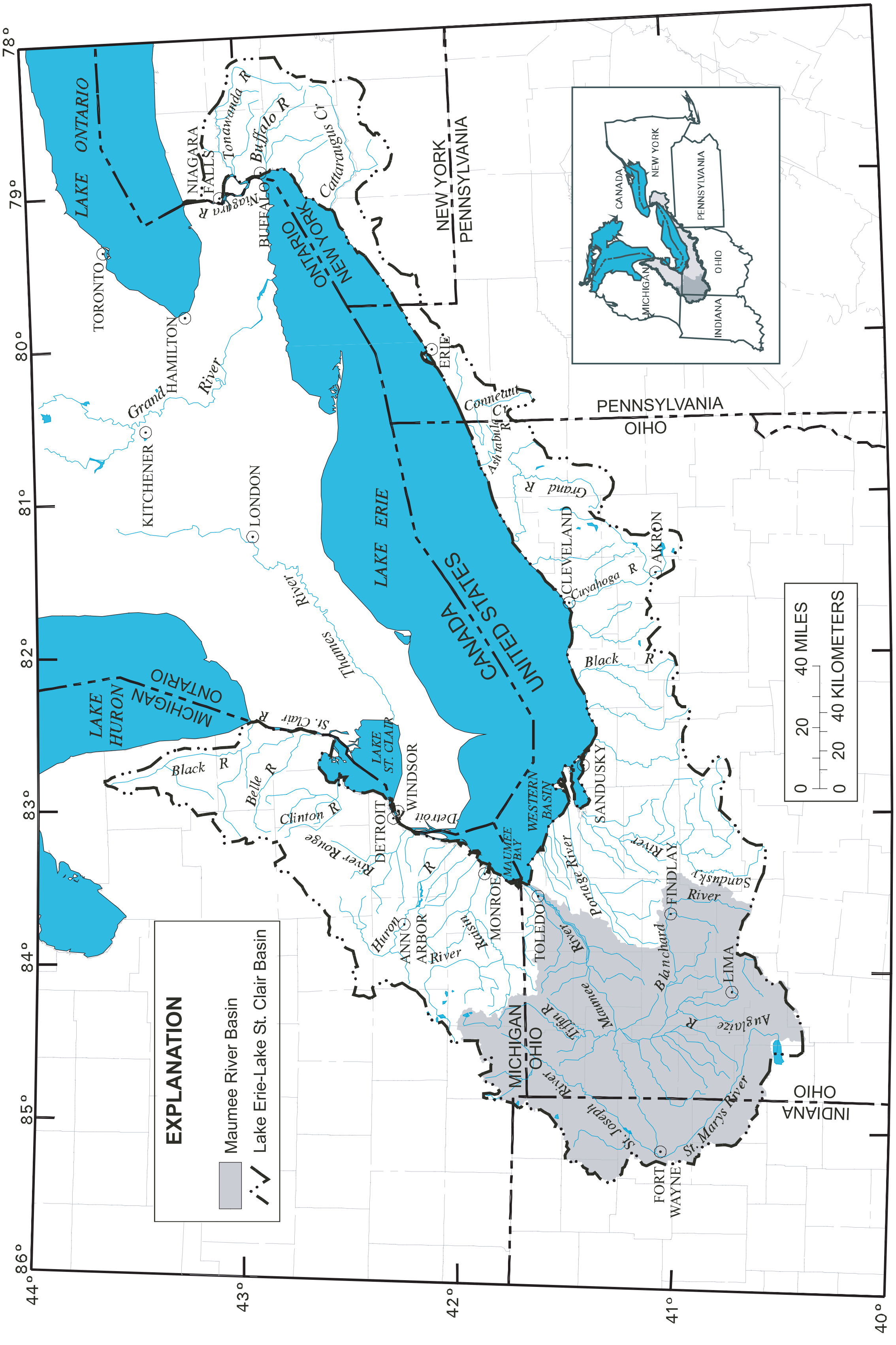


Figure 1. Lake Erie-Lake St. Clair Basin study unit showing Maumee River Basin.

the spatial variation and location, type, and amount of conservation-tillage practices, soil-erosion rates, and soil loss in the Maumee River Basin. Trends in daily streamflow for the Maumee River at Waterville, Ohio and the Auglaize River near Ft. Jennings, Ohio from 1970–98 were examined along with trends in daily suspended-sediment discharge. Trends in suspended-sediment discharge were related to trends in streamflow and interpreted in relation to information on crop types, soil-loss estimates, and changes in conservation-tillage practices.

Previous investigations

Because it is a major source of agrochemicals and sediments to Lake Erie, the Maumee River has been the focus of many water-quality studies (Jones and others, 1977; Logan, 1978; Baker, 1982, 1988; Richards and Baker, 1993; Baker and others, 1998). Suspended-sediment concentrations, discharges, yields, and trends have been summarized for the Maumee River Basin by Hindall (1989), Baker (1982, 1988), Richards and Baker (1993), and Baker and others (1998). Antilla and Tobin (1978) were the first to report on sediment discharges, concentrations, and yields with data collected from 1950–74.

Suspended-sediment discharge in the Maumee River Basin has been measured at one site near the downstream end of the basin, at the Maumee River at Waterville, Ohio. The Maumee River at Waterville receives drainage from 6,330 mi^2 or 95.8 percent of the 6,609 mi^2 basin. Daily suspended-sediment records have been reported for this site by the USGS from 1950–84 and from 1988–98 (Shindel and others, 1999). Another long-term monitoring program at this site is operated by the Heidelberg College Water-Quality Laboratory, in Tiffin, Ohio. For the Heidelberg Water-Quality Program, daily or more frequent samples for analysis of total nonfilterable residue have been collected from 1975–84 and 1988–98 (Baker and others, 1998). These data are valuable for characterizing the mass transport and trends over time in concentrations and discharges to Lake Erie of suspended sediment, fertilizers, and pesticides.

Compared to other tributary streams, the Maumee River is the largest source of suspended sediments to Lake Erie, and the average and range of annual suspended-sediment discharges in the Maumee River far exceed that reported for the other principal streams of the Lake Erie Basin (table 1). The large size of the Maumee River Basin and year-to-year variations in rainfall result in annual discharges of suspended sediment that ranged from 275,000 tons to 1,940,000 tons—a factor of 7 (table 1). The importance of tributaries such as the Auglaize River as major sources of suspended-sediment discharges to the Maumee River were first reported by Antilla and Tobin (1978).

Analyses of trends in suspended-sediment discharge were reported by Hindall (1989). Trends in total nonfilterable residue concentrations were reported by Richards and Baker (1993) and Baker and others (1998). Although no trends in suspended-sediment discharge were detected for the Maumee River at Waterville from 1950–87 (Hindall, 1989) or in total nonfilterable residue from 1975–90 (Richards and Baker, 1993), an approximate 17.5 percent downward trend in the concentration of total nonfilterable residue was reported recently for 1975–95 (Baker and others, 1998). The reason for this downward trend was attributed to conservation tillage (Baker and others, 1998). Little is known about trends upstream from Waterville, and the trends at Waterville have not been interpreted in relation to areal patterns in soil loss and conservation tillage. Another water-quality study was undertaken in the Palouse River Basin in Washington and Idaho as part of the NAWQA Program (Ebbert and Roe, 1998). That study reported on potential reductions in soil erosion and sediment discharge from 1979–94 resulting from erosion control practices such as conservation tillage and other practices for dry-land farming.

Several previous studies have examined the drainage class, surface texture, hydrologic group, and parent material of soils in the Maumee River Basin in relation to soil-erosion potential and conservation practices. Logan (1978) reported that soils of the basin are mostly fine textured and produce sediment during runoff in relation to their slope, internal drainage, texture, and susceptibility to sediment transport. Beasely (1985) modeled soil-erosion potential in the Maumee River Basin and model predictions suggest that relatively higher soil-erosion rates are likely to be associated with watersheds containing soils derived from till, lacustrine deposits, or lacustrine-till deposits that are poorly to very poorly drained with high runoff potential (Beasely, 1985). Jones and others (1977) found that the very poorly drained and fine-textured Paulding soils yielded the highest suspended-sediment concentrations compared to the somewhat poorly drained Hoytville soils, and the moderately well-drained Mill

Table 1. Characteristics of suspended-sediment concentration, discharge, and yield in selected streams of the Lake Erie-Lake St. Clair Basin

[mg/L, milligrams per liter; ton/yr, tons per year; ton/mi^2/yr, tons per square mile per year; NR, not reported]

	Clinton River	River Raisin		Auglaize River	Maumee River		Sandusky River		Cuyahoga River		Grand River
Period of record	1974–80	1966–72 1978–80	1982–85	1946–70	1946–70 1988–94	1982–85	1946–70 1988–94	1982–85	1946–70 1988–94	1982–85	1946–70 1988–91
Mean or range of annual mean concentrations (mg/L)	42	42	49-91	216	244[a]	180-205	250[a]	144-283	266[a]	158-269	102[a]
Average sediment discharge or range of annual sediment discharges (ton/yr x 1,000)	NR	NR	47-88	373	275-1,940[b]	989-1,410	197-350[b]	118-433	99-431[b]	180-273	65-261[c]
Yield or range of annual yields (ton/mi^2/yr)	22	47-63	17-33	187	43-306[b]	156-223	75-431[b]	94-346	140-610[b]	231-386	95-381[c]
Reference	(1)	(1)	(2)	(3)	(3, 4)	(2)	(3, 4)	(2)	(3, 4)	(2)	(3, 4)

[a] Corresponds to 1946-70 period of record.
[b] Corresponds to 1988-94 period of record.
[c] Corresponds to 1988-91 period of record.

[1] Cummings, 1983.
[2] Baker, 1988.
[3] Antilla and Tobin, 1978.
[4] Shindel and others, 1991-95.

grove soils (Jones and others, 1977). Conclusions by Jones and others (1977) were that fine-textured, nearly flat watersheds in the Maumee River Basin may represent significant contributing areas of sediment discharge to the Maumee River.

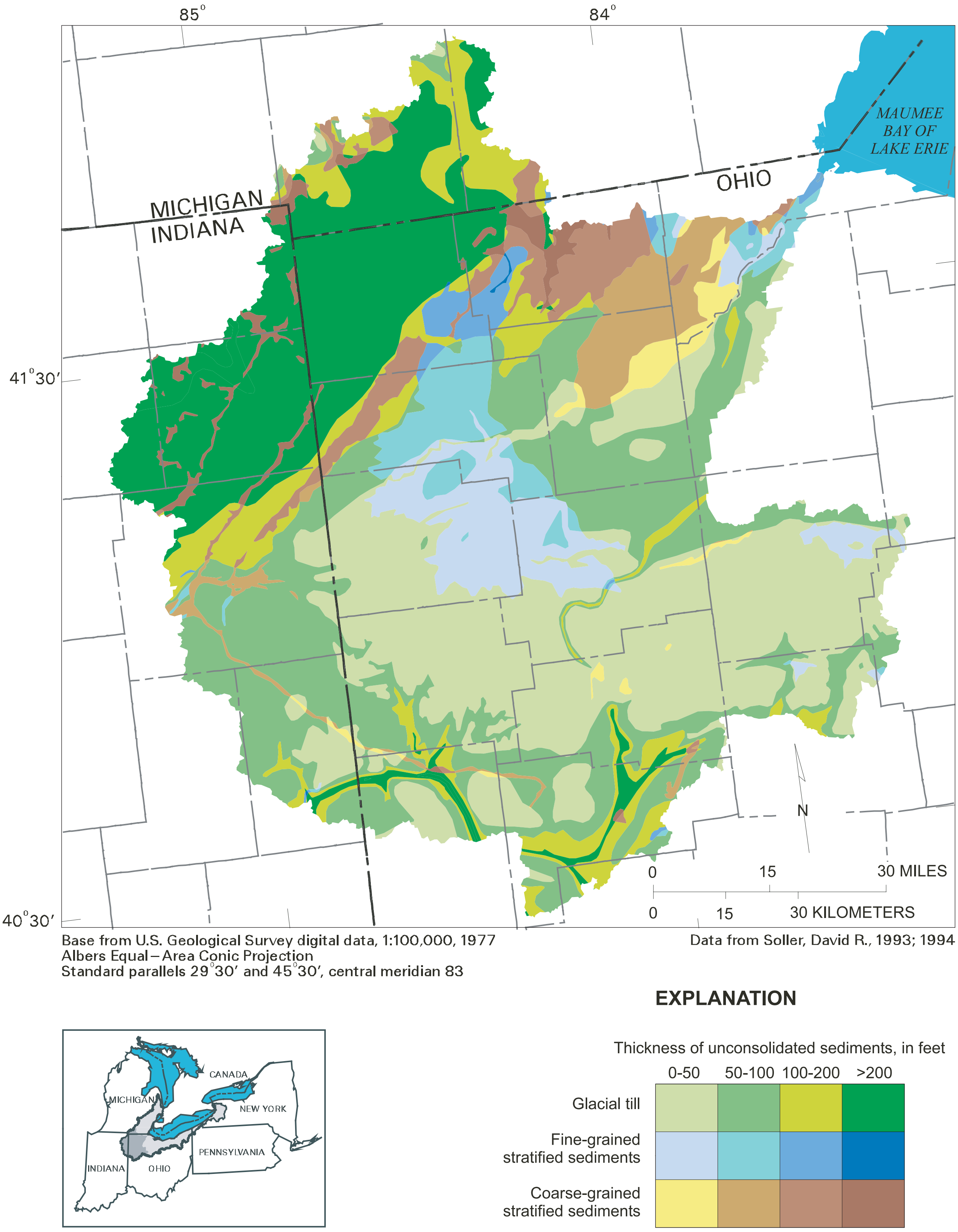
Environmental and hydrologic setting

The Maumee River, with a drainage area of 6,609 mi^2, is the largest stream discharging to Lake Erie in the United States and Canada (fig. 1). The Maumee River discharges just under 24 percent of the surface water that flows into Lake Erie from the United States, excluding that which is delivered from the upper lakes through the St. Clair River and Detroit River connecting channels (Casey and others, 1997). The four largest tributaries to the Maumee River, in descending order, are the Auglaize River, the St. Joseph River, the St. Marys River, and the Tiffin River (fig. 1). The Maumee River is formed by the confluence of the St. Joseph and St. Marys Rivers near Ft. Wayne, Ind.

The basin comprises a flat lake plain in the center and sloping till plains around the edges. The U.S. Department of Agriculture (1993) reported the average slope of the Maumee River from Fort Wayne to Toledo is 1.3 ft/mi. The average slopes of the major tributaries of the Maumee River are 2.8 ft/mi for the St. Marys River; 1.6 ft/mi for the St. Joseph River, 1.2 ft/mi for the Tiffin River; 3.2 ft/mi for the Auglaize River; and 0.9 ft/mi for the Blanchard River. Some of the headwaters of these tributaries have slopes of 10 ft/mi., especially those in the upper St. Joseph River Basin.

The modern Maumee River was formed during the glacial ice recession from the western end of the Lake Erie Basin, between 8,000 and 12,000 years ago. The Maumee River Basin is overlain by three types of Pleistocene glacial deposits—till, consisting of poorly sorted and generally unstratified particles ranging in size from clay to large boulders; and to a lesser degree, coarse-grained stratified sediments, consisting of sand and gravel; and fine-grained stratified sediments, consisting of clay, silt, and very fine sand (Casey and others, 1997). Sediments overlying bedrock range in thickness from less than 1 ft near Lake Erie to more than 200 ft in northwestern Indiana and southeastern Michigan (fig. 2).

The stream-drainage pattern of the Maumee River is dendritic owing to the consistent thick cover of surficial material deposited over the sandstones and shales in the northwestern part of the basin and the thin layers of surficial material deposited on the relatively flat limestone and dolomite bedrock units in the southern part of the basin (Casey and others, 1997). The dendritic pattern of stream development in the



Base from U.S. Geological Survey digital data, 1:100,000, 1977
Albers Equal–Area Conic Projection
Standard parallels 29°30′ and 45°30′, central meridian 83

Data from Soller, David R., 1993; 1994

Figure 2. Distribution and thickness of unconsolidated sediments in the Maumee River Basin.

basin shortens the distances from land surfaces to waterways and increases the efficiency of sediment delivery to streams.

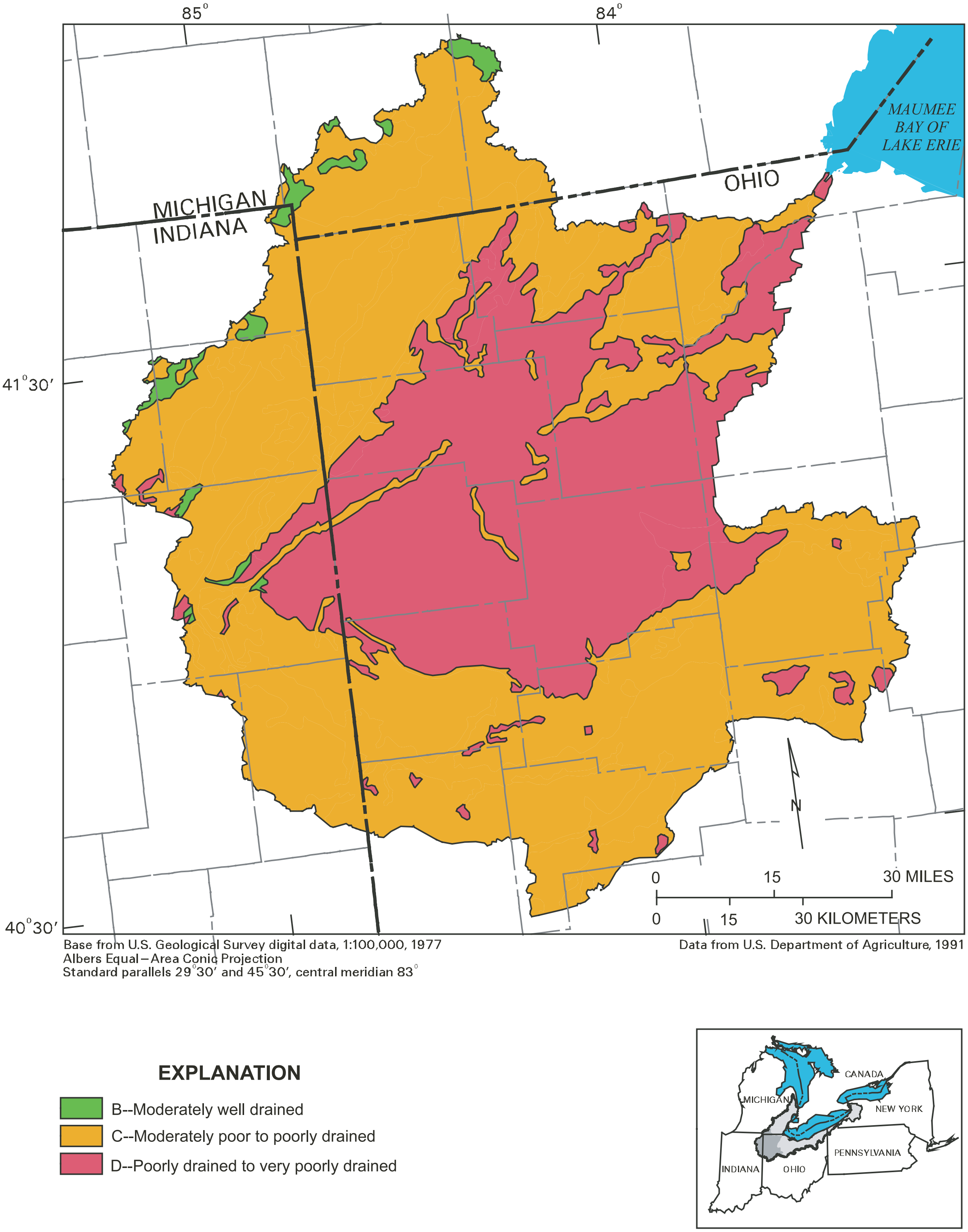
Areal patterns in suspended-sediment discharges are influenced by human and natural factors such as precipitation, climate, physiography, geology, and land use. The factors most affecting soil erosion and sediment transport from the land surface are intensity and duration of rainfall, topography, soil characteristics, and vegetative cover (Antilla and Tobin, 1978, p. 4). Rainfall is the most important and most variable factor from year to year (Guy, 1969). Annual precipitation from 1961–90 in the Maumee River Basin ranged from 31.9 in. near Lake Erie to 39.8 in. in the extreme southwestern part of the basin (Casey and others, 1997). Rainfall is highest in May and June and lowest in January and February (Casey and others, 1997). As a result of seasonally low evaporation and evapotranspiration, streamflow in the Maumee River are highest in February, March, and April and lowest in September and October (Casey and others, 1997, p. 40).

The parent materials of soils in the Maumee River Basin are the three types of glacial deposits mentioned previously. More than 90 percent of the soils in the basin are poorly to very poorly drained silts, clays, and fine sands of lacustrine or till origin (Beasely, 1985). Runoff potential of soils and soil-drainage characteristics are described by a classification of soils into four soil hydrologic groups; A-D (fig. 3). Group A soils are well-drained to excessively well-drained sands or gravels with low runoff potential. None of the soils in the Maumee River Basin are in Group A. Group B soils are well drained to moderately well drained with moderately fine to moderately coarse textures and moderate runoff potential. A small fraction of soils in the Maumee River Basin are in Group B, most of which are in southeastern Michigan (fig. 3). Group C soils are moderately poor to poorly drained soils with slow infiltration rates and moderately high runoff potential. Group D soils are soils with a permanently high water table consisting of clays, with a claypan, clay layer, or other relatively impervious layer near the surface and are poorly drained to very poorly drained with high runoff potential. Most soils in the Maumee River Basin are in the soil hydrologic groups C and D (fig. 3).

Dual hydrologic groups, A/D, B/D, and C/D are given for certain wet Group D soils that are artificially drained by tiles and (or) ditches. The dual group indicates that soil permeability has been increased through the use of drainage improvements. Artificial drainage from tiles increases runoff and decreases sediment discharge by increasing infiltration to the depth of the tile. In tile-drainage systems, runoff is quickly directed from the tiles to a system of ditches and eventually to streams (Logan, 1978; Fausey and others, 1995). Ditches may store eroded sediments because of their proximity to fields where gulley, sheet, and rill erosion occur.

The Maumee River Basin lies in the eastern U.S. Corn Belt. The major crops grown in the basin are corn, soybeans, wheat, oats, and alfalfa (hay). In 1996–97, 78.6 percent of all agricultural lands were cropland, and the crop rotation was corn and soybeans with some wheat and other small grains. As a percentage of total crops, 87.2 percent were row crops; 28.8 percent corn, 43.8 percent soybeans, and 14.6 percent small grains (Hess, 1995). As a percentage of total crops in 1975–76, 93.7 percent of all agricultural lands were cropland; 34.4 percent corn, 34.8 percent soybeans, and 24.5 percent small grains (Logan, 1978). The relative percentage of wide-row crops to total cropland has remained largely the same from 1975–98, between 69.2 percent and 72.6 percent. Greater soil erosion is associated with wide-row crops such as corn and soybeans, compared to narrow-row crops such as wheat and other small grains.

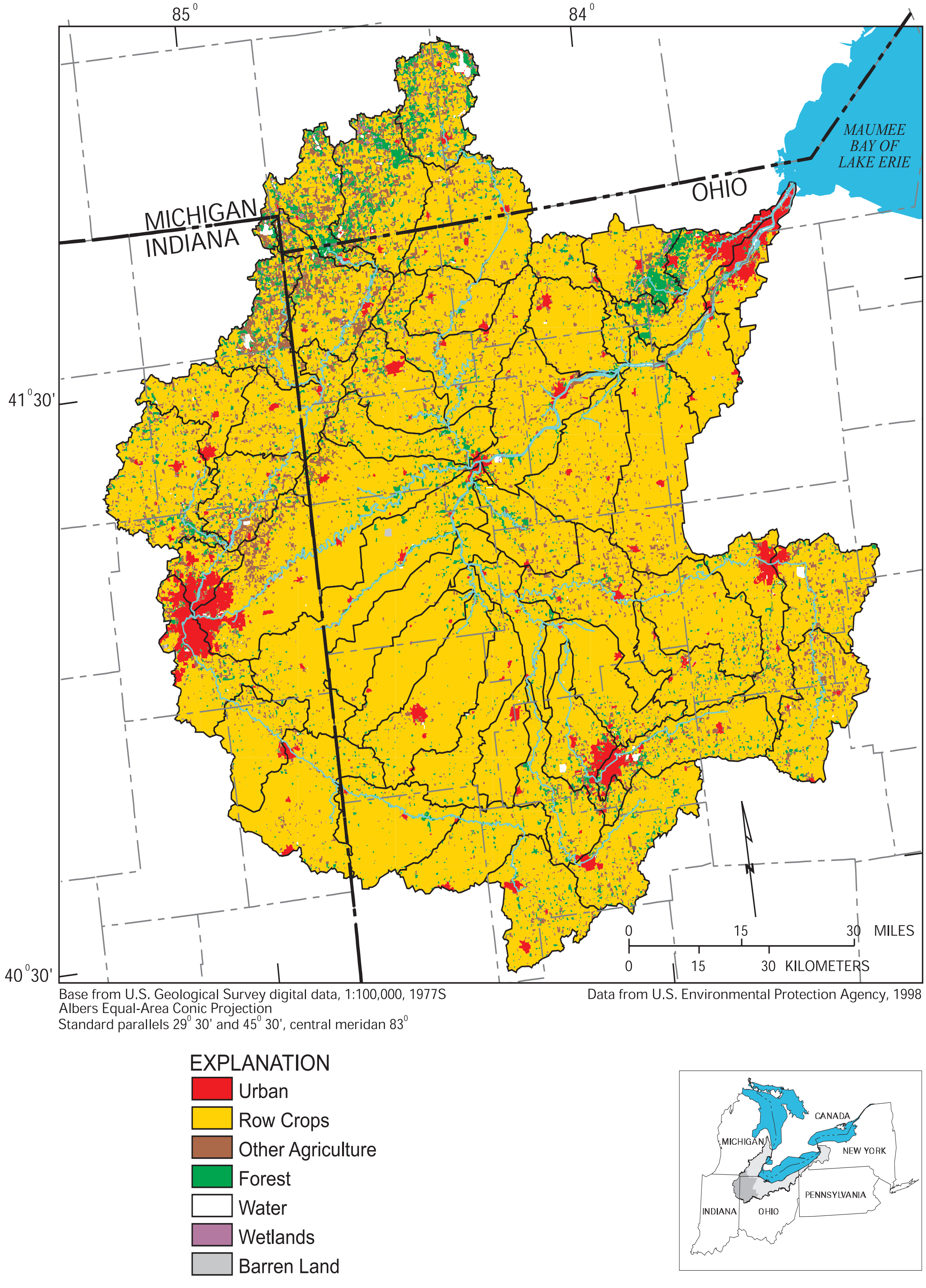
Campbell (1995) documented changes in land use in the Maumee River Basin during the past 160 years and showed that today, the basin is a highly altered environment compared to its natural condition. The central part of the Maumee River Basin extending from Toledo, Ohio, to Ft.Wayne, Ind., contains the highest clay content soils (fig. 3). This area was originally a large wetland called the Black Swamp, about one-third the size of the original Everglades. Human influences in the Maumee River Basin began with the logging of the Black Swamp as early as 1840. By 1870, half the basin had been cleared of trees for agriculture and drainage ditches were being installed. During the past 150 years, nearly all original wetlands have been deforested, drained, and converted to productive farmland (Campbell, 1995). In 1994, just over 70 percent of the basin was agricultural (fig. 4) and only 10 percent of the original wetland remained (Campbell, 1995). The Maumee River Basin is affected by urban land use as well as agricultural land use (fig. 4). Major cities in the basin with populations of more than 100,000 (in 1990) are Toledo, Ohio and



Base from U.S. Geological Survey digital data, 1:100,000, 1977
Albers Equal–Area Conic Projection
Standard parallels 29°30′ and 45°30′, central meridian 83°

Data from U.S. Department of Agriculture, 1991

Figure 3. Soil hydrologic groups in the Maumee River Basin.



Base from U.S. Geological Survey digital data, 1:100,000, 1977S
Albers Equal-Area Conic Projection
Standard parallels 29° 30' and 45° 30', central meridan 83°

Data from U.S. Environmental Protection Agency, 1998

Figure 4. Land use in the Maumee River Basin, 1994.

Ft. Wayne, Ind. (American Map Corporation, 1993 and fig. 1).

Conservation tillage increases crop residue at the soil surface and protects the soil by reducing the impact of rain drops. Conservation tillage reduces sheet and rill erosion, reduces concentrated flow, and enhances infiltration. Conservation tillage consists of three types of practices; no till, mulch till, and ridge till. No till is a minimum cultivation method that preserves 40 percent or more of the crop-residue cover from the previous year's crop on the surface of the field. Mulch till and ridge till are methods that preserve about 30 percent or more of crop-residue cover at the surface of the field. Conservation tillage was used by farmers on about 50 percent of all the corn and soybean acres in northwestern Ohio from 1993–98 (fig. 5). During that time, about 40 percent of the total acres in conservation tillage were in no till practices (U.S. Department of Agriculture, 1998).

Data collection and analysis

Suspended-sediment data were collected by the USGS as part of three ongoing water-quality projects—the National Water Quality Assessment Program in the Lake Erie–Lake St. Clair Basin, the Toledo Harbor Project of the U.S. Army Corps of Engineers-Buffalo District, and the sediment-inventory network of the USGS and the ODNR (Ohio Department of Natural Resources). Table 2 and figure 6 show the stream sites sampled as part of these projects.

Sample collection and analysis

Data were aggregated from eight stream sites with drainage areas ranging from 332 mi^2 to 6,330 mi^2. Daily streamflow data were available for all sites during the time periods when suspended-sediment samples were collected (table 2). The eight sites sampled include three sites on the main stem and five sites on tributary streams (fig. 6). The main stem sites are the Maumee River at New Haven, Ind., just downstream from the point where the St. Joseph River and St. Marys River join to become the Maumee River; midway along the main stem near Defiance, Ohio; and at a site representing 95.8 percent of the drainage basin, at Waterville, Ohio (fig. 6). The five other sites are on major tributaries to the Maumee River. One of five tributary sampling sites is in Indiana—the St. Joseph River near Newville, Ind. Four sampling sites are in Ohio—the Auglaize River near Defiance, the Auglaize

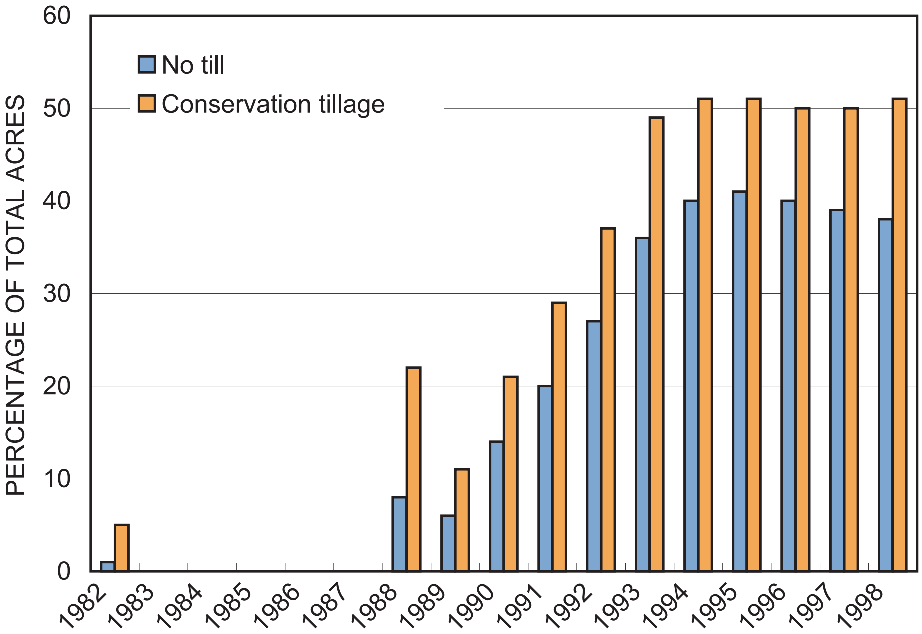


Figure 5. Trends in conservation tillage on corn and soybean fields in northwestern Ohio, 1982–98 (Ohio Lake Erie Commission, 1993; U.S. Department of Agriculture, 1998).

Table 2. Suspended-sediment sampling sites in the Maumee River Basin, 1950-98

[no., number; mi^2, square miles; DA, drainage area; S, suspended-sediment samples; B, bedload samples; P, suspended-sediment particle-size samples; BP, streambed particle size; years are water years]

Site number	Site name (no. on figure 6)	DA (mi^2)	Period of record		Type of sample S, B, P, BP	Frequency of suspended-sediment sampling
			Streamflow	Sediment		
04176500	St. Joseph River near Newville, Ind. (6)	610	1939–98	1996–98	S, BP	Weekly to monthly
04183500	Maumee River at New Haven, Ind. (7)	1,967	1956–98	1996–98	S,BP	Weekly to monthly
04185000	Tiffin River at Stryker, Ohio (3)	410	1922–28 1940–98	1970–74	S,P	Weekly to monthly
04186500	Auglaize River near Ft. Jennings, Ohio (5)	332	1921–35 1939–98	1970–74 1996–98	S,P,BP	Weekly to monthly
04189000	Blanchard River near Findlay, Ohio (8)	346	1924–35 1941–98	1970–74	S,P	Weekly to monthly
04191500	Auglaize River near Defiance, Ohio (4)	2,318	1915–98	1970–74	S,P	Daily
04192500	Maumee River near Defiance, Ohio (2)	5,545	1924–35, 1939–74, 1978–98	1997–98	S,P	Daily
04193500	Maumee River at Waterville, Ohio (1)	6,330	1898–01, 1921–35, 1939–98	1950–84 1987–98	S,P,BP	Daily

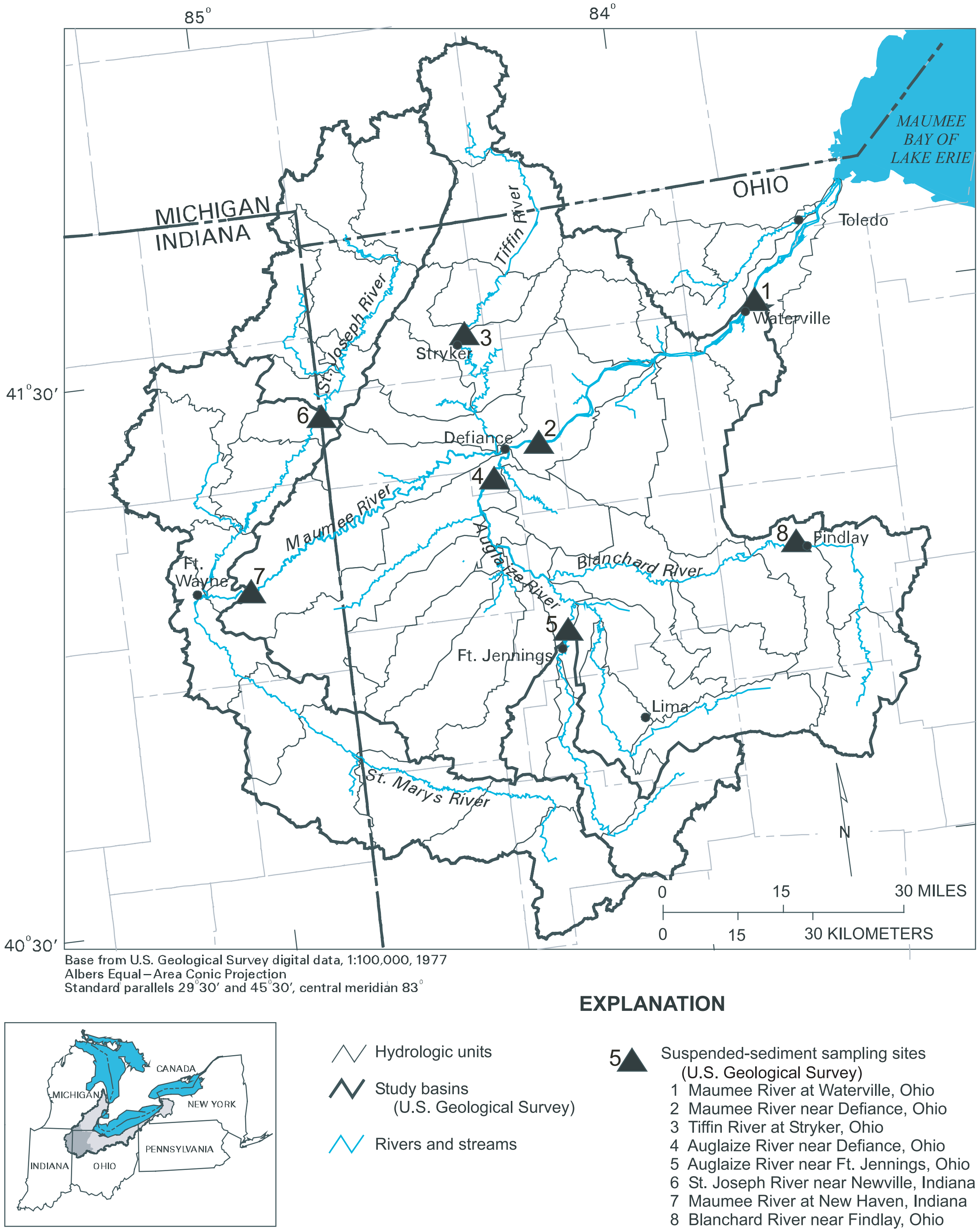
River near Ft. Jennings, the Blanchard River near Findlay, and the Tiffin River at Stryker (fig. 6). The Maumee River at Waterville is part of the long-term (1950–98) sediment data-collection network in Ohio and was also sampled from 1996–98 as part of the NAWQA Program. Data from this single site provides a unique opportunity to compare findings from two different sediment-data collection projects having different sample-collection frequencies and periods of record.

All sediment samples were collected by the USGS using methods that provided a sample that contained an average water-sediment mixture representing all suspended particles sizes in the stream cross section for the flow condition at the time of sampling (Antilla and Tobin, 1978; Edwards and Glysson, 1999; Ward and Harr, 1990; Shelton, 1994). Sample-collection methods detailed in Shelton (1994) and Edwards and Glysson (1999) were used for all sediment samples collected as part of the NAWQA Program. Suspended-sediment samples collected and analyzed by other USGS programs used equivalent collection methods.

Analyses of samples for suspended-sediment concentration were done at the Heidelberg College Water-Quality Laboratory for samples collected from 1988–98. Samples collected prior to 1988 were analyzed at the USGS's Ohio District sediment laboratory. Analysis of suspended-sediment concentration was done at both laboratories using the methods described in Guy (1969).

Computation of suspended-sediment discharge

Suspended-sediment discharge, Qs, is the time rate at which the dry weight of suspended-sediment passes a section of a stream (Antilla and Tobin, 1978). Suspended-sediment load is a term often used synonymously with suspended-sediment discharge and their meaning is considered equivalent for this report. Values for Qs can be reported as instantaneous, daily, monthly, seasonal, or annual. The exact method used for computing daily suspended-sediment discharge for this report depended on the sampling frequency. For daily-record stations, daily suspended-sediment discharge was computed by multiplying the instantaneous suspended-sediment concentration by the daily streamflow and a conversion factor to convert milligrams per liter per second to tons per day (Porterfield, 1972). Where suspended-sediment samples were collected at weekly to monthly frequencies,



Base from U.S. Geological Survey digital data, 1:100,000, 1977
Albers Equal–Area Conic Projection
Standard parallels 29°30′ and 45°30′, central meridian 83°

Figure 6. Suspended-sediment sampling sites in the Maumee River Basin, 1950–98.

suspended-sediment discharges were computed using a regression-based, multi-parameter statistical model (Cohn and others, 1989; Crawford, 1991). The model, LOADEST2 (Crawford, 1996), constructs a suspended-sediment transport curve based on coefficients developed from a multiple regression model with three or more parameters. The calibration data set consists of natural log-transformed values for instantaneous or daily streamflow in cubic feet per second, the natural log-transformed values for instantaneous suspended-sediment concentration in milligrams per liter, and decimal time.

The regression coefficients from the calibration data set for slope, intercept, season, and time are used to construct the model that predicts daily suspended-sediment discharge from daily streamflow. The model used for this report was developed from the MLE (maximum likelihood estimate) method. Results are reported in tons per day and can be summed to provide annual and seasonal values. The model output also provides standard deviations for the average daily suspended-sediment discharge for the year and average seasonal daily suspended-sediment discharges for spring, summer, fall, and winter. Summary statistics are provided for minimum, maximum, and the following percentiles: 25th, 50th, 75th, 90th, 95th, and 99th. A more detailed description of the use of LOADEST2 is given in the appendix to this report.

Computation of suspended-sediment budget

A suspended-sediment budget for the Maumee River Basin was constructed to express the percentage of average annual suspended-sediment discharge (in tons per year) contributed from sites in subbasins upstream from the Maumee River at Waterville, Ohio. Annual suspended-sediment discharges were computed using estimates from available data at eight sites (table 2); five sites sampled from 1996–98 and three sites sampled from 1970–74. Two of the three sites for which only retrospective data were used, contributed only a small percentage of the annual discharge relative to the sites monitored from 1996–98. The percentage of the annual suspended-sediment discharge from areas upstream from the Maumee River at Waterville were computed by dividing each into the suspended-sediment discharge for the Maumee River at Waterville and multiplying by 100 to provide the percent of total. The suspended-sediment discharge at Waterville is assumed to represent 100 percent of the drainage area of the basin for purposes of this report. In reality, the site at Waterville represents 95.8 percent of the total drainage area of the Maumee River Basin.

To obtain average annual suspended-sediment discharge estimates for sites with no data, retrospective data (1970–74) and (or) recent data (1996–98) were used, and extrapolations were made to the ungaged sites. Where data were available for an upstream site but not for the most downstream site of the subbasin, suspended-sediment discharge was estimated for the downstream unmeasured site by multiplying the average annual yield in tons per square mile per year from the upstream site by the drainage area for the downstream site. Because suspended-sediment yield usually decreases with increasing drainage area, a ratio of either the drainage areas or the yields was used as a correction factor where possible. Retrospective data were used only in the absence of recent data. If both periods of data were available, a comparison was made to evaluate the similarity of sediment yield from the retrospective period to the recent period and from upstream to downstream sites. Land use (fig. 4) and other basin characteristics, such as soils and slopes, are similar in areas where extrapolations were made.

For the Auglaize River, the annual suspended-sediment discharge near Defiance for 1996–98 was estimated from data obtained at the upstream site near Ft. Jennings from 1996–98 and from retrospective data collected from 1970–74 at both sites. The average annual yields of suspended sediment for both sites reported by Antilla and Tobin (1978) were compared to the average annual yield computed for the Auglaize River near Ft. Jennings for 1996–98. Historically, the yield computed for the Auglaize River near Ft. Jennings, Ohio was 236 ton/mi^2, and the yield computed for the Auglaize River near Defiance, Ohio was 216 ton/mi^2 (Antilla and Tobin, 1978). The ratio of the two yields, 0.915, was used as the correction factor to compute the annual suspended-sediment discharge for the Defiance site based on 1996–98 data from the Ft. Jennings site. The corrected average annual yield estimated for the Auglaize River near Defiance was multiplied by the drainage area of the Auglaize River near Defiance, Ohio to provide the annual suspended-sediment discharge for the subbasin. For the St. Joseph River, only recent average annual yield estimates were available. The suspended-sediment discharge for the St. Joseph River at Ft. Wayne, Ind. was estimated by multiplying the yield computed for the St. Joseph River near Newville, Ind. by the drainage area near the mouth at the Ft. Wayne streamflow gaging station. The estimate for the St. Marys River and the Maumee River upstream from New Haven, Ind. was made by subtracting the value for the St. Joseph River from the value for the Maumee River at New Haven. Average annual sediment yield from the 1970–74 data set was the only retrospective data relied on entirely and was substituted in the sediment budget for the Tiffin River at Stryker. Data from the Blanchard River near Findlay, Ohio was not used for the computation of suspended-sediment budgets although yield estimates for the Blanchard River were compared to other sites in the Auglaize River Basin.

Crops, conservation tillage, and soil loss data

Agricultural data on crops, conservation-tillage practices, and soil-erosion rates were obtained from tillage transect surveys compiled for northwestern Ohio and northeastern Indiana for 1996–98 and for the Michigan portion of the St. Joseph River Basin for 1998. The Tillage Transect Survey is a data base developed by the CTIC (Conservation Technology Information Center) at Purdue University (Hess, 1996). Tillage Transect Survey is a computerized tracking system used by the NRCS to record various types of agricultural data. Tillage transect data are collected at approximately 400 agricultural fields per county using a random-selection method. Field surveys of crop types, land-management practices, soils, slopes, and other surface attributes are made from roadsides. Experienced NRCS district conservationists who collect these data provide user confidence in the quality of the data base. Data are scanned into a relational data base and can be retrieved by county or by 11-digit hydrologic unit, which is equivalent to a part of a watershed. Survey data in tillage transect files represent only agricultural land uses and do not include other land uses.

From 1996–98, there were different levels of county participation in completing the tillage transect forms. In 1996–97, data files for 46 of 49 11-digit hydrologic units in the Maumee River Basin contained data on crops, tillage practices, and soil-erosion rates. In 1998, fewer counties participated. For this report, data from 1996–97 were used except when not available, as was the case for the Michigan section of the St. Joseph River Basin for which 1998 data were used. Data for crops, tillage practices, and soil-erosion rates were retrieved from tillage transect files by 11-digit hydrologic unit. Maps showing the percentage of fields in conservation tillage and soil-loss by 11-digit hydrologic units were constructed by overlaying these data on areas of mapped agricultural land use for the Maumee River Basin.

Soil-erosion rate is the unit area soil loss, expressed in tons per acre or tons per square mile. Soil-erosion rates are computed in the tillage transect program by use of the USLE (Universal Soil Loss Equation) (Wischmeier and Smith, 1978). The USLE can be used to predict the average rate of soil erosion for each combination of crop system and management practices in association with a specified soil type, rainfall pattern, and topography (Wischmeier and Smith, 1978). As such, soil-erosion rate is an average value based on factors that are set in the USLE. Some factors, such as soil type and drainage class, change little from year to year, but others, such as land use, cropping system, and management practices, can be changed by market forces and weather patterns from year to year.

Soil loss, in tons per year, is computed by multiplying the average soil-erosion rate for each 11-digit hydrologic unit for each year by the area of each 11-digit hydrologic unit. Soil loss by 11-digit hydrologic unit was further averaged for 1996–97. Soil loss represents only that eroded from the land surface as sheet and rill erosion and does not include erosion from stream banks or channels. Bank and channel erosion are thought to contribute only about 1 percent per year to the suspended-sediment discharge of the Maumee River Basin (U.S. Department of Agriculture, 1993). Soil loss from the land surface, or wash load, is useful for comparing the values in this report to those reported by other investigators (Logan, 1978; Baker, 1982). Soil-erosion rates from cropland in the Maumee River Basin reported in the tillage transect files range from less than 1.0 to 5.0 ton/acre.

The tillage transect files do not contain soil-erosion rates for land cover other than agricultural land. A value of 0.03 ton/acre is a typical estimate of soil loss from forested land, which is the second most common type of land cover in the Maumee River Basin. The value, 0.03, is mid-range between the values reported for soil-erosion rates on forested land in general, which range from 0.001 to 0.06 ton/acre (Kimberlin and Moldenhauer, 1977). Forested land contributes a minor amount soil erosion in the Maumee River Basin and was not included in the estimates reported here.

Trend analysis

Trends in suspended-sediment discharge were analyzed at two sites, the Maumee River at Waterville and the Auglaize River near Ft. Jennings. The significance level set for the trend test statistics was $\alpha=0.05$. A parametric approach was used for suspended-sediment trend analysis at both sites. Ordinary least squares regression with multiple explanatory variables was used to detect trends in daily suspended-sediment discharge for data collected from 1970–98 at the Maumee River at Waterville, Ohio. The data set of daily suspended-sediment discharges was nearly continuous with missing data only from 1984–87. The multiple-regression model used to test for trends at the Maumee River at Waterville specified streamflow, season, and time as explanatory variables. Serial correlation of the residuals with time was corrected by using the auto-correlated errors procedures, AUTOREG, in SAS (Helsel and Hirsch, 1992, p. 250-253). Afterwards, the regression model was checked for adequacy, that is (1) a linear form of the relation between suspended-sediment discharge and time, (2) normality, homoscedasticity and independence of residuals, and (3) slope and other coefficients that are significantly different from zero (Helsel and Hirsch, 1992). The results from the trend test for the Maumee River at Waterville were plotted as a time series of regression residual values corrected for streamflow and season. Results were smoothed using LOWESS (Locally Weighted Scatterplot Smoothing) (Cleveland, 1979) with a smoothing factor of 0.6 to show the trend over time in the residuals of daily suspended-sediment discharge.

For the Auglaize River near Ft. Jennings, Ohio, a two-sample step-trend test was done using ANCOVA (analysis of covariance) to compare estimates of observed daily suspended-sediment discharge for 1970–74 to 1996–98 (Helsel and Hirsch, 1992, p. 348-351). Step-trend procedures such as ANCOVA are recommended when the time periods to be compared are broken-up by a relatively long time interval (Helsel and Hirsch, 1992, p. 349). For the Auglaize River near Ft. Jennings, there is a 23-year lapse between the periods of data collection.

The ANCOVA for the Auglaize River near Ft. Jennings was used to compare the two data sets of instantaneous suspended-sediment discharge, streamflow, and season (1970–74 and 1996–98). These data sets were the same calibration data sets used in LOADEST2 to predict daily suspended-sediment discharge. An indicator variable was used to discriminate between the 48 values of instantaneous suspended-sediment discharge from samples collected from 1996–98 from the combined data set of 88 instantaneous values (1970–74 and 1996–98). The ANCOVA tested whether the instantaneous suspended-sediment discharge from the combined data set was significantly different from the more recent data set (1996–98). The test result is based on the probability value associated with the indicator variable comparing the data sets from the two time periods. To determine the amount and percent change over time in suspended-sediment discharge for the Auglaize River near Ft. Jennings, annual suspended-sediment discharges were computed using a set of daily streamflow values for 1997 and the two suspended-sediment rating curves generated from LOADEST2, one for 1970–74, and the other for 1996–98.

Relation of suspended-sediment discharges and yields to soil loss, soil-erosion rates, delivery ratios, and conservation tillage

Soil loss (erosion) and sedimentation by water primarily involve the processes of detachment, transport, and deposition of sediment from raindrop impact and flowing water. In turn, these processes are affected by drainage area size, slope, soil drainage, and vegetative cover that determine the proportion of sediment that is delivered to waterways. The proportion of the export of these materials from the land surface out of the drainage basin (delivery ratio) and the unit area discharge of suspended sediment (yield) are measures that can be used to identify areas of proportionately greater suspended-sediment discharge. In the Maumee River Basin, soil losses are usually less than the tolerable amount (from 2–4 ton/acre). Suspended-sediment discharges from the basin are considered high even though soil loss is low because of the relatively large size of the drainage area.

Suspended-sediment discharge and yield

The annual and seasonal mean daily values for suspended-sediment discharge, the standard deviation of the mean daily values, data-collection period, drainage area, number of samples, and LOADEST2 model coefficients, are shown in table 3 for the five sites sampled from 1996–98. Because suspended-sediment discharges from daily record stations on the Maumee

River near Defiance and at Waterville were used in the data analysis, these results are compared to the LOADEST2 estimates to examine differences in sampling frequency (table 3). Retrospective data (1970–74) and combined data (1970–74 and 1996–98) for the Auglaize River near Ft. Jennings are also shown in table 3.

Annual and seasonal mean daily values for suspended-sediment discharge increase with increasing drainage area, although values for the St. Joseph River are smaller than those for the Auglaize River near Ft. Jennings even though the drainage area contributing suspended sediment to the St. Joseph River is almost twice as large. In general, the highest mean daily suspended-sediment discharges are in the spring, followed by summer, winter, and fall. One exception is the Auglaize River, where the highest mean daily values are in summer. This pattern, which is evident in both data sets (1970–74 and 1996–98) was unexpected, and its cause is not known. The standard deviations of the mean daily values were about 20 percent of the mean but ranged from about 3.3 to 45 percent of the mean. Standard deviations of mean daily suspended-sediment discharge are useful to assess the uncertainty of estimates and to compare differences among sites and among seasons at the same site.

It is possible to compare estimates of suspended-sediment discharge computed using LOADEST2 to those generated from daily record because both types of estimates are available for the Maumee River near Defiance and at Waterville. For these two main stem sites, LOADEST2 provided somewhat higher estimates of mean daily suspended-sediment discharge than did a daily value summed for each year and averaged. For the main stem near Defiance, the two estimates fell within 2 standard deviations of each other. For Waterville, the daily value estimate fell more than 2 standard deviations below the LOADEST2 estimate. It is assumed that the daily value would be more representative of the suspended-sediment discharge than the modeled value. This comparison provides some measure of the uncertainty of using rating-curve models to estimate annual suspended-sediment discharges from data collected at weekly to monthly sampling frequencies.

Average and annual suspended-sediment discharges and yields are compared for the Maumee River Basin at the five sites sampled from 1996–98 (table 4). Annual variations in these measures are

Table 3. Site name, data-collection period, drainage area, model coefficients, annual and seasonal mean daily suspended-sediment discharges

[DA, drainage area; mi^2, square mile; β_o, y-intercept; β_1, β_2 slope coefficients; β_3,β_4, seasonal coefficients; β_5, decimal time coefficient; ln, natural logarithm; *n*, sample size; d, day; nc, not computed; --, term not needed in model]

Site name	Data-collection period	DA (mi^2)	Model coefficients							Annual and seasonal average daily suspended-sediment discharge (and standard deviation), in tons per day				
			β_o	β_1	β_2	β_3	β_4	β_5	*n*	Annual	Spring	Summer	Fall	Winter
St. Joseph River near Newville, Ind.	1996–98	610	1.8824	1.6013	--	-0.2871	-0.7446	--	52	200 (20)	260 (33)	230 (15)	62 (28)	140 (30)
Maumee River at New Haven, Ind.	1996–98	1,967	0.82875	1.6942	--	-.22997	-.52227	--	32	1,100 (130)	5,600 (210)	1,300 (210)	240 (71)	880 (140)
Auglaize River near Ft. Jennings, Ohio	1970–74	332	5.8162	0.5450	0.0919	-.5572	-.9715	--	40	540 (150)	230 (36)	1,700 (520)	10 (2)	220 (51)
	1996–98		2.6661	1.5797	--	-.41961	-.93885	--	48	260 (52)	160 (29)	740 (160)	7 (1)	130 (35)
Maumee River at Defiance, Ohio	1997–98 LOADEST2	5,545	1828.8	0.63172	.07351	-.46255	-.22506	-0.9135	299	6,100 (430)	9,100 (740)	5,500 (670)	1,100 (80)	8,400 (410)
	Daily value								730	5,370				
Maumee River at Waterville, Ohio	1996–98 LOADEST2	6,330	219.25	.23102	.08200	-.25508	-.22267	-1.0944	294	6,300 (590)	10,700 (1,000)	5,000 (1,000)	1,000 (54)	8,300 (450)
	Daily value								1,096	4,960				

related to natural factors such as drainage area, rainfall, soil erosion driven by runoff, soil drainage and runoff potential, crop type, cover, and conservation tillage practices. Annual and average annual suspended-sediment discharge increased with drainage area, although not proportionately (table 4). Average annual suspended-sediment discharge for the period 1996–98 ranged from 71,800 ton/yr for the St. Joseph River near Newville to 1,960,000 ton/yr for the Maumee River at Defiance (table 4). The Auglaize River near Ft. Jennings discharged an average of 88,900 ton/yr of suspended sediment from 1996–98, 1.2 times that of the St. Joseph River near Newville for the same time period even though the drainage area contributing to the Auglaize River near Ft. Jennings is just 54.4 percent the size of the drainage area contributing to the St. Joseph River near Newville (table 4).

The unit discharge (yield) of suspended sediment, measured in tons per square mile per year for the sites sampled from 1996–98, ranged from 118 ton/mi^2/yr for the St. Joseph River near Newville to 354 ton/mi^2/yr for the Maumee River near Defiance, Ohio (table 4). The average yields from the tributaries and the main stem differ considerably, with the highest average annual tributary yields coming from the Auglaize River near Ft. Jennings, which drains relatively fine textured and very poorly drained soils with low permeability and high runoff potential. The greatest annual and average annual yields of suspended-sediment in the Maumee River Basin reported by Logan (1977; 1978, p. 79) were also in areas with the finest textured soils. When normalized against streamflow, instantaneous suspended-sediment yields, unlike annual yields, decrease with increasing drainage area for the Auglaize River near Ft. Jennings, St. Joseph River near Newville, Maumee River at New Haven, and Maumee River at Waterville (fig. 7).

Soil loss, soil-erosion rates, conservation tillage, and delivery ratios

Soil loss from the land surface, in tons per year, is greatest in the similarly sized hydrologic units at the outer edges of the Maumee River Basin where stream

Table 4. Soil loss, soil loss as a percentage of the total at Waterville, Ohio, suspended-sediment discharge, soil-erosion rates, and delivery ratios for selected sites in the Maumee River Basin; 1996–98

[t/mi^2/yr, tons per square mile per year; DR, Delivery Ratio; mi^2, square mile; avg, average; nd, no data]

Site name (Drainage area in mi^2)	Water year	(1) Total soil loss (tons)	Soil loss as a percentage of total at Waterville, Ohio	Soil erosion rate (ton/mi^2)	(2) Suspended-sediment discharge (tons)	Annual yield (ton/mi^2/yr)	Delivery ratio (2/1)
St. Joseph River near Newville, Indiana (610)	1996	977,000	19.0		91,300	150	0.093
	1997	995,000	18.5		54,800	89.8	0.055
	1998	919,000	nd		69,400	114	0.076
	avg	964,000	18.4	1,580	71,800	118	0.074
Maumee River at New Haven, Indiana (1,967)	1996	2,470,000	48.1		402,000	204	0.163
	1997	2,680,000	49.8		438,000	223	0.164
	1998	nd	nd		365,000	186	nd
	avg	2,580,000	49.0	1,310	402,000	205	0.156
Auglaize River near Ft. Jennings, Ohio (332)	1996	244,000	4.75		91,300	275	0.374
	1997	285,000	5.30		102,000	308	0.359
	1998	nd	nd		73,000	220	nd
	avg	264,000	5.02	795	88,900	268	0.337
Maumee River near Defiance, Ohio (5,545)	1996	4,510,000	87.7		nd	nd	nd
	1997	5,020,000	93.3		2,350,000	424	0.468
	1998	nd	nd		1,570,000	283	nd
	avg	4,760,000	90.5	858	1,960,000	354	0.412
Maumee River at Waterville, Ohio (6,330)	1996	5,140,000	100		1,360,000	215	0.265
	1997	5,380,000	100		2,070,000	327	0.385
	1998	nd	nd		1,990,000	314	nd
	avg	5,260,000	100	831	1,810,000	285	0.344

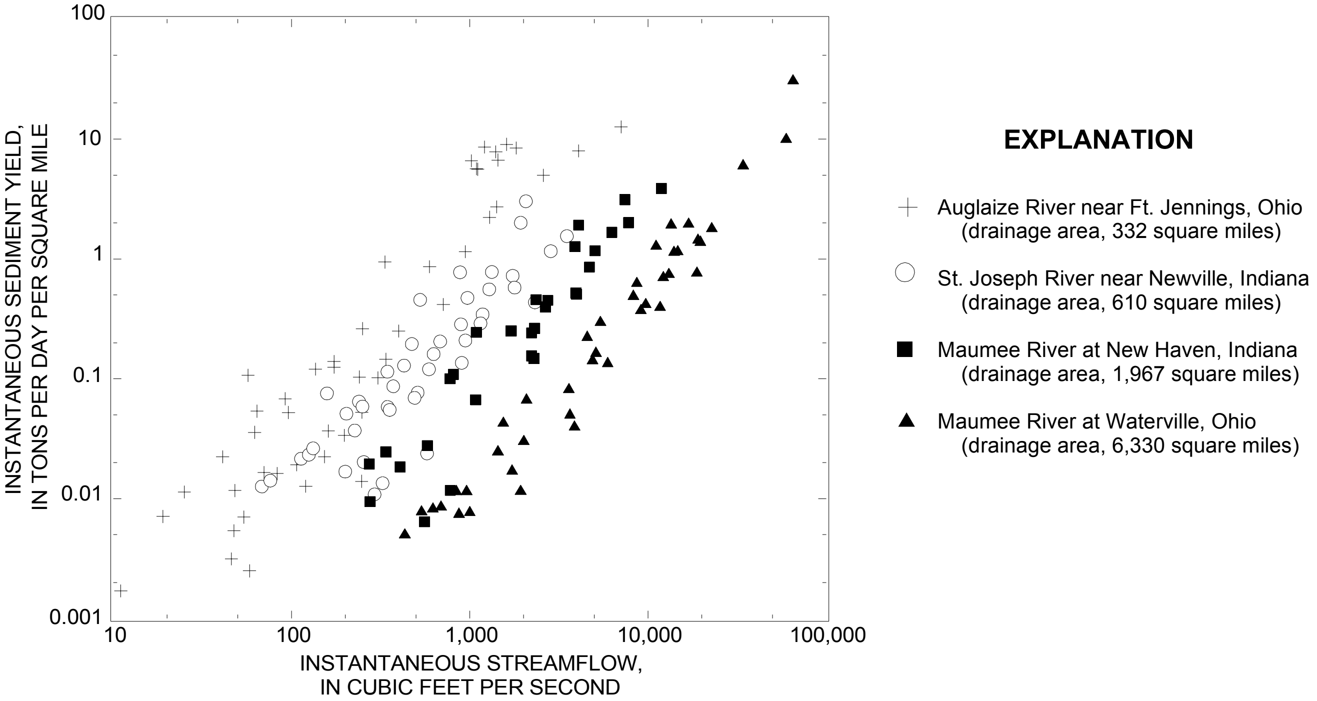
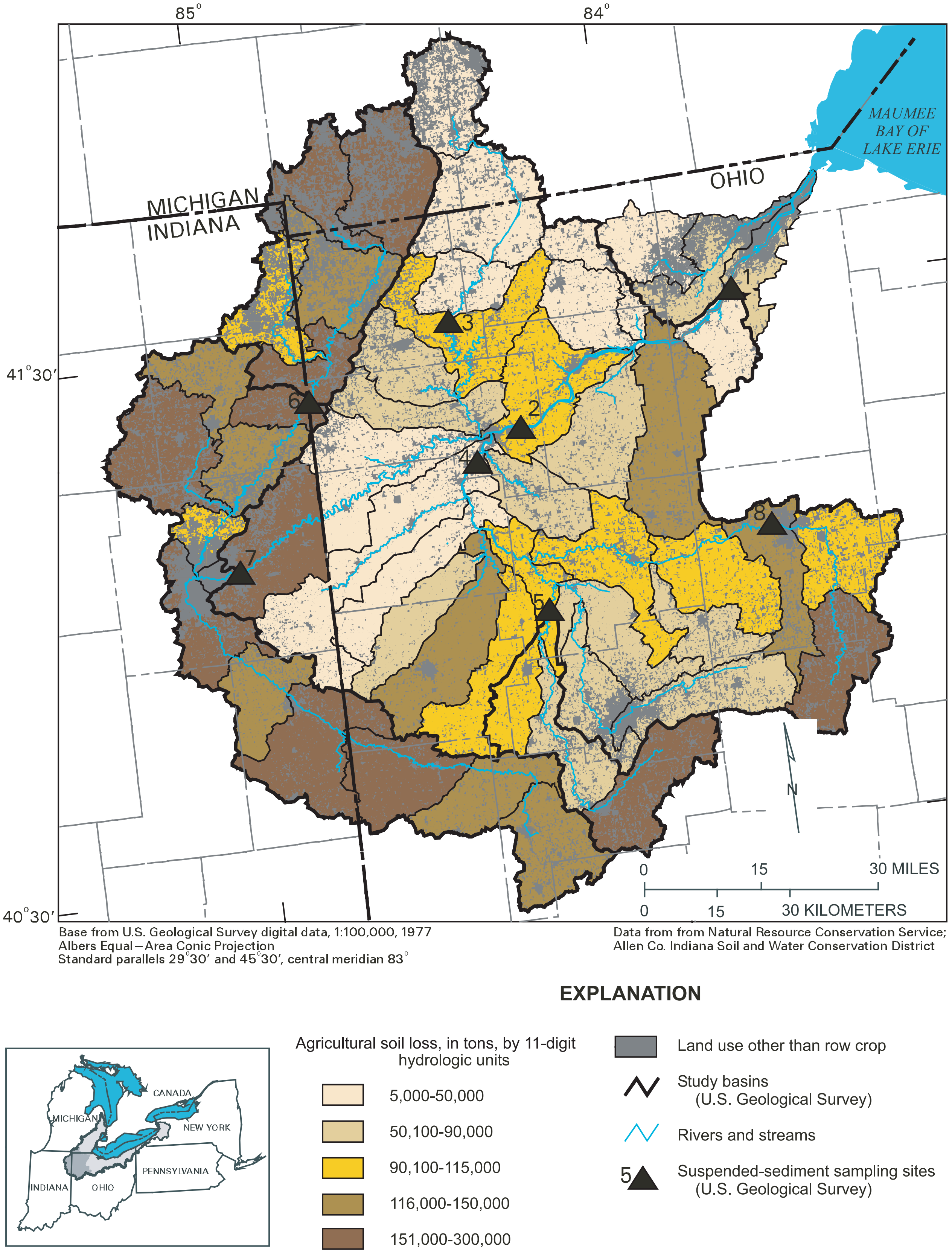


Figure 7. Relation between instantaneous suspended-sediment yield and instantaneous streamflow at selected sites in the Maumee River Basin, 1996–98

slope is the greatest (fig. 8). In comparison, soil loss is much lower in the hydrologic units in the relatively flat center of the basin (fig. 8). Like suspended-sediment discharge, soil loss increases in a downstream direction as drainage area increases at monitored sites (table 4). From 1996–98, soil loss ranged from an average of 264,000 ton/yr in the smallest monitored basin, the Auglaize River near Ft. Jennings, to an average of 5,260,000 ton/yr for the Maumee River at Waterville, the largest monitored basin (table 4). Unlike soil loss, which increased in a downstream direction, average soil-erosion rates from 1996–98 differed from basin to basin with the highest rates in the St. Joseph River near Newville at 1,580 ton/mi^2; followed by the Maumee River at New Haven at 1,310 ton/mi^2; the Maumee River near Defiance at 858 ton/mi^2; the Maumee River at Waterville at 831 ton/mi^2, and the Auglaize River near Ft. Jennings at 795 ton/mi^2.

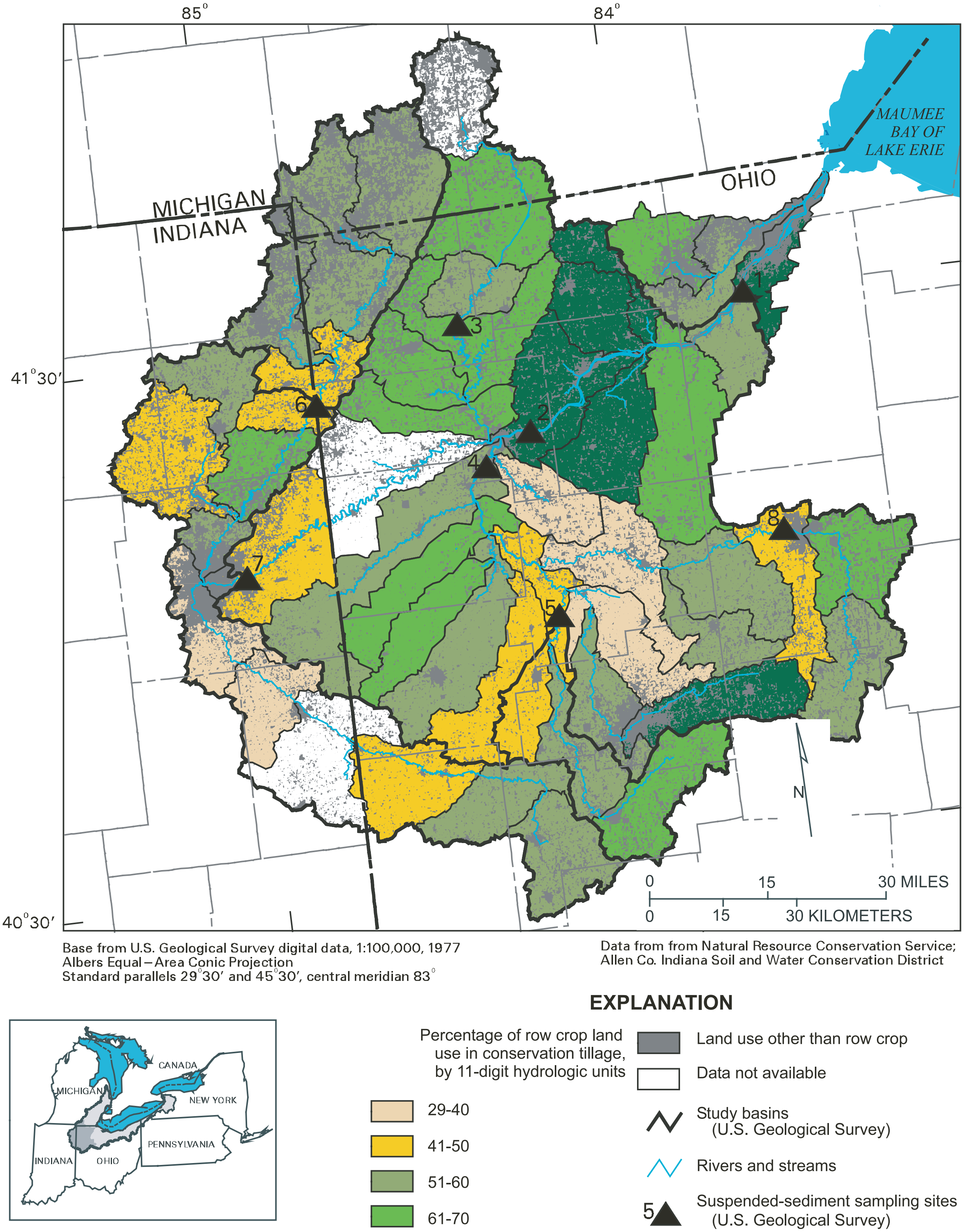
Because soil loss is determined, in part, by land cover and crop residue, conservation tillage patterns for 1996–98 were mapped for the 11-digit hydrologic units in the Maumee River Basin to determine where the greatest amounts of conservation tillage were being used (fig. 9). Cover and cropping practices, which can cause relatively large annual variations in soil loss, remained largely the same from 1996–97. The percentage of fields in conservation tillage was highest in small subbasins of the main stem downstream from Defiance, in the Tiffin River Basin, and in the St. Joseph River Basin. Comparing figures 8 and 9, the percentage of fields in conservation tillage was somewhat lower in the hydrologic units draining to the main stem between New Haven and Defiance where soil loss also was lower relative to the rest of the basin. Conservation tillage was relatively higher in some areas with higher soil loss such as the St. Joseph River Basin and relatively lower in some areas with high soil loss such as the St. Marys River Basin and Auglaize River Basin (figs. 8 and 9).

Typically, not all eroded soil leaves the basin or even the field where it originates. The DR (Delivery Ratio) is the fraction of soil loss that leaves the basin by stream transport. The DR is computed by dividing suspended-sediment discharge in tons per year by soil loss in tons per year. For this report, only the suspended fraction of sediment discharge was used to compute DRs. Bed load also contributes to sediment.


Base from U.S. Geological Survey digital data, 1:100,000, 1977
Albers Equal–Area Conic Projection
Standard parallels 29°30′ and 45°30′, central meridian 83°

Data from from Natural Resource Conservation Service;
Allen Co. Indiana Soil and Water Conservation District

Figure 8. Soil loss in the Maumee River Basin by hydrologic unit, 1996-98.



Base from U.S. Geological Survey digital data, 1:100,000, 1977
Albers Equal–Area Conic Projection
Standard parallels 29°30′ and 45°30′, central meridian 83°

Data from from Natural Resource Conservation Service;
Allen Co. Indiana Soil and Water Conservation District

Figure 9. Percentage of fields in conservation tillage in the Maumee River Basin by hydrologic unit, 1996-98.

discharge, but detailed information of this type is not available for the Maumee River or its tributaries. Values for suspended-sediment DRs range from 0 to 1.0. A delivery ratio of 0 indicates complete retention of soil loss in a basin with no transport as sediment discharge. A delivery ratio of 1.0 indicates that all soil loss is transported from a basin as sediment discharge.

The average annual DRs at the five sites measured from 1996–98 (table 4) ranged by a factor of 5.6; from 0.074 at the St. Joseph River near Newville to 0.412 at the Maumee River near Defiance (table 4). The DRs reported herein for the Auglaize River near Ft. Jennings and the St. Joseph River near Newville are similar to those reported by Logan (1978, p. 79). Logan (1978) reported DRs from small subbasins containing very poorly drained soils that ranged from 0.217 to 0.619 and DRs from subbasins containing moderately well-drained to somewhat poorly drained soils that ranged from 0.063 to 0.161. The long-term average DR reported for the Maumee River at Waterville by NRCS in the late 1980s was 0.12 (U.S. Department of Agriculture, 1993). The Great Lakes Basin Commission (reported by Logan, 1978) estimated an average DR for the Maumee River at Waterville of 0.149. The average DR computed for the Maumee River at Waterville in this report, 0.344, is about three times higher than the long-term DRs reported by Baker (1982) and U.S. Department of Agriculture (1993, p. 3). Although DRs reported by Baker (1982) and USDA (1993) are long-term averages, the DRs reported in this study were computed from samples collected during two relatively wet years and so might be expected to be higher than a long-term average. Delivery ratios reported for rivers in the United States range from 0.03 to 0.95 (Holeman, 1968). Delivery ratios reported for the Maumee River appear to be low to mid-range compared to rivers of the nation and world (Holeman, 1968; Trimble, 1975).

The findings in this report suggest that the highest DRs and yields are associated with subbasins in the Maumee River with the lowest soil-erosion rates. These are areas of fine-textured, poorly drained soils with high runoff potential. These areas of fine-textured soils were not necessarily the same areas where conservation tillage was used in the highest percentages (figs. 8 and 9). These findings further suggest that the poorly drained soils with high runoff potential are more readily exported from subbasins and do not accumulate in the watershed to the same degree as coarse-grained particles. Because of their smaller size, fine particles can be transported for longer periods of time and greater distances than coarse-grained particles. In addition, these areas of very fine-textured soils may be the most important areas to control in terms of reducing the amount of sediment dredged from the lower Maumee River. These findings are consistent with those reported by other investigators (Jones and others, 1977; Logan, 1978; Beasely, 1985) about the importance of areas of fine-textured, poorly drained soils with high runoff potential to suspended-sediment discharge.

Suspended-sediment budget

Suspended-sediment budgets can be useful for sediment management and control in the Maumee River Basin by helping to further identify areas that discharge the greatest amounts of suspended sediment. A question that can be answered through use of a sediment budget is which subbasins or segments of the main stem contribute the greatest amounts of suspended sediment to the downstream end of the basin at Waterville?

Results of the suspended-sediment discharge computations and sediment budget for 1996–98 (table 5, fig. 10) indicate that average annual suspended-sediment discharges in the Maumee River main stem increased from 402,000 ton/yr at New Haven, Ind., to 1,960,000 ton/yr at Defiance, Ohio and then decreased to 1,810,000 ton/yr at Waterville, Ohio. Expressed as percentage of the total suspended sediment measured at Waterville, Ohio, 22.2 percent of the total passes through the main stem at New Haven and 108 percent of the total passes through the main stem near Defiance, Ohio (table 5, fig. 10). The small difference, 8 percent, between the main stem sites at Waterville and near Defiance is likely within the precision of the load-estimation method.

The estimated amount of sediment discharged from the major tributaries for 1996–98 was 565,000 ton/yr from the Auglaize River, 277,000 ton/yr from the St. Marys River and the portion of the main stem that flowed past New Haven, Ind.; 125,000 ton/yr from the St. Joseph River; and 43,500 ton/yr from the Tiffin River (table 5). Expressed as a percentage of the total measured at Waterville, Ohio; 31.2 percent was discharged from the Auglaize River; 15.3 percent was discharged from the St. Marys River and flowed past New Haven, Ind.; 6.91 percent was discharged from

Table 5. Drainage area, average annual streamflow, and suspended-sediment discharge at selected sites in the Maumee River Basin, expressed as a percentage of the total at Waterville, Ohio, 1996–98

[ft^3/s, cubic feet per second; ton/yr, tons per year; mi^2, square mile]

Site name (time period of data collection)	Mean annual streamflow; 1996–98 (ft^3/s)	Percentage of average annual streamflow at Waterville, Ohio 1996-98	Average annual suspended-sediment discharge (ton/yr)	Percentage of average annual suspended-sediment discharge at Waterville, Ohio	Drainage area (mi^2)
Tiffin River at Stryker, Ohio (1970–74)	458	6.62	23,000	1.27	410
Tiffin River Basin, Michigan and Ohio	869	12.6	43,500	2.40	777
St. Joseph River near Newville, Ind. (1996–98)	678	9.80	71,800	3.97	610
St. Joseph River at Ft. Wayne, Ind.	1,250	18.1	125,000	6.91	1,060
St. Marys River and Maumee River between Ft. Wayne and New Haven, Ind. (1996–98)	1,140	16.5	277,000	15.3	762
Auglaize River near Ft. Jennings, Ohio (1996–98)	367	5.30	88,900	4.91	332
Auglaize River near Defiance, Ohio (1970–74)	2,560	37.0	565,000	31.2	2,318
Maumee River from New Haven to Defiance, Ohio	295	4.26	954,000	52.7	483
Maumee River from Defiance to Waterville, Ohio	796	11.5	(150,000)[a]	-8.29	785
Maumee River at New Haven, Ind. (1996–98)	2,390	34.5	402,000	22.2	1,967
Maumee River near Defiance, Ohio (1997–98)	6,120	88.4	1,960,000	108	5,545
Maumee River at Waterville, Ohio (1996–98)	6,920	100	1,810,000	100	6,330

[a] Suspended-sediment discharge at upstream site is higher than at downstream site.

the St. Joseph River; and 2.40 percent was discharged from the Tiffin River (table 5, fig. 10).

The average amount of suspended-sediment discharged from the Auglaize, the St. Joseph, the St. Marys, and the Tiffin Rivers; the four largest tributaries to the Maumee River, is estimated to be about 1,010,000 tons; 950,000 tons less than the 1,960,000 tons measured at the downstream site on the main stem near Defiance, Ohio. The total tributary contribution was 800,000 tons less than the 1,810,000 ton/yr discharged from the main stem at Waterville. A relatively large amount of suspended sediment, 954,000 tons or 52.7 percent of the total suspended-sediment discharged at Waterville, was discharged in the main stem between New Haven, Ind., and Defiance, Ohio. This sediment discharge could not be attributed to the four major tributaries—the Auglaize, St. Joseph, St. Marys, or Tiffin Rivers—but is attributed to a small drainage area of the main stem of only 483 mi^2 between New Haven, Ind. and Defiance, Ohio (table 5, fig. 10). The suspended-sediment yield computed for this area is 1,980 ton/mi^2/yr.

Potential sources of this additional sediment could be the tributaries draining to the main stem between New Haven and Defiance and (or) sediment deposited and stored in the main stem channel, the flood plains, and ditches. These deposits would be available for resuspension during floods. Another explanation may be errors in the suspended-sediment budget resulting from the use of retrospective data to estimate tributary sediment discharge. For example, extrapolations using upstream estimates to compute

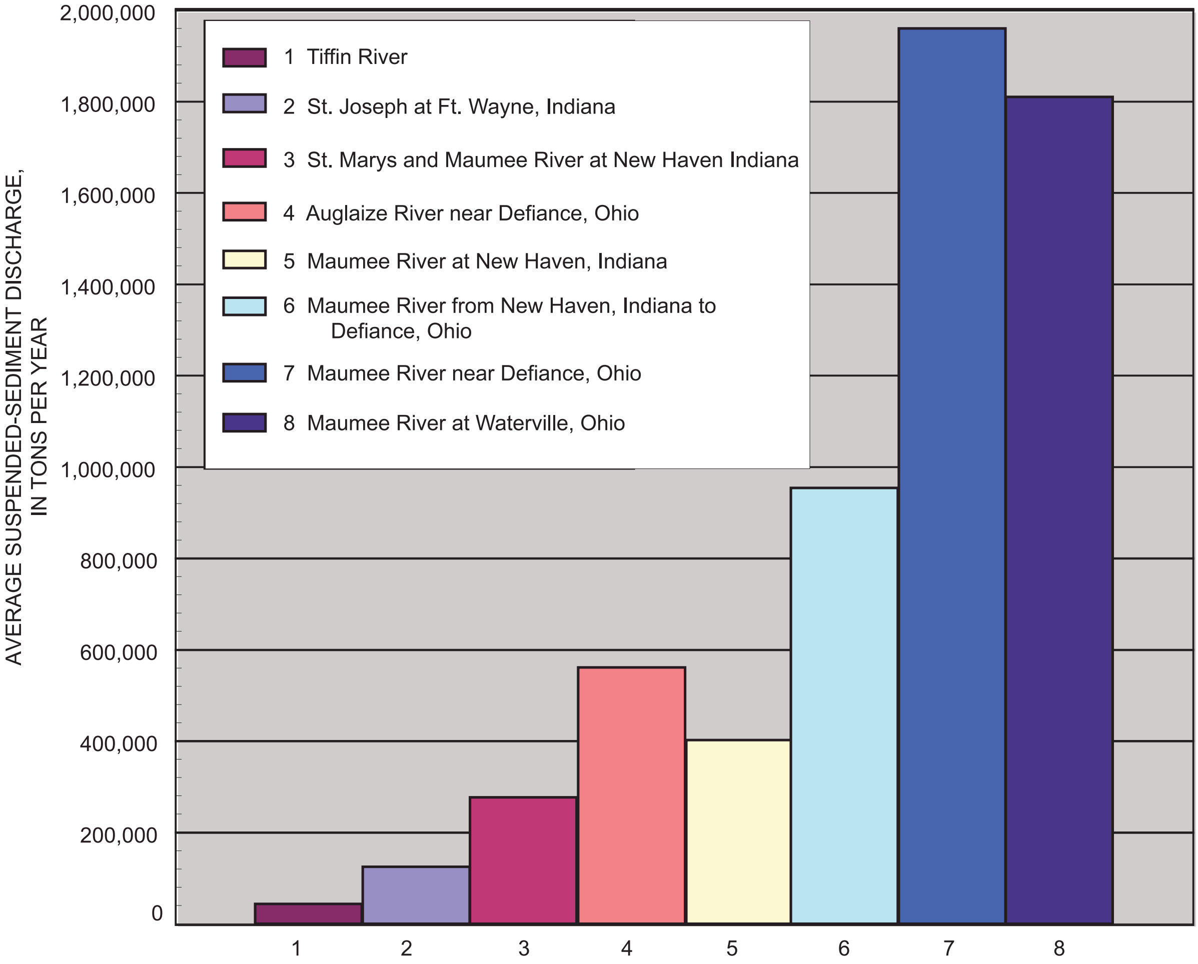


Figure 10. Suspended-sediment budget for the Maumee River Basin, 1996–98.

the suspended-sediment discharge at the downstream terminus of major tributaries could be a partial explanation for the elevated yields computed for the main stem from New Haven to Defiance. Another source of error could be the greater uncertainty arising from computations based on samples collected at a less than daily frequency at all but two main stem sites. Clearly, the estimates of the suspended-sediment budget could be improved by additional data collection at selected sites.

Trends in soil loss, conservation tillage, streamflow, and suspended-sediment discharge

The periods of time over which trends are examined in this report, 1970–98 and 1970–74 compared to 1996–98, represent periods of change in farming practices in the Maumee River Basin that may affect changes in suspended-sediment discharge. From the early 1950s to late 1970s, a combination of high commodity prices, the increased use of agricultural chemicals, and larger and more efficient farming machines led to the elimination of fence rows and a switch from a longer to a shorter crop rotation. These factors led to greater soil erosion and sedimentation in the Maumee River Basin (Logan, 1978; U.S. Department of Agriculture, 1993). Field sizes before 1950 were from 5 to 10 acres and were planted in small grains and hay. “Small fields and long rotations provided a reasonable measure of soil erosion and sediment control until the period following World War II” (U.S. Department of Agriculture, 1993). With the use of larger, more efficient farm machinery, farm size increased from 1975–95 even though the number of farms decreased (Baker and others, 1998). Comparison of estimates for the Maumee River Basin from the mid-1970s (Logan, 1978) to the mid-1990s from tillage transect data, shows a downward trend in number of acres planted in corn and small grains of 6.5 percent and 9.0 percent, respectively. Over the same period, 9.0 percent more acres were planted in soybeans. Overall, from 1975–95 total crop acres remained relatively stable (Baker and others, 1998).

Soil losses and soil erosion rates from agricultural lands in the Maumee River Basin during the 1970s, at a time when conservation tillage was not used (Logan, 1978, p. 21; Waldron, 1984, p. 24), were estimated to be about 9 million ton/yr (U.S. Department of Agriculture, 1993) or about 2.24 ton/acre on average (Baker, 1982, p. 21). Conservation tillage was used on 5 percent or less of all crop fields before 1988, on 15 to 30 percent of all crop fields from 1988–92, and on about 50 percent of all crop fields from 1993–98 (fig. 5). At an average of 1.30 ton/acre, the average soil erosion rate for the Maumee River Basin reported in this study appears to be 58 percent less than that reported in the 1970s. There would be some uncertainty in this estimated downward trend because the parameter values used in USLE estimates from the late 1970s (Baker, 1982) could not be checked against the parameter values used in the tillage transect files for 1996–98.

Changes in suspended-sediment discharges resulting from best-management practices such as conservation tillage can be difficult to detect because of the high degree of variability from year to year in precipitation, streamflow, and suspended-sediment discharge. Hydrologic factors that can affect suspended-sediment discharge are major floods and droughts. Casey and others (1997) reported the occurrence of major floods and droughts in the Lake Erie–Lake St. Clair Basin on the basis of work compiled by Paulson and others (1991) and flood and drought reports from the USGS's Michigan, Indiana, and Ohio Offices (1990–98). Major floods in Maumee River Basin between 1950–98 were in January and February 1959, in March 1978, and in March 1982. Major floods on the St. Joseph River were noted in March 1982 and on the Blanchard River in June 1981. Greater than average streamflows were recorded on the Auglaize River from 1968–87, interrupted by a mild drought from 1975–77 and in 1988. Droughts also were recorded for the Auglaize River in 1957 and statewide in southeastern Michigan, Ohio, and Indiana in 1988. This anecdotal information can be used to help interpret results of trend tests. Higher than average streamflows were noted in the Maumee River Basin during the study (1996–98).

Auglaize River near Ft. Jennings, Ohio

A highly significant downward trend in mean daily suspended-sediment discharge for the Auglaize River near Ft. Jennings (p=0.0011) was detected when suspended-sediment discharges from 1996–98 were compared to those from 1970–74. The coefficients for streamflow, season, and the indicator variable discriminating between the two data sets were all highly significant (p<0.001, table 6). The R^2 value, or coefficient of determination, was 0.936, indicating that the model accounted for most of the variation in suspended-sediment discharge (table 6). Because the indicator variable was significantly different from 0, the two data sets were judged to be significantly different

Table 6. Statistics, model coefficients, and probability values associated with trends in suspended-sediment discharge for the Auglaize River near Ft. Jennings, Ohio and Maumee River at Waterville, Ohio

[Q, streamflow terms; *n*, sample size; β_o, y-intercept; β_1, ln Q term of slope; β_2, Q^2 term of slope; β_3, seasonal coefficient for sin(2pi*decimal time); β_4, seasonal coefficient for cos(2pi*decimal time); β_5, coefficient of decimal time; ln, natural logarithm; *I*, indicator variable; *Lag 1*, coefficient of serial correlation for lag e_i-1 residuals; *Lag 2*, coefficient of serial correlation for lag e_i-2 residuals; nc, not computed; --, term not needed in model; nr, not reported]

Site name (Data- collection period)	Model statistics	*n*	Model coefficients (approximate *p-values)*									Durbin-Watson statistic
			R^2	β_o	β_1	β_3	β_4	β_5	*I*	*Lag 1*	*Lag 2*	
Auglaize River near Ft. Jennings, Ohio (1970–74 compared to 1996–98)	F-statistic 303.3 *p*=0.0001	88	0.936	3.1443 (0.0001)	1.5855 (0.0001)	-0.5400 (0.0001)	-0.9522 (0.0001)	--	-0.5079 (0.0011)	--	--	--
Maumee River at Waterville, Ohio (1970–98)	nr	9,490	.985	-3.9253 (0.3824)	1.6131 (0.0001)	-0.2557 (0.0001)	-0.4424 (0.0001)	-0.0054 (0.0174)	--	-1.0070 (0.0001)	0.1491 (0.0001)	1.9799

from each other. The sign of the indicator variable was negative, indicating that the suspended-sediment discharge computed for 1996–98 was lower than that in 1970–74.

The Kendall-tau test indicated no significant long-term trend in mean daily streamflow from 1970–98 at the USGS streamflow gage at the Auglaize River near Ft. Jennings. Box plots of streamflow comparing daily values during 1970–74 and 1996–98 show that the maximum streamflows, the flows at which most sediment is transported, were fairly similar for the two time periods. The median and range of daily streamflows were higher in the more recent time period (fig. 11). The reason for the trend in the suspended-sediment discharge, therefore, does not appear to be related to a long-term trend or large difference in mean daily streamflow even though greater than average streamflows were reported on the Auglaize River from 1996–98 and elevated streamflows were previously documented from 1968–87 (Paulson and others, 1991). The effects of streamflow on average daily suspended-sediment discharge were factored out of the ANCOVA, leaving the conclusion that if other important variables, such as streamflow, were not changing over the same period, the differences detected in suspended-sediment discharges may be the result of widespread adoption of conservation tillage. A scatterplot (fig. 12) of daily suspended-sediment discharge shows that at the same streamflows, the suspended-sediment discharge was proportionately lower in 1996–98 than in 1970–74.

Maumee River at Waterville, Ohio

Downward trends in average daily suspended-sediment discharge were detected from 1970–98 at the Maumee River at Waterville, Ohio. After the removal of serial correlation of the errors with time, the coefficients of the slope and seasonal terms (b_1–b_4) were found to be significantly different from zero (*p*= 0.0001, table 6). The coefficient for time, -0.0054 (b_5 in table 6), was significant at *p*=0.0174, indicating a long-term downward trend during 1970–98. Because the residuals of the parametric regression model, although distributed symmetrically, were not distributed normally, the nonparametric Kendall-tau

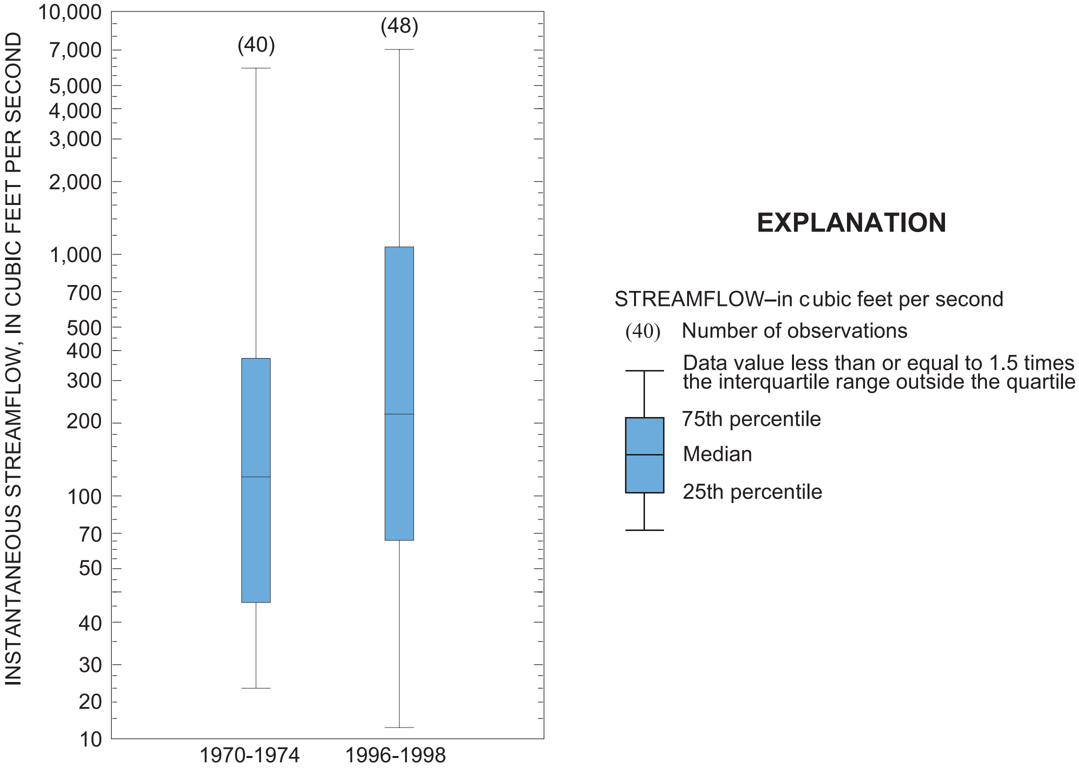


Figure 11. Instantaneous streamflow at the Auglaize River near Ft. Jennings, Ohio, 1970–74 and 1996–98.

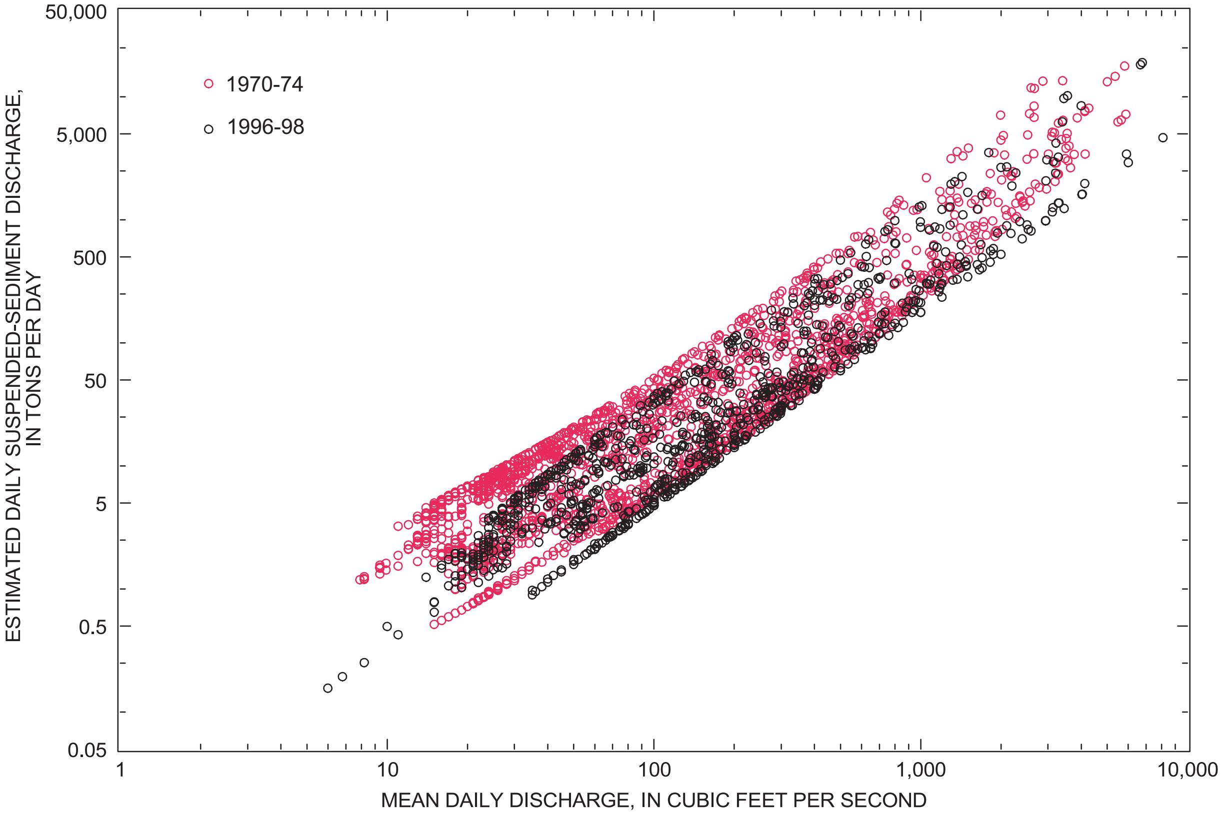


Figure 12. Estimated daily suspended-sediment discharges for the Auglaize River near Ft. Jennings, Ohio, 1970–74 and 1996–98.

test also was used to test for monotonic trends with time in suspended-sediment discharge (adjusted for streamflow, season, and serial correlation). The Kendall-tau statistic computed for the correlation between the residuals of daily suspended-sediment discharge and time was -0.02968 (*p*=0.0001). Trends in mean daily streamflow also examined for the time series using the Kendall-tau test indicated no significant change in mean daily streamflow from 1970–98. The reason for this downward trend is inferred to be the widespread adoption of conservation tillage throughout the Maumee River Basin.

The time trend in the daily values for suspended-sediment discharge corrected for variability caused by streamflow, season, and serial correlation are plotted in figure 13. The LOWESS smoothed line shows the downward trend with time from 1970–98. A sharp downward trend is noticeable from about 1978–82 and may be the result of a recovery from accelerated soil erosion caused by the adoption of row-crop rotations in the mid-1950s to mid-1970s and higher than normal streamflow discharges during the same time. The downward trend with time appears to resume in the late 1980s, about the time when conservation tillage was first adopted. The downward trend appears to continue but at a slightly higher rate from 1993–98, about the time of accelerated adoption of conservation tillage in the basin (fig. 13).

Implications for sediment management

Natural factors like slope, soil texture, and soil-runoff potential play important roles in determining the effectiveness of conservation tillage in reducing sediment discharge in the Maumee River Basin. Comparatively higher delivery ratios and higher yields are associated with the areas of either comparatively lower soil-erosion rates or comparatively lower use of conservation tillage. These areas are characterized by relatively fine-textured soils that are more vulnerable to displacement and transport by water. Where these soil

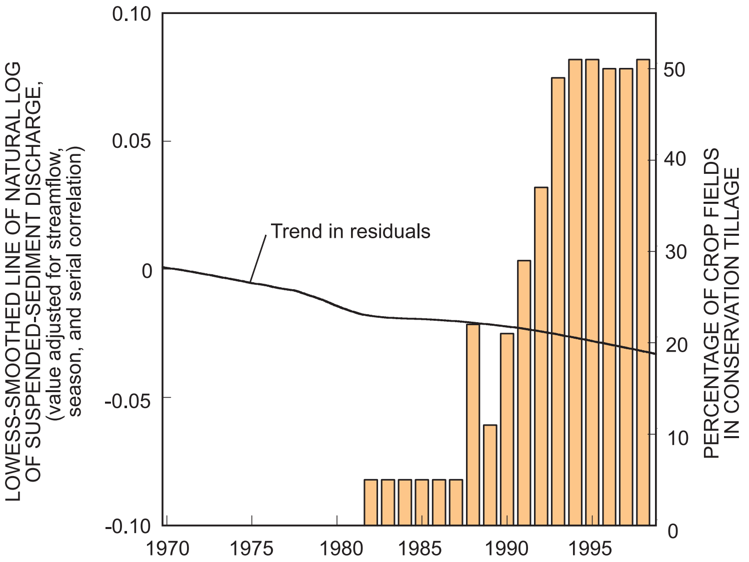


Figure 13. Relation of trend in the residuals of the natural logarithms of daily suspended-sediment discharges for the Maumee River at Waterville, Ohio, 1970–98 to increases in percentage of crop fields in conservation tillage, 1982–98.

types and slopes are present, as in the basins of the Auglaize and St. Marys Rivers, suspended-sediment discharges appear to be greater, and sediment appears to be transported more efficiently to downstream areas, as indicated by relatively higher yields and delivery ratios. These findings are not obvious when only the USLE estimates of soil erosion are considered. Water-quality data were needed to draw these conclusions.

Evaluation of sediment-reduction goals

The statistical models that detected significant downward trends in suspended-sediment discharges for the Auglaize River near Ft. Jennings and Maumee River at Waterville were used to estimate the change in tons of suspended-sediment discharged per year and to what degree the goals set by the USACE and Ohio Lake Erie Commission are being attained. To determine suspended-sediment reductions for the Auglaize River near Ft. Jennings, annual suspended-sediment discharges were computed using a set of daily streamflow values for 1997 and the two suspended-sediment rating curves generated from LOADEST2, one for 1970–74, and the other for 1996–98. The annual suspended-sediment discharge for 1997 computed using the old rating curve (1970–74) was 560 ton/d and 205,000 ton/yr compared to 280 ton/d and 102,000 ton/yr computed using the new rating curve (1996–98). Annual suspended-sediment discharge is 49.8 percent lower in the 1996–98 data set than in the 1970–74 data set (fig. 14). This result can be interpreted to mean that at the same daily streamflows, sediment discharge in the later period was about half that in the earlier period. If realistic, the 49.8 percent decrease in suspended-sediment discharge corresponds to an increase in the use of conservation-tillage practices to 65.3 percent in the areas upstream from Ft. Jennings from 1996–98. A large seasonal variation in average daily suspended-sediment discharge took place in both time periods (fig. 14), with the highest seasonal daily suspended-sediment discharges in summer (fig. 14 and table 3).

A slightly different computation was used to estimate the decrease in suspended-sediment discharge for the Maumee River at Waterville. The slope of the regression line used for computing suspended-sediment discharge indicates that suspended-sediment discharge is decreasing at an average rate of 0.4 percent per year, or 11.2 percent during 1970–98. At a rate of 0.4 percent per year or 6,700 ton/yr, a total cumulative decrease per year for the past six years (1993–98), when conservation tillage was the highest, is estimated to be about 81,000 tons. The average use of

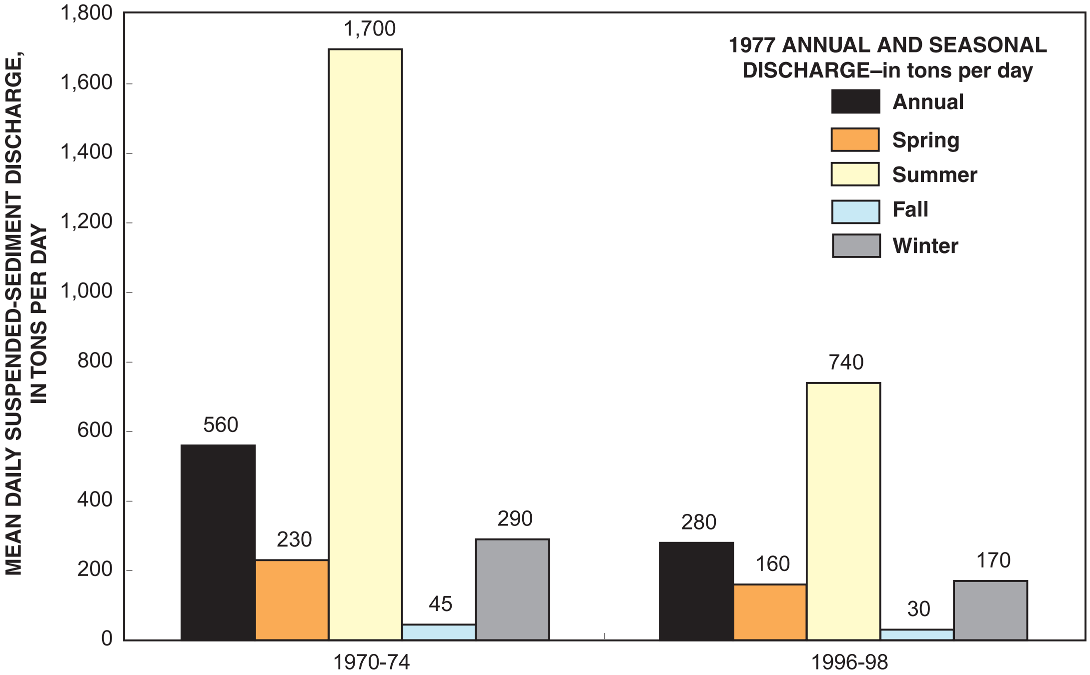


Figure 14. Mean daily suspended-sediment discharges for the Auglaize River near Ft. Jennings, Ohio, 1970-74 and 1996-98.

conservation tillage for 1996–98 was 55.4 percent in the Maumee River Basin, compared to about 50 percent for northwestern Ohio and 45.0 percent Statewide (U.S. Department of Agriculture, 1998 and fig. 5).

The trend data for the Maumee River at Waterville can be used to evaluate attainment of sediment-dredging-reduction goals established for the Port of Toledo. The U.S. Department of Agriculture (1998) recommended that use of conservation tillage could reduce the agricultural contribution to sediment dredged from the main stem of the river in Toledo, Ohio by 15 percent. The annual average suspended-sediment discharge at Waterville from 1950–92 was 1,270,000 ton/yr (rounded to 1,300,000; U.S. Department of Agriculture, 1998; Shindel and others, 1993). The trapping efficiency of suspended sediment by the Maumee River is estimated to be about 0.33, or 33 percent of the discharge of sediment at the Maumee River at Waterville, Ohio (U.S. Department of Agriculture, 1993, 1998). Based on empirical data from the USDA, the estimated average density of sediment dredged from the river is about 0.54 ton/yd^3. The reciprocal of this value, 1.85, is used as a conversion factor to compute the cubic yards per ton of sediment from tons per year. The computation used by USDA for determining success in reaching this goal is:

$$1{,}300{,}000 \text{ ton/yr} \times 0.33 \text{ (trapping efficiency)} \times (1.85 \text{ yd}^3/\text{ton}) = 793{,}650 \text{ yd}^3/\text{yr}$$

This formula was used to determine the 1992 reference condition of 800,000 yd^3 of sediment (rounded) dredged from the navigation channel. A 15 percent reduction in 800,000 yd^3 is 120,000 yd^3. If the trapping efficiency estimate is reasonable, a back-calculation from a 15 percent reduction goal of 680,000 yd^3 to an equivalent average annual discharge of suspended-sediment from the Maumee River at Waterville is 1,110,000 ton/yr.

The time, in years and days expressed as decimal time (dectime), required to reach the goals established by the USDA and the Ohio Lake Erie Commission (1998) can be evaluated for the Maumee River at Waterville. The time it would take to achieve 15 and 67 percent reductions in suspended-sediment discharge can be computed from the coefficients of the statistical model (table 6) as follows:

$$Qs = b_o Q^{bl} \exp^{(\text{dectime}*b5)}$$

Q = Streamflow, in cubic feet per second

b_o = y intercept

b_1 = Coefficient of slope

b_5 = Coefficient of time

dectime = ln (1-fractional reduction goal)/ b_5

If the fractional reduction goals are set to 0.85 and 0.33, the time necessary to reach a goal of a 15 and 67 percent reduction, respectively, is computed to be 30.1 and 205 years. This prediction assumes that the conditions leading to the downward trend in suspended-sediment discharge will remain roughly the same as in the time series analyzed.

Major source areas of sediment

Increasing the use of conservation tillage or other practices in areas showing the highest sediment-delivery ratios and highest yields, like the Auglaize and St. Marys Rivers, might accelerate reductions in the need for dredging at downstream sites. Slightly coarser soil types appear to be retained to a greater degree in the basin where they originate and these soil particles have the tendency to be deposited and remain in ditches, stream channels, and flood plains. This appears to be the case in the St. Joseph and Tiffin Rivers.

The relations between sediment-particle size, sediment sources, and stream transport have been known for many years (Mulkey and Falco, 1977). If the capacity of the stream to transport sediment is lower when the particles are sand sized, then relatively more sediment deposition and storage may take place in watersheds consisting of more coarse-textured soils. As the use of conservation tillage increases and soil losses decrease, sediment transport from certain stream basins may increase temporarily as the streams erode sediment from alluvial and colluvial deposits. In this case, sediment yields may remain the same or even increase, at least temporarily, even though conservation practices are effectively decreasing soil erosion from the land surface (Trimble, 1975, 1999). Natural factors such as hydrology, slope, soil texture, and watershed size, may be as important as conservation tillage in controlling the delivery of sediment from the land surface to the downstream areas in the Maumee River Basin.

Implementation of best-management practices

Sediment discharge and channel deposition can affect aquatic biota and their habitats as well as result in a continuing need to dredge streams and the lower main stem of the Maumee River. Best-management practices for soil-erosion control can address both problems. Conservation tillage practiced on different types of soils in the Maumee River Basin might result in somewhat different benefits. Sedimentation and dredging of stream channels and ditches to remove sediment affects aquatic biota and stream-channel-habitat. For example, embeddedness, or the burial of large particles in a stream channel by sediment, is a primary factor that degrades habitat and the diversity of fish and freshwater mussel communities in the St. Joseph River Basin (Ohio Environmental Protection Agency, 1994). Stream channel habitat data collected in 1996–97, as part of the NAWQA study, showed that the degree of embeddedness of large particles in riffles, about 70 percent in the channel of the St. Joseph River near Newville, was the highest of four sites measured in the Maumee River Basin. Embeddedness in riffles measured for the Auglaize River near Ft. Jennings, at 55 percent, where sediment transport rather than deposition may be the dominant fluvial process, was lower than that in the St. Joseph River near Newville. At the St. Joseph River near Newville, the dominant substrate types in riffles, where the coarsest particles are typically found, were sands followed by gravels and cobbles, whereas at the Auglaize River near Ft. Jennings, the dominant substrate types in riffles were cobbles and exposed bedrock.

Conservation tillage applied in areas of poorly drained clay soils may be more effective at controlling sediment transport over long distances than in areas of moderately drained to poorly drained silty to sandy soils. Compared to other soil textures, poorly drained soils in the Maumee River Basin are characterized by lower rates of soil erosion and relatively higher delivery ratios and yields. Conversely, when conservation tillage is applied to soils that are silty to sandy and which are retained to a greater degree in stream basins, greater benefits might be gained by the local aquatic biota and their stream channel habitats. In either situation, benefits to human and natural systems are achieved.

The use of riparian buffer strips along waterways is a management practice gaining favor as a method to control erosion of stream banks and stream channels. Grassed buffer strips along small waterways and wooded riparian corridors along larger streams reduce small rivulets of concentrated flow, protect stream channels and banks, and capture sheet and rill erosion from the land surface. The use of riparian buffers would complement the use of conservation tillage in the control of suspended sediment discharge. Riparian buffers are a best-management practice that could benefit aquatic biota and reduce maintenance dredging in navigation channels. Tracking and evaluation of buffer strips and concurrent monitoring of suspended sediments and aquatic biota may be helpful in the same way that tracking of conservation tillage and monitoring suspended-sediment discharge was helpful in evaluating the effectiveness of the conservation tillage in reducing suspended-sediment discharge.

Summary and conclusions

The U.S. Geological Survey began an intensive water-quality investigation in the Lake Erie–Lake St. Clair Basin in 1994 as part of its National Water-Quality Assessment Program. As part of the this investigation, studies of suspended-sediment discharge in relation to conservation tillage were undertaken in the Maumee River Basin. This report (1) describes areal patterns in conservation tillage, soil loss, soil-erosion rates, suspended-sediment discharges, yields, and delivery ratios at selected locations in the Maumee River Basin, (2) describes how suspended-sediment discharge is changing with time in relation to conservation-tillage practices and other factors like agricultural management and hydrology of the basin, and (3) improves our understanding of the primary natural and human factors that affect suspended-sediment discharge.

Erosion of soils from farm fields in agricultural areas results in the need for maintenance dredging of approximately 300,000 tons of sediment each year from the lower 7 miles of the Maumee River at an average annual cost of about $2.2 million. Aquatic biota are affected by intensive agricultural land use, mainly through the degradation of stream-channel habitat as a result of sediment deposition, dredging, and channelization. Reductions in soil erosion from farm fields can decrease the amount of material that is transported, deposited, and dredged from the Maumee River and tributaries.

Nearly all sediment dredged from the lower main stem of the Maumee River is thought to originate in the watershed upstream from Toledo. The Maumee River is the largest tributary source of suspended sediments discharged to Lake Erie. The large size of the Maumee River Basin and year-to-year variations in rainfall resulted in annual discharges of suspended sediment that ranged from 275,000 tons to 1,940,000 tons—a factor of 7. Large variations in suspended-sediment discharge and yield were measured in the Maumee River Basin from March 1996 to February 1998. Mean annual suspended-sediment discharge for the period ranged from 71,800 tons for the St. Joseph River near Newville to 1,960,000 ton/yr for the Maumee River at Defiance. From 1996–98, the average unit discharge of suspended sediment, or the yield, ranged from 118 ton/mi^2 for the St. Joseph River near Newville to 354 ton/mi^2 for the Maumee River at Defiance. Delivery ratios differed as much from site to site and over time as did sediment discharge and yield, and with similar patterns to sediment yield. Average delivery ratios of suspended sediment—the fraction of soil loss in a basin that leaves by stream transport—ranged by a factor of 5.6 from 1996–98, from 0.074 at the St. Joseph River near Newville to 0.412 at the Maumee River near Defiance, Ohio. The highest delivery ratios and yields on the main stem came from the reach between New Haven, Indiana and Defiance, Ohio. These areas of the basin are characterized by some of the lowest soil-erosion rates and the finest textured and most poorly drained soils with highest runoff potential. Although these areas contributed the greatest unit area discharges of suspended sediment, they were the areas with some of the lowest soil-erosion rates and lowest use of conservation tillage.

Expressed as percentage of the total measured at Waterville, Ohio, 31.2 percent of the suspended sediment in the basin was discharged from the Auglaize River, 15.3 percent was discharged from the St. Marys River and flowed past New Haven, Ind., 6.91 percent was discharged from the St. Joseph River, and 2.40 percent was discharged from the Tiffin River. The total amount of suspended sediment discharged from these four tributaries was 1,010,000 tons—950,000 tons less than the 1,960,000 tons discharged from the main stem at Defiance, Ohio. The tributary contribution was 800,000 tons less than the 1,810,000 ton/yr discharged on average from the main stem at Waterville from 1996–98.

Trends in suspended-sediment discharge were examined statistically at two sites. Suspended-sediment discharges in the Auglaize River near Ft. Jennings from 1970–74 were compared to discharges for the period 1996–98. Suspended-sediment discharges in the Maumee River at Waterville were compared over the period 1970–98. Suspended-sediment discharges, normalized for streamflow and season, were 49.8 percent lower at the Auglaize River near Ft. Jennings, Ohio from 1996–98 compared to 1970–74. The reason for the trends in the suspended-sediment discharge may be the widespread use of conservation tillage. If realistic, the 49.8 percent decrease in suspended-sediment discharge at the Auglaize River near Ft. Jennings corresponds to a similar magnitude change of 65.3 percent in the use of conservation-tillage practices from the early period compared to the later period. A long-term average decrease during the period of record of 11.2 percent was detected for the Maumee River at Waterville. The use of conservation tillage at a rate of 55.4 percent in the Maumee River Basin from 1993–98 equates to a decrease of 0.4 percent per year in suspended-sediment discharge. Trends in mean daily streamflow also examined for 1970–98 using the Kendall-tau test indicated no significant changes at the USGS streamflow gaging stations at the Auglaize River near Ft. Jennings and at the Maumee River at Waterville.

Natural factors like slope, soil texture, and runoff potential play an important role in determining the effectiveness of conservation tillage in reducing suspended-sediment discharge in the Maumee River Basin. Comparatively higher delivery ratios and higher yields of suspended sediment were found in areas with high erosion rates, poorly drained to very poorly drained soils with high runoff potential, and relatively low use of conservation tillage. Where these conditions exist singly or in combination, as in the Auglaize and St. Marys Rivers, suspended-sediment discharges appear to be greater and sediment appears to be exported more efficiently to downstream areas. These findings are not obvious when only the Universal Soil Loss Equation estimates of soil erosion are considered. Water-quality data were needed to draw these conclusions.

Sediment discharge and channel deposition can affect aquatic biota and their habitats as well as result in a continuing need to dredge the streams of the basin and lower main stem of the Maumee River. Conservation tillage may be more effective at controlling sediment transport over long distances when these practices are applied to poorly drained soils with high runoff potential than to moderately drained to poorly drained silty to sandy soils that have higher rates of soil erosion but relatively lower delivery ratios and yields. Conversely, when conservation tillage is applied to soils that are silty to sandy and retained to a greater degree in stream basins, greater benefits might be gained locally by aquatic biota and their stream-channel habitats. In either situation, benefits to human and natural systems are achieved.

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APPENDIX

Description of the use of LOADEST2

Suspended-sediment discharges for this report were estimated by the rating-curve method (Cohn and others, 1989, 1992; Crawford, 1991, 1996). For each site, a rating curve was selected from among eight candidate models on the basis of Aikaike's information criterion (Judge and others, 1985). This criterion involves a measure of model precision and a measure of model parsimony and is designed to trade-off precision for parsimony (that is, it evaluates increasing model complexity and compares it to increased model precision and only selects the more complex model when the increased precision exceeds a certain threshold). The eight models considered are:

Model 1: ln (load) = b0 + b1 ln (streamflow),

Model 2: ln (load) = b0 + b1 ln (streamflow) + b2 ln (streamflow)**2,

Model 3: ln (load) = b0 + b1 ln (streamflow) + b2 dectime,

Model 4: ln (load) = b0 + b1 ln (streamflow) + b2 sin (dectime) + b3 cos (dectime),

Model 5: ln (load) = b0 + b1 ln (streamflow) + b2 ln (streamflow)**2 + b3 dectime,

Model 6: ln (load) = b0 + b1 ln (streamflow) + b2 ln (streamflow)**2 + b3 sin (dectime) + b4 cos (dectime),

Model 7: ln (load) = b0 + b1 ln (streamflow) + b2 sin (dectime) + b3 cos (dectime) + b4 dectime,

Model 8: ln (load) = b0 + b1 ln (streamflow) + b2 ln (streamflow)**2 + b3 sin (dectime) + b4 cos (dectime) + b5 dectime.

where:

b0–b5 are rating-curve parameters;

streamflow is instantaneous or daily streamflow, in cubic feet per second,

load is suspended-sediment discharge, in tons per day, and

dectime is time in fractional years (for example, midnight on December 31, 1992 is 1993.0000; 1200 on July 2, 1993 is 1993.5000; and 0100 on September 30, 1993 is 1993.7453.)

Because model parameters are estimated from a model in which the response variable (load) is log transformed using natural logs, a correction for transformation bias is necessary when converting model predictions back from logarithmic units into arithmetic units (Miller, 1984). The method of Bradu and Mundlak (1970) was used. An estimate of the uncertainty in the estimated loads was obtained using the method described by Likes (1980) and Gilroy and others (1990).

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