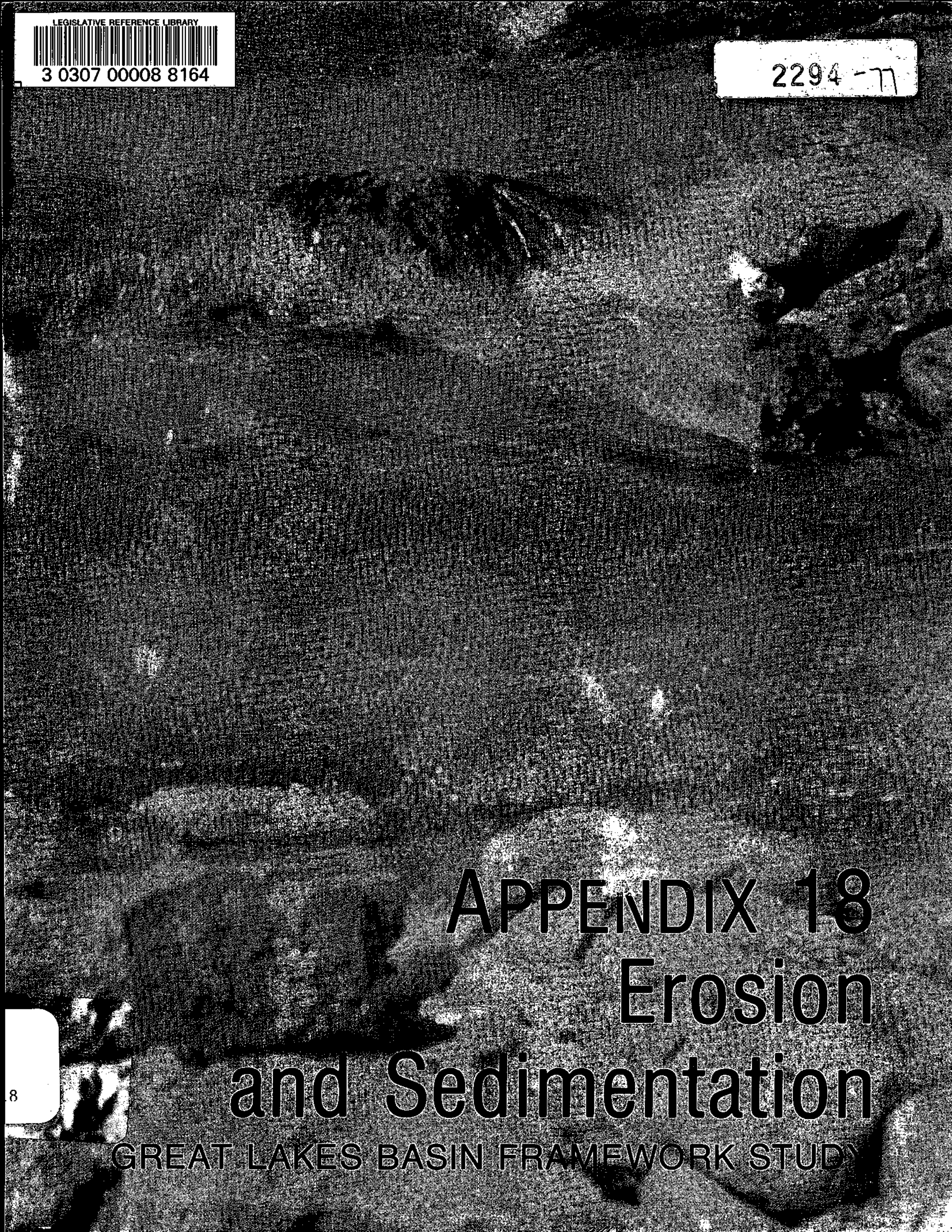

APPENDIX 18
Erosion and Sedimentation

GREAT LAKES BASIN FRAMEWORK STUDY

Great Lakes Basin Framework Study

APPENDIX 18

EROSION AND SEDIMENTATION

GREAT LAKES BASIN COMMISSION

Prepared by Erosion and Sedimentation Work Group

Sponsored by Soil Conservation Service

U.S. Department of Agriculture

Published by the Public Information Office, Great Lakes Basin Commission, 3475 Plymouth Road, P.O. Box 999, Ann Arbor, Michigan 48106. Printed in 1975.
Cover photo by Kristine Moore Meves.

This appendix to the *Report* of the *Great Lakes Basin Framework Study* was prepared at field level under the auspices of the Great Lakes Basin Commission to provide data for use in the conduct of the Study and preparation of the *Report*. The conclusions and recommendations herein are those of the group preparing the appendix and not necessarily those of the Basin Commission. The recommendations of the Great Lakes Basin Commission are included in the *Report*.

OUTLINE

SYNOPSIS

Appendix 18, *Erosion and Sedimentation*, surveys the phenomena of erosion and sedimentation processes as they occur in the Great Lakes Region. Local mean rates of erosion from various sources (sheet erosion, channel erosion, bank erosion, and urban construction) are quantified. Resulting rates of sedimentation and other damages are explored.

A major aspect of this study is the presentation of future trends in erosion and sedimentation rates. These rates, based upon economic projections of land needs for crop production and urban expansion, are presented by Basin planning subarea. Future needed amounts of erosion control measures on rural lands are analyzed, and the acres of urbanizing land needing erosion protection are presented.

Limitations of existing programs to reduce erosion and sedimentation to levels acceptable for future needs are surveyed. Alternative methods and procedures are discussed, and general recommendations for future action are expressed. The physical characteristics of the various planning subareas in the Basin, as they relate to effects on erosion and sedimentation rates, are defined.

FOREWORD

This study began during fiscal year 1968. All eight States with land lying within the Great Lakes Basin and those nine Federal agencies at that time active in water resource development were invited to participate in the study.

A work group on erosion and sedimentation was established with the chairmanship given to the U.S. Soil Conservation Service. The work group included:

James R. Thompson, (work group chairman) Soil Conservation Service, U.S. Department of Agriculture, Michigan

Robert Adams, Department of Highways, State of Michigan

Russell Hill, Department of Agriculture, State of Michigan

John Kennaugh, Michigan Grand River Council

Richard Kerr, Forest Service, U.S. Department of Agriculture

Donald McCormack, Soil Conservation Service, U.S. Department of Agriculture, Ohio

Stanley Quackenbush, Department of Agriculture, State of Michigan

Alexander Ritchie, Department of Natural Resources, State of Ohio

William Walsh, Department of Natural Resources, State of Michigan

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INTRODUCTION

The objectives of this work group, as stated in the Plan of Study, were "to collect data on erosion and sedimentation and to define the nature, intensity, and trends of these problems within the planning subareas of the Basin and consider alternative solutions to these problems and recommend those most desirable."

The method of investigation and analysis involved gathering factual data and other information of both a quantitative and qualitative nature. Analytical techniques were applied to these data in order to express problems in the desired way. Conclusions about the nature and extent of problems, suggested solutions, and alternatives were the product of reasoned thought based upon experience and logical deduction.

Section 1

TRENDS IN EROSION RATES AND LAND TREATMENT NEEDS

1.1 Current Gross Erosion Rates

Sections 2, 3, and 4 define the intensity of erosion problems and problems with sediment production as they exist at present. These conditions are the basis for future trends in 1980, 2000, and 2020. This section presents the computed rates of erosion in these target years. They are based upon projected changes in cropland distribution, land use changes, and in levels of land management and technology.

Projections of cropland changes and shifts in land use have been made by the economists on a planning subarea basis. Current erosion and sedimentation rates have been computed and are presented by counties and by the use of isograms in Sections 2 and 3. The projected trends in erosion and sedimentation rates presented in this section are for planning subareas and involve the individual counties. The planning subareas, which contain an average of a dozen counties each, tend to reflect regional trends. They provide a more reliable base than would projections made by individual counties.

The gross erosion rates for the 15 planning subareas were computed on a weighted basis. These weighted average annual gross erosion rates were applied to the various acreage values for the planning subareas to determine total erosion in the areas. The total computed gross erosion in the approximately 190 counties included in the 15 planning subareas is more than 165 million tons annually, occurring on 83.5 million acres of land. This is a mean average of the approximately 2.0 tons from each acre of land in the Basin. Table 18–1 is a summary of mean annual gross erosion rates and total tons by planning subareas in the Basin under the cropping and land use condition in the late 1960s.

The data on Table 18–1 were assembled for the planning subareas using rates of erosion from various sources as shown on Table 18–2. Planning Subarea 2.3 is used as an example.

TABLE 18–1 Summary of Mean Annual Gross Erosion Rates and Total Tons of Erosion

Planning Subarea	Computed Gross Erosion Rate[1]	Acres in Planning Subarea (Thousands)	Total Tons (Thousands)
1.1	0.33	9,473	3,126
1.2	0.24	6,442	1,546
2.1	1.55	10,011	15,517
2.2	5.40	5,212	28,144
2.3	3.99	8,955	35,730
2.4	0.76	8,094	6,151
3.1	0.42	4,018	1,687
3.2	1.86	4,424	8,229
4.1	2.66	3,980	13,008
4.2	4.65	6,319	29,383
4.3	1.97	2,309	4,549
4.4	1.13	3,070	3,469
5.1	1.56	2,459	3,836
5.2	1.84	5,427	9,986
5.3	0.74	3,385	2,505
	2.00[2]	83,578	166,866

[1]Tons/Acre/Year

[2]Weighted Mean

TABLE 18–2 Gross Erosion for Planning Subarea 2.3—Current (1970)

Erosion Source	Acres (1000)	Erosion Rate (T/ac/yr)	Total Tons (1000)
Rural Ag. & Non-Ag.	6429.0	5.33	34,276
Forest Land	1705.0	0.17	293
Built-up Urban	818.0	0.25	205
Urban Construction	3.3	b[1]	526
Other Sources[2]	-----	----	430
Total Land Area	8955.0	3.99+	35,730

[1]Variable rate with individual urban complex (from Section 6)

[2]Includes streambank, roadside, and gully erosion (see Section 3)

1.2 Projected Erosion Rates

The projected gross erosion rates were estimated by adjusting the future C values in conformance with the projected cropland and other land use shift for 1980, 2000 and 2020. (The C values are the cover factor used in the universal soil loss equation as described in Section 4, Sheet Erosion Rates.)

Since the universal soil loss equation is a linear equation, an adjusted sheet erosion rate computation is directly proportional to the change in the C value if all of the other factors remain constant. It was on this basis that projected sheet erosion rates were computed. The values for erosion from urban construction are taken from data developed in Section 6, Urban Erosion. The projected changes in cropland, land use, and levels of urban construction for target year 1980 are shown on Table 18–13 for Planning Subarea 2.3. The summary of gross erosion is also shown.

TABLE 18–3 Gross Erosion for Planning Subarea 2.3—Target Year 1980

Erosion Source	Acres (1000)	Erosion Rate (T/ac/yr)	Total Tons (1000)
Rural Ag. & Non-Ag.	6,345	5.37	34,114
Forest Land	1,643	0.17	286
Built-up Urban	923	0.25	231
Urban Construction	44	--	597
Other Sources	---	--	450
Total Land Area	8,955	3.99-	35,718

It is interesting to note that there is an insignificant change in the projected gross erosion rate for Planning Subarea 2.3 between the late 1960s and 1980. The backup data for this projection show more shift than this result would indicate. There is a slight decrease in projected row crops but a sizeable increase in small grain, from 10 percent of the planning subarea to nearly 11.5 percent. This accounts for the increase in the mean erosion rate for the rural agricultural land. The increase in acreage of urban built-up area, where erosion rates are lower, counteracts this increase. The net result is an insignificant change in gross erosion for Planning Subarea 2.3.

This phenomenon works in different ways in the various planning subareas, and the changes in the gross erosion rates reflect the combinations of changes forecast by the economic projections. The percent changes range from minus 16.9 percent to plus 3.7 percent in the gross erosion rates. The large decrease in Planning Subarea 2.4 is due to a projected sizeable decrease in row and small grain acreage by the year 1980. The 3.7 percent increase in gross erosion in Planning Subarea 4.2 is due to a large projected increase in row crops on the lake plain soils in this area. The 10.4 percent decrease in gross erosion in Planning Subarea 2.2 is due to a projected increase in the acreage of urban built-up land around the Chicago and Milwaukee metropolitan complexes. In the Cleveland area, Planning Subarea 4.3, the 14.2 percent decrease in gross erosion by 1980 is due to a sharp drop in projected row crop acreage and a sizeable increase in urban built-up area.

Table 18–4 summarizes the present and the projected mean gross erosion rates for the planning subareas in the Great Lakes Region by target years.

The projected gross erosion rates for target year 2000 show a continuing downward trend for most of the planning subareas in the Basin. The exceptions are Planning Subareas 2.3, 3.2, and 4.2 where the projected demands for row crops either remain steady or show an upturn.

Economic projections show a sharp upturn

TABLE 18–4 Summary of Gross Erosion by Target Year

Planning Subarea	Gross Erosion (tons/acre/year) Current	1980	2000	2020
1.1	0.33	0.34	0.32	0.32
1.2	0.24	0.23	0.22	0.22
2.1	1.55	1.45	1.27	1.51
2.2	5.40	4.84	4.05	3.44
2.3	3.99	3.99	3.93	4.77
2.4	0.76	0.62	0.52	0.64
3.1	0.42	0.41	0.36	0.36
3.2	1.86	1.88	2.30	2.55
4.1	2.66	2.53	2.21	2.46
4.2	4.65	4.82	4.98	5.23
4.3	1.97	1.69	1.72	1.88
4.4	1.13	1.02	0.77	0.78
5.1	1.56	1.35	1.28	1.28
5.2	1.84	1.58	1.11	1.30
5.3	0.74	0.64	0.60	0.60
(weighted mean)	2.00	1.88	1.78	1.92

in the demand for row crops by 2000. The demand in Planning Subarea 2.3 will rapidly increase and will be approximately 33 percent greater in 2020 than in 2000. The demand for row crops in Planning Subarea 3.2 will increase rapidly, and will be approximately 40 percent greater in 2020 than at present. The demand for row crops increases steadily from 1970 to 2020 in Planning Subarea 4.2. The total increase will amount to 25 percent during this 50 year period. This amounts to a sizeable acreage increase in row crops for Planning Subarea 4.2, in which approximately 45 percent of the land is cultivated to row crops at the present time.

The effects of urbanization are quite evident in some of the planning subareas. The effect of the massive urbanization that is projected for the Chicago and Milwaukee metropolitan areas is evidenced by the reverse trend in the gross erosion rates for Planning Subarea 2.2 from the present to year 2020. Row crops will decrease by 20 percent in this period, but the amount of land in urban build-up will increase 140 percent. The lowering effect that urbanization has on gross erosion rates is also evident in the other planning subareas where large metropolitan areas exist.

1.3 The Effect of Conservation Practices on Erosion Rates

In talking about erosion rates the question immediately arises as to what role conservation practices have had on the erosion rates computed for the planning subareas in the Great Lakes Basin. The discussion that follows should put present and future conservation practices into perspective as to need and effectiveness.

The gross erosion rates in this chapter include sources of erosion from agricultural land, urban erosion, and miscellaneous sources such as streambank and roadside erosion. The great bulk of the erosion comes from agricultural and other rural land in the various planning subareas. This is true for the planning subareas in the northern Lake areas where timber, swamp, and brush land are predominant, and in planning subareas where an extensive agriculture exists. However, the source of urban erosion is very sizeable in the planning subareas with large urban areas. Erosion from agricultural and other rural land sources accounts for 75 percent or more of all sources and 90 percent or more of many planning subareas. For this reason, the discussion that follows refers to agricultural and other rural land erosion rates.

Conservation practices are applied to land for a variety of purposes: erosion control, maintaining fertility levels, maintaining tilth and soil workability characteristics, maintaining and improving air and moisture relationships in the soil, and many others. Erosion control is an important and a widely used component of these practices. Practices commonly used for erosion control are:

(1) conservation cropping systems including residue management and minimum tillage
(2) contour farming systems including strip cropping on the contour or field strips oriented across the slopes
(3) level or low-gradient terrace systems
(4) vegetative practices to stabilize waterways, channel banks, and other steep, bare, or exposed areas
(5) stabilizing structures
(6) buffer strips

The summary of conservation practices taken from Appendix 13, *Land Use and Management*,[3] shows that approximately 950,000 acres of land have been treated by contour farming, strip cropping, and grassed waterways. In addition, 8.3 million acres have been protected by conservation cropping (crop rotation) systems. The summary of land acreage presented in Appendix 19, *Economic and Demographic Studies*, indicates that there are 28.6 million acres of cropland in the Great Lakes Basin. It is very likely that the land treated with mechanical erosion control practices also has conservation cropping systems as well. Thus there are 8.3 million acres of cropland in the Basin with a reasonably high degree of erosion control protection.

The erosion control effects from conservation cropping systems (or crop rotations) have been discounted in the erosion values shown in this section and in those shown in Section 4, Sheet Erosion Rates. The reason these effects are integrated into the figures is that the distribution of cover provided by the cropping rotations was used in the computation of the sheet erosion rates. Thus the cover effect, as provided by crop rotations, is reflected in the C values used in sheet erosion computations.

The unaccounted-for erosion control effects are those provided by the mechanical practices applied on the above-mentioned 950,000 acres. The effectiveness of mechanical control practices to reduce erosion rates is described in Agricultural Handbook No. 282.[16] This effectiveness varies with slope steepness and with slope length. Generally, contour farming reduces erosion rates on land slopes where it is normally used (2 to 12 percent slope), to 0.5 or 0.6 of the erosion rate without this practice. Strip cropping on the contour will reduce erosion rates to 0.4 to 0.5 of their rate without this practice. Adequately designed terrace systems reduce erosion rate to 0.2 to 0.3 of its former value without any mechanical practices. The land in the Great Lakes Basin on which mechanical erosion control practices have been established include:

(1)	contour farming	394,272 acres
(2)	strip cropping	511,842 acres
(3)	terracing	13,000 acres
(4)	grassed waterways	32,163 acres
		951,277 acres

The above 951,277 acres amount to 3.3 percent of the 28.6 million acres of cropland in the Basin. The weighted effect of these mechanical practices may prove values in Table 18–5 to be overestimated by several percent in some of the planning subareas.

The adaptability and acceptance of mechanical erosion control practices is highly variable throughout the Basin, and the number of practices already established is also variable. Landscape relief characteristics and type of farming are important factors. Planning Subareas 5.1 and 5.2 have the highest percentages of the cropland protected by mechanical practices, 14 percent. Planning Subarea 2.1 has approximately 6 percent of the cropland protected. Planning Subarea 2.3 has approximately 2 percent and Planning Subareas 4.2 and 1.1 have only approximately 0.3 percent of the cropland protected by mechanical practices. However, nearly 30 percent of the total cropland has protection by the use of conservation crop rotations.

The mechanical practices that have been established and have not been discounted in the values on Table 18–5 result in a possible overestimation of erosion rates in Planning Subareas 5.1 and 5.2 by as much as five percent. The overestimation may be as high as three percent in Planning Subarea 2.1, one percent in Planning Subarea 2.3, and an insignificant amount in Planning Subareas 1.1 and 4.2. The other planning subareas may be overestimated by a fraction of one percent to a few percent. On the average, mechanical erosion control practices have reduced the mean average sheet erosion rates in the Great Lakes Basin by two percent.

As mentioned above, the effects of reducing erosion rates due to the utilization of crop rotations have been discounted in the values on Table 18–5. The crop rotations, which have been established on approximately 30 percent of the cropland acres in the Basin, have variable effects on the reduction of erosion rates. However, they have approximately the same effectiveness as the mechanical practices for controlling erosion. Crop rotations account for approximately 10 times as much protection from erosion as do supporting mechanical practices because they are used on 10 times as much land.

The amount of land protected by crop rotations varies considerably between planning subareas. The percentage of land protected ranges from a few percent to nearly 50 percent. Most planning subareas have between 25 and 40 percent of the cropland protected. An analysis of the utilization of conservation erosion control practices in the Great Lakes Basin indicates that these practices have reduced erosion rates 20 to 25 percent.

1.4 Land Treatment Needs and Costs for Erosion Control

The Conservation Needs Inventory (CNI) based on the years 1966 through 1967 indicates that 16.1 million acres of cropland in the Great Lakes Basin lack adequate crop rotations to fulfill the goal of conserving longtime productivity. In addition to crop rotations, the inventory indicates the need for 682,000 acres of contouring and 2,324,000 acres of strip cropping, terracing, and diversions. Three hundred sixty-six thousand acres of pasture land need protection against erosion. In addition there is a need for 420,000 acres of cropland and 200,000 acres of pasture land to be retired to less intense use. The inventory also indicates the need for nearly four million acres of cover crops. Based upon past rates of installation, it is estimated that there is a need for an additional 65,000 acres of grass waterways and approximately 10,000 grade stabilization structures in gullies and other channels. These needs are summarized on Table 18–5.

Table 18–6 gives estimated annual costs to establish and maintain the needed mechanical and vegetative control practices to control erosion on the agricultural land in the Basin. These costs[20] are based upon $0.20 per acre for contouring, $0.50 per acre for strip cropping, $2.50 per acre for terraces and diversions, $20 per acre for grassed waterways, and $5.50 per acre to give pasture land protection for erosion control.

TABLE 18–5 Planning Subarea Distribution of Conservation Needs for Erosion Control (1000 Acres)

Planning Subarea	Crop Rotations	Con-touring	Strips, Terraces, Divisions	Less Intense Land Use		Grass Waterways	Pasture Protection	Cover Crops
				Cropland	Pasture			
1.1	171.8	3.2	8.9	3.8	1.0	1.0	12.0	33.0
1.2	100.3	5.8	16.0	2.4	2.1	4.5	13.7	20.5
2.1	1,676.4	126.9	740.3	72.2	14.4	10.2	80.1	121.0
2.2	1,784.6	226.0	287.7	66.7	11.2	2.6	24.5	498.9
2.3	2,955.1	113.8	383.7	90.3	10.6	8.2	50.4	968.2
2.4	502.1	23.6	139.0	33.0	29.5	2.6	37.9	145.7
3.1	264.2	4.1	24.1	5.4	3.6	2.4	19.1	104.3
3.2	1,376.7	5.7	87.0	10.8	14.1	2.0	19.8	655.5
4.1	1,153.3	7.5	17.3	11.2	3.2	1.0	22.7	574.3
4.2	3,617.1	49.9	94.0	16.5	1.0	9.0	10.2	411.4
4.3	394.4	9.7	42.8	10.0	1.5	6.1	2.6	3.9
4.4	358.0	8.1	62.1	7.1	12.1	3.2	8.3	53.4
5.1	504.2	27.3	112.7	5.9	5.2	7.4	9.1	157.8
5.2	933.6	62.9	297.7	65.4	53.5	4.4	28.1	142.7
5.3	353.3	7.5	10.7	19.3	36.0	0.4	27.9	13.8
Total	16,145.1	682.0	2,324.0	420.0	199.5	65.0	366.4	3,904.4

TABLE 18–6 Estimated Annual Costs of Needed Conservation Practices for Erosion Control, by Planning Subarea (Cost Base 1963)

Planning Subarea	Contouring	Strips, Terraces, and Diversions	Grass Waterways	Pasture Protection	Cover Crops	Stabilization Structures
1.1	0.7	5.4	20.0	66.0	165.0	0.9
1.2	1.4	9.6	110.0	75.4	102.5	0.2
2.1	30.4	444.0	196.0	440.0	605.0	14.9
2.2	54.2	173.0	53.6	134.8	2,494.0	7.3
2.3	37.4	230.0	160.0	277.2	4,841.0	22.7
2.4	5.8	84.0	53.4	208.0	728.5	2.3
3.1	1.0	14.4	48.0	105.0	521.5	1.3
3.2	1.3	52.2	40.1	108.9	3,277.5	47.4
4.1	1.8	10.4	21.6	124.9	2,871.5	30.0
4.2	12.0	56.4	177.6	56.1	2,057.0	18.3
4.3	2.3	27.6	120.0	14.3	19.5	--
4.4	1.9	37.2	67.2	45.7	267.0	3.0
5.1	7.4	67.6	144.0	50.0	789.0	1.3
5.2	15.1	178.8	87.6	154.6	713.5	0.5
5.3	1.8	6.5	9.6	153.4	69.0	--
Subtotals	174.5	1,397.1	1,308.7	2,014.3	19,521.5	150.1

Grand Total - 24,566.2

Annual costs for establishing and maintaining cover crops for erosion control range from \$3.50 to \$8.00 per acre. Costs shown on Table 18–6 are based upon \$5.00 per acre. Grade stabilization structures are variable in costs. Most range from \$300 to \$400 and can be amortized over a 25-year period. For this analysis a figure of \$15 per structure per year is used.

Thus, the total annual cost to install the mechanical and vegetative practices needed to maintain the longtime productivity of the agricultural land in the Basin is approximately 24.6 million dollars. This figure represents the annual cost to install and maintain an erosion control conservation job on 32.1 million acres, 28.6 million acres of cropland and 3.5 million acres of pasture. This total does not include the nearly five million acres of land in the Basin that is nonforested and nonagricultural, and on which some treatment is needed for erosion control. It likewise does not include the estimated 42,000 acres that are currently denuded by construction activity each year (Section 6). Costs to control this urban erosion are unknown.

Accelerated erosion is occurring in approximately 139,000 acres of State, county, and private forest land. Improperly performed logging activity, grazing, and fires are principal causes. Another erosion source is former crop and pasture land reverting to forest on which adequate tree and litter cover has not developed. The total cost of treating these 139,000 acres is estimated at \$5.7 million. This is the total cost, not annual cost. It is estimated that 58,000 acres of this eroding forest land will be treated by 2020 at a cost of \$2.4 million. These costs include both technical assistance and installation costs.

The costs and amount of conservation treatment for erosion control as discussed above are the minimum requirements for erosion control. This amount of treatment, particularly that relating to cover crops, may be considerably less than that needed to control sedimentation rates to levels that may be demanded in the future. This aspect is discussed in Section 12.

1.5 Future Rates of Application

Table 18–7 summarizes projected estimates of ongoing rates of application of treatment for erosion control made in Appendix 13, *Land Use and Management*.[3] The rates of application of this treatment recommended by this work group as an accelerated program are also shown.

TABLE 18–7 Projected Application of Conservation Practices for Erosion Control (Cropland and Pasture)

Planning Subarea	To Target Year	Program (1000 Acres) Ongoing	Accelerated
1.1	1980	16.4	19.7
	2000	49.3	54.2
	2020	69.0	75.6
1.2	1980	13.3	14.7
	2000	36.8	40.4
	2020	51.5	56.4
2.1	1980	149.3	179.2
	2000	448.0	492.8
	2020	627.2	687.0
2.2	1980	143.2	171.8
	2000	429.5	472.4
	2020	601.3	658.5
2.3	1980	305.1	366.1
	2000	915.3	1,006.8
	2020	1,281.5	1,403.5
2.4	1980	105.7	126.9
	2000	317.2	348.9
	2020	444.0	486.3
3.1	1980	28.4	34.0
	2000	85.1	93.7
	2020	119.2	130.5
3.2	1980	111.5	133.8
	2000	334.5	368.0
	2020	468.3	513.0
4.1	1980	92.2	116.6
	2000	291.6	320.7
	2020	408.2	447.0
4.2	1980	115.3	138.3
	2000	345.8	380.4
	2020	484.1	530.2
4.3	1980	25.7	30.9
	2000	77.2	84.9
	2020	108.1	118.4
4.4	1980	35.3	42.4
	2000	105.9	116.5
	2020	148.3	162.4
5.1	1980	57.4	68.9
	2000	172.3	189.5
	2020	241.2	264.1
5.2	1980	93.7	112.5
	2000	281.2	309.3
	2020	393.6	431.1
5.3	1980	24.2	29.0
	2000	72.6	79.8
	2020	101.6	111.3

Section 2

SEDIMENT PRODUCTION RATES AND THEIR TRENDS

The erosion process on land affects downstream water and related resources. Runoff water carries products of erosion and other solid wastes and deposits this product as sediment. In many situations, this product remains suspended in downstream waters for prolonged periods and constitutes a detriment to the quality of water.

2.1 Nature of the Sedimentation Process

Sediment is transported as a suspension in water and as a bedload movement. These two broad forms plays in the transport of sediment load and suspended load. There are apparently no sharp divisions between the two forms of transport except that bedload moves close to the channel bottom (thalweg) and the suspended load is dispersed through the depth and width of the moving water. The physical mechanisms of both forms of transport are complex, and it is beyond the scope of this appendix to explore their nature.

Generally, bedload movement involves the more coarse-textured, heavy materials that require relatively high channel velocities. Suspended sediment movement occurs in moving water over a much wider range of velocities. In both forms of sediment transport, depth of flow, velocity of flow, and the nature of the material being transported are important factors in sediment transport rates.

The quantitative role that each of these two broad forms plays in the transport of sediment in the Great Lakes Basin is not known. It is speculated that the majority of sediment transport occurs as suspended sediment. Locally, however, bedload transport is significant and must be recognized in relation to certain types of sedimentation damage. However, this study is concerned with total quantities of transport and the nature and degree of resulting damages and other problems. The modes of transportation are of secondary importance.

2.2 Measured and Estimated Sediment Yields

The information presented on the maps in this section are estimates of total sediment yields that result from all erosion sources and by all modes of transport. The estimates of sediment production are computations of gross erosion values plus the application of delivery ratios as selected from the curve shown in Figure 18–1. This curve, developed by John W. Roehl of the U.S. Soil Conservation Service,[10] is the best available data for estimating delivery ratios.

The series of maps in Figures 18–2 through 18–15 show estimates of sediment production at specific locations within the planning subareas. The locations marked with an asterisk on the small tables on each map are the values for sediment production furnished by the U.S. Geological Survey from longtime measures at these points.[1] Table 18–8 compares several locations in the Great Lakes Basin where measured data on longtime average annual sediment production are available. Estimates of sediment made by using Figure 18–1 and gross erosion computations are also included in the tables.

The apparent large discrepancies in the two values shown for the Maumee River at Waterville, Ohio, and the Cuyahoga River at Independence, Ohio, have two possible explanations. The error concerning the Maumee River is introduced by extrapolating the curve for such a large drainage area. The curve must be extrapolated for drainage areas larger than 400 to 500 square miles (Figure 18–1). The second discrepancy, which concerns the Cuyahoga River near Cleveland, is related to the inflow of solids to the streams and rivers in the vicinity of large metropolitan areas. Use of estimates of soil erosion alone in these areas is insufficient to explain the quantities of solids that appear as sediment load in these waters. This phenomenon is discussed in Sections 6 and 8.

TABLE 18–8 Comparison of USGS Measured Data to the Estimating Method (Tons per Year)

Location	USGS Measured Data	Estimated Method
St. Marys River at Fort Wayne, Indiana	139,000	115,000
Cass River at Frankenmuth, Michigan	52,500	49,900
Popple River at Fence, Wisconsin	860	1,500
Maumee River at Waterville, Ohio	1,179,000	480,000
Cuyahoga River at Independence, Ohio	200,456	62,000
Portage River at Oak Harbor, Ohio	89,000	66,000
Sandusky River at Fremont, Ohio	226,000	145,000

2.3 Regional Sediment Production Maps

Computed sediment yields and some measured yields are shown for specific locations on Figures 18–2 through 18–15. Figures 18–16c through 18–30c are Basinwide maps showing sediment production rates on a regional basis. These rates are shown by means of isograms, or lines of equal value, representing equal sediment yields. These lines are based on gross erosion values, which will be presented in Section 3, and delivery ratios taken from the curve in Figure 18–1.

These maps imply that an average watershed of 10 square miles (Figures 18–16c to 18–20c), 50 square miles (Figures 18–21c to 18–25c), or 100 square miles (Figures 18–26c to 18–30c) will yield approximately the amount of sediment shown by the lines. Values may be interpolated by stating the rate in terms such as nearly, more than, approximately, less than, or between. It is not intended to isolate a specific watershed, say a 10-square-mile drainage area located in Planning Subarea 2.3, which lies between the 4000 and 5000 tons annual sediment yield line, and interpret the sediment yield as perhaps 4600 tons per year. The logical interpretation would be the following: an average 10-square-mile watershed located near the geometric center of Planning Subarea 2.3 will have a sediment production rate between 4000 and 5000 tons per year. If the location is fairly close to the 4000 ton line,

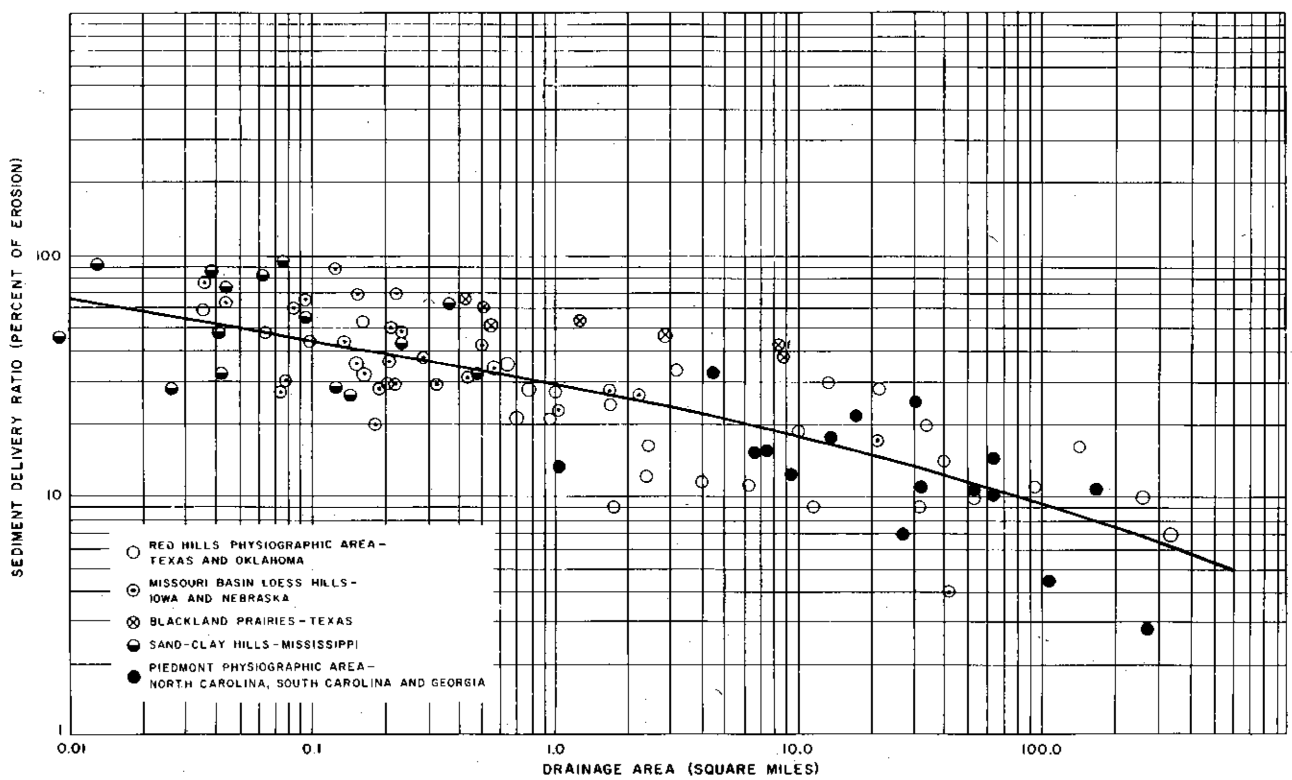


FIGURE 18–1 Sediment Delivery Ratio Versus Drainage Area. Percent of eroded soil material transported to the downstream outlet of streams based upon their damage area.

it should be stated as having a sediment yield of more than 4000 tons per year, or less than 4000 tons per year if it is on the low side of the 4000 ton line.

These maps express the degree and intensity of sediment production rates on a regional, subregional, and zone basis where generalized planning data are desirable, but detail sufficient for design purposes is not essential. Lines of equal sediment production reflect geographical changes of soil type, slope, and other relief characteristics, cropping patterns and other land use differences, and rainfall. The use of isograms in this manner has a tendency to smooth out choppy changes that occur locally across the land. However, caution should be exercised in applying data from these maps, particularly for the smaller drainage areas (10 square miles). Caution should be used in making arbitrary statements about a small local area for either discussion or design purposes. Use of these maps for this purpose could cause misleading interpretations.

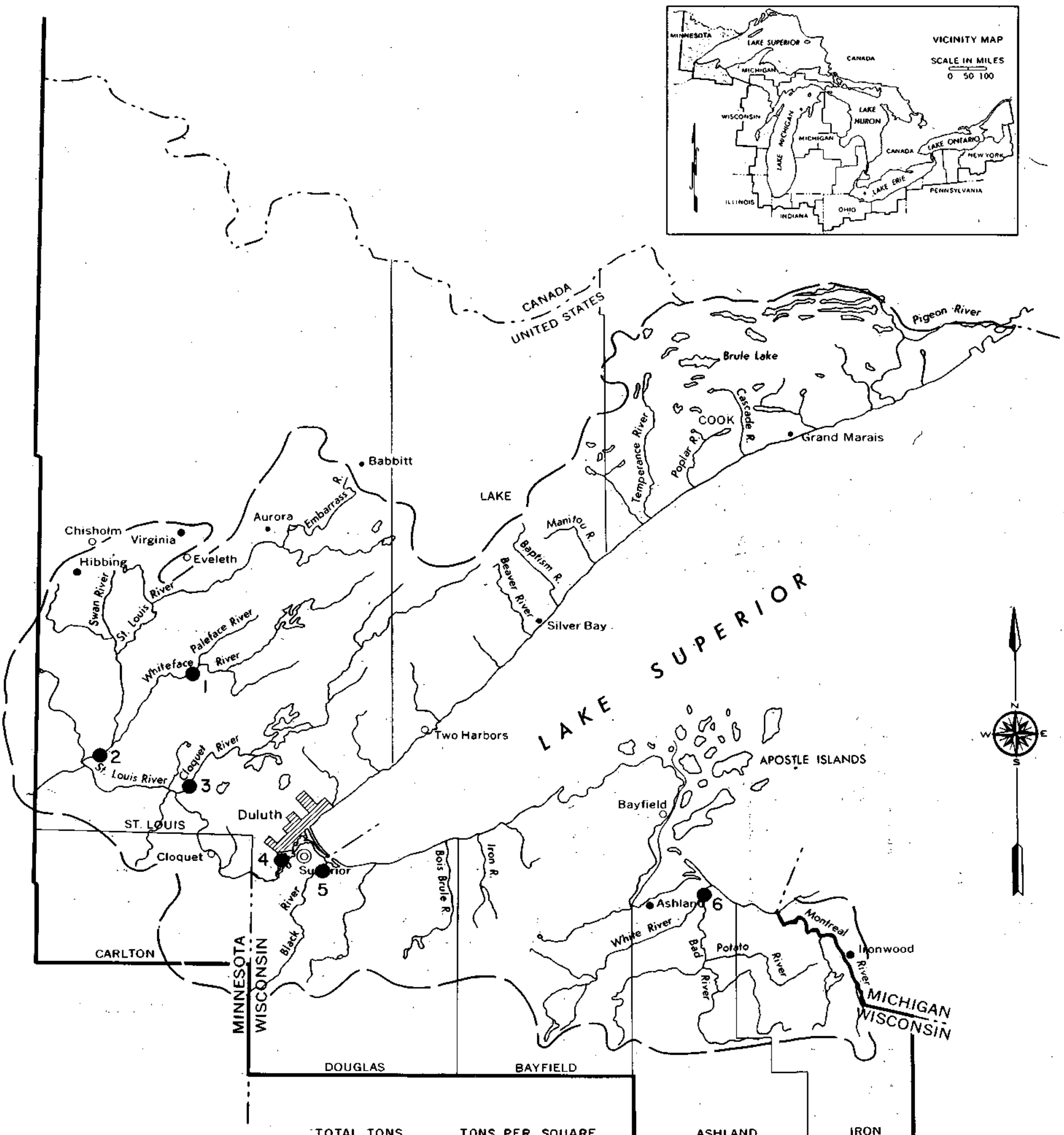
2.4 Trends in Sediment Production Rates

The rate and amount of sediment delivered to a downstream point is a function of the quantity of solids available for transport and the capacity of the individual stream system to transport these solids. Thus, sediment production rates will vary according to the characteristics of the watershed. Capacity to transport sediment is dependent on watershed relief, hydraulics, shape, and vegetative characteristics. Available solids are a product of soil erodibility, precipitation, cover, and other characteristics.

Most factors that control the capacity to transport sediment in a given watershed generally remain constant or have very slow rates of change. Factors that control the availability of solids for transport can change more rapidly. Cover and runoff characteristics may change most rapidly. These are the factors whose changes are reflected in the trends of erosion rates discussed in Section 1.

Since the factors that control capacity to transport are constant or very slow to change, sediment production rates will parallel closely the changes in available solids. These rates will vary with the changes in erosion rates and the input of other solids into the stream system. Thus, the trend in sediment production rates will closely parallel the trend in erosion rates. Generally, forest land provides the greatest cover protection against erosion. Sediment production rates are the least in Great Lakes Basin areas where forest cover is most extensive. A special analysis made by the U.S. Forest Service shows this high correlation between the percentage of forest cover and sediment production rates.

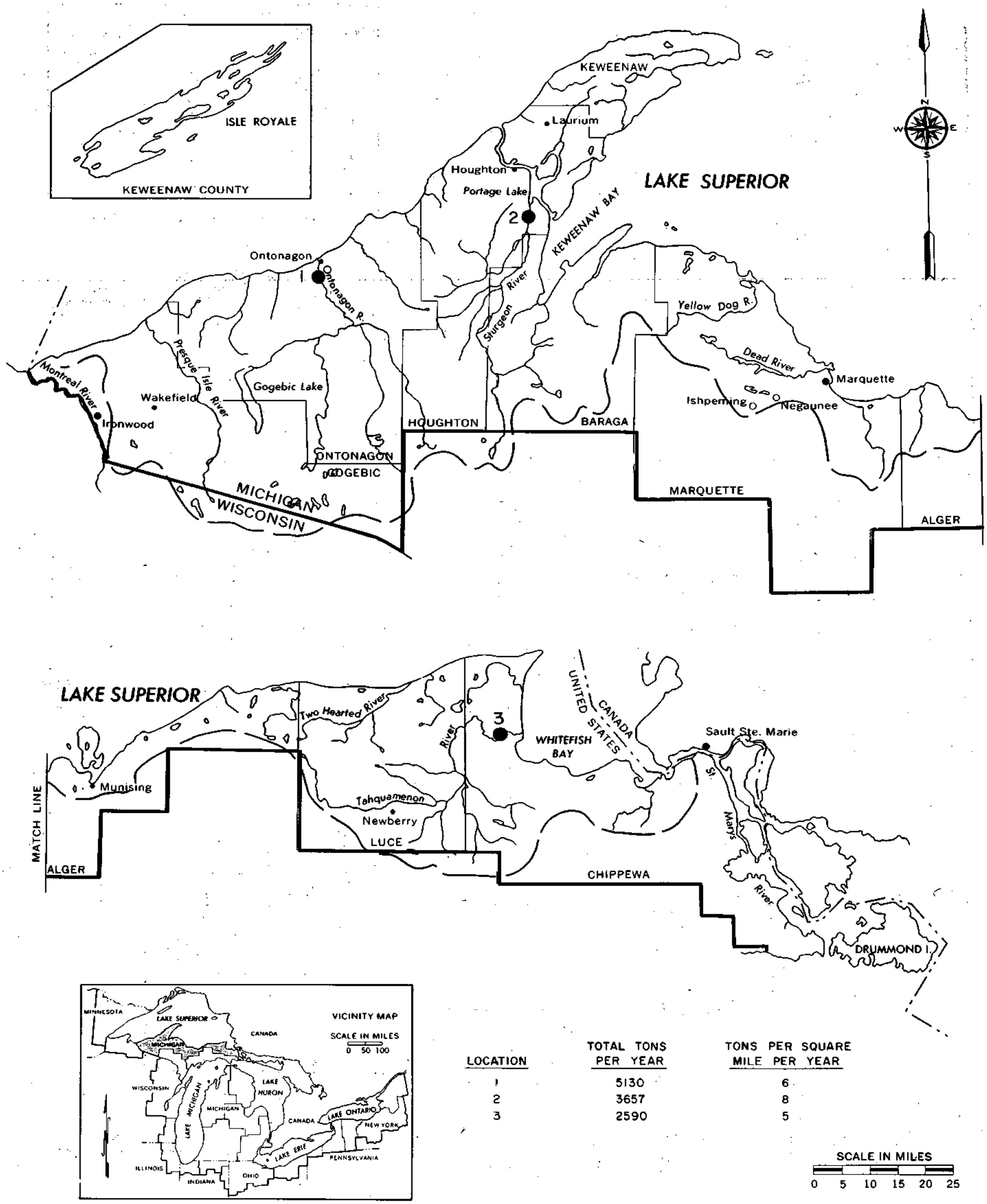
Changes in the individual watershed that affect the opportunity for lodgment of the sediment or other solids will alter sediment production rates. Installation of a floodwater retarding reservoir will increase the opportunity for lodgment of sediment. Alterations in channel shape, gradient, or location will also change the sediment production rate. Therefore to predict trends in sediment production rates, some knowledge of future projects is needed. Unfortunately this knowledge was not available at the time of this erosion and sedimentation study.



LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	317	1
2	6720	4
3	3850	6
4	11650	3
5	2760	18
6	10240	10

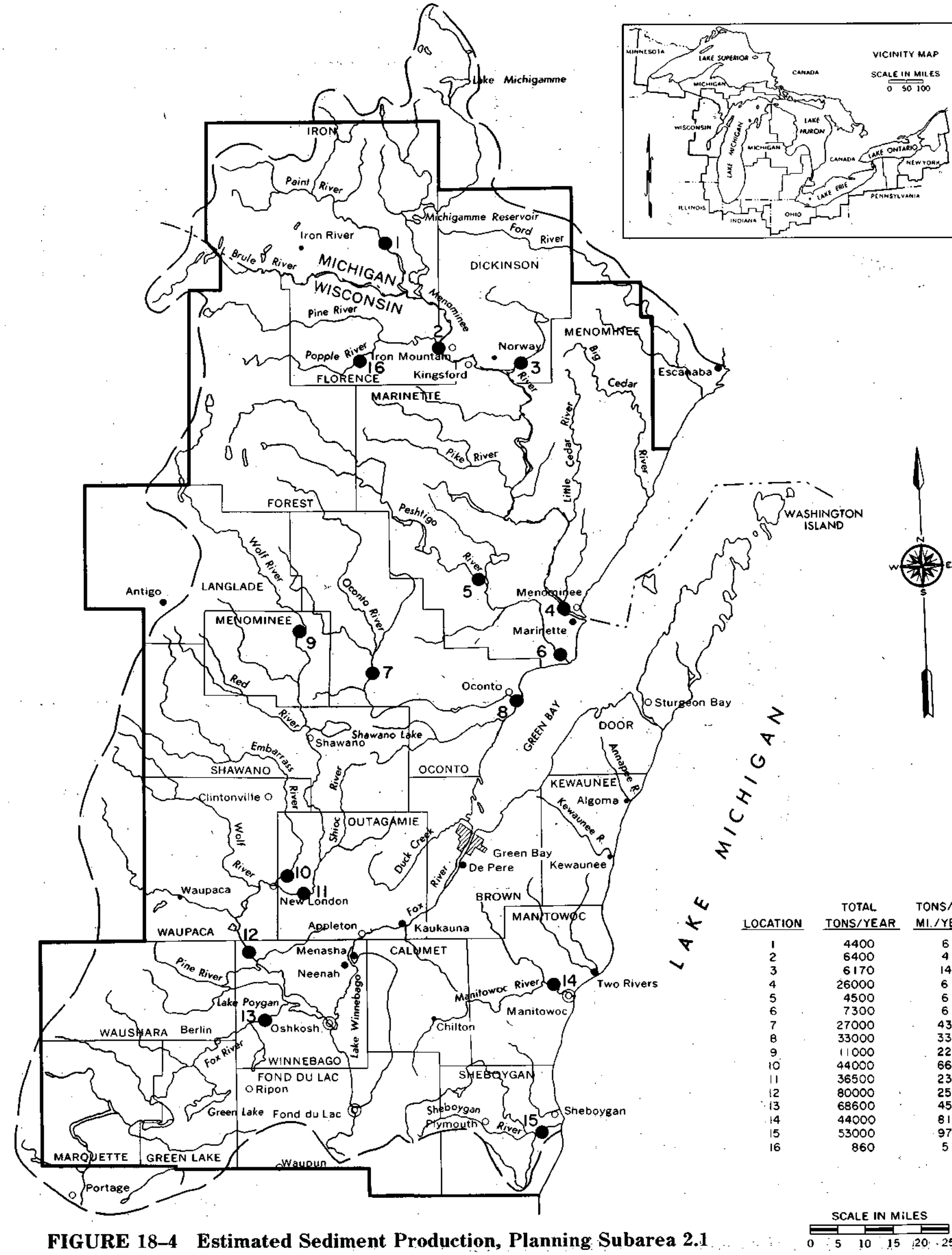
SCALE IN MILES
0 5 10 15 20 25

FIGURE 18–2 Estimated Sediment Production, Planning Subarea 1.1



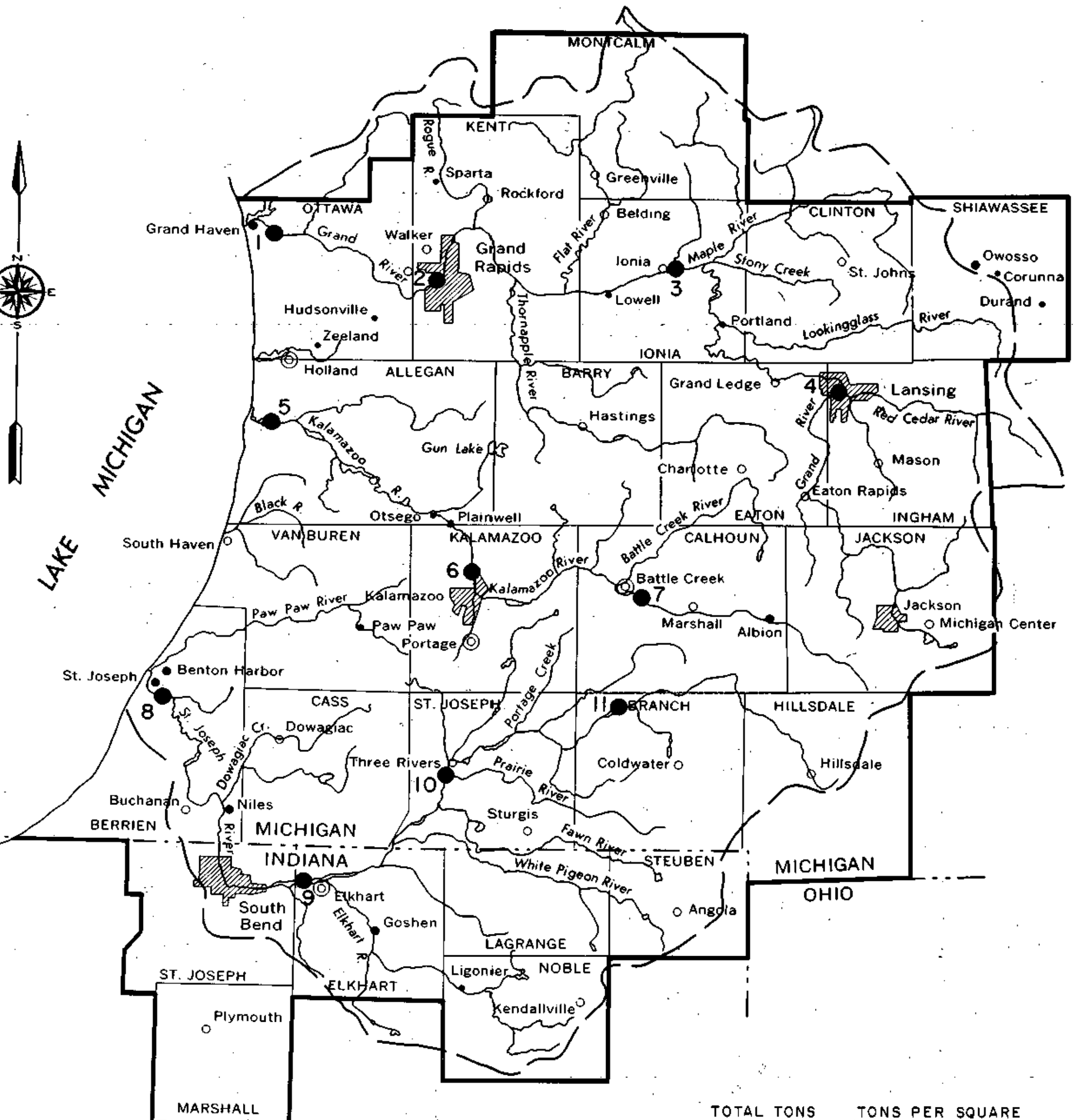
LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	5130	6
2	3657	8
3	2590	5

FIGURE 18-3 Estimated Sediment Production, Planning Subarea 1.2

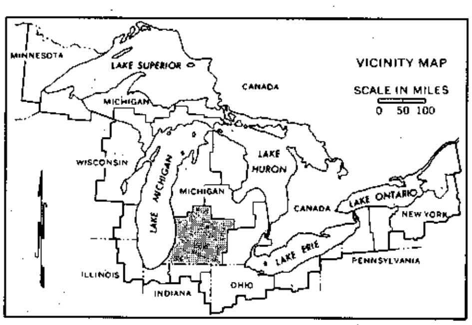


LOCATION	TOTAL TONS/YEAR	TONS/SQ. MI./YEAR
1	4400	6
2	6400	4
3	6170	14
4	26000	6
5	4500	6
6	7300	6
7	27000	43
8	33000	33
9	11000	22
10	44000	66
11	36500	23
12	80000	25
13	68600	45
14	44000	81
15	53000	97
16	860	5

FIGURE 18–4 Estimated Sediment Production, Planning Subarea 2.1

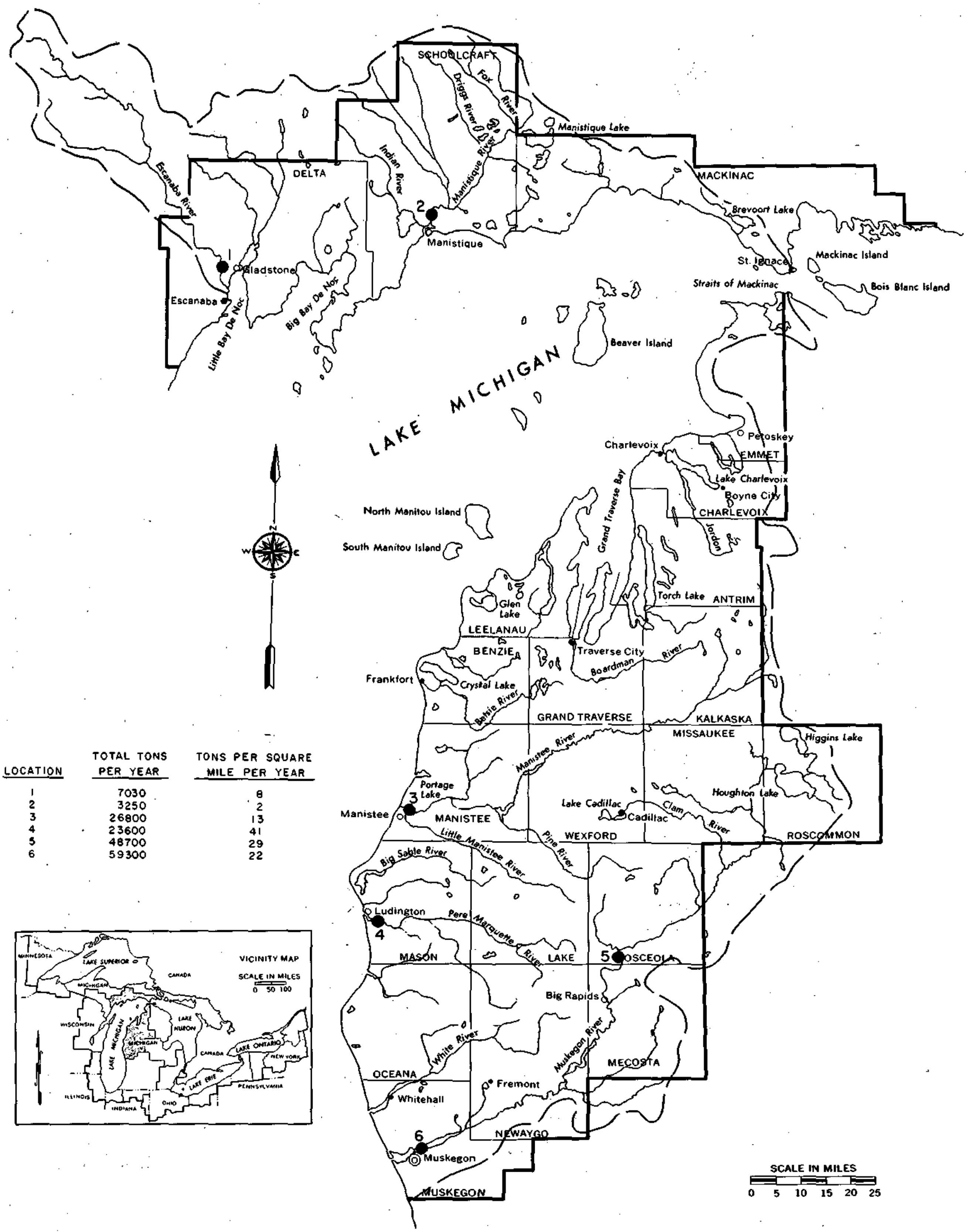


LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	225000	41
2	205000	44
3	140000	48
4	100000	82
5	125000	64
6	88000	87
7	78000	96
8	255000	53
9	190000	57
10	120000	90
11	36000	180



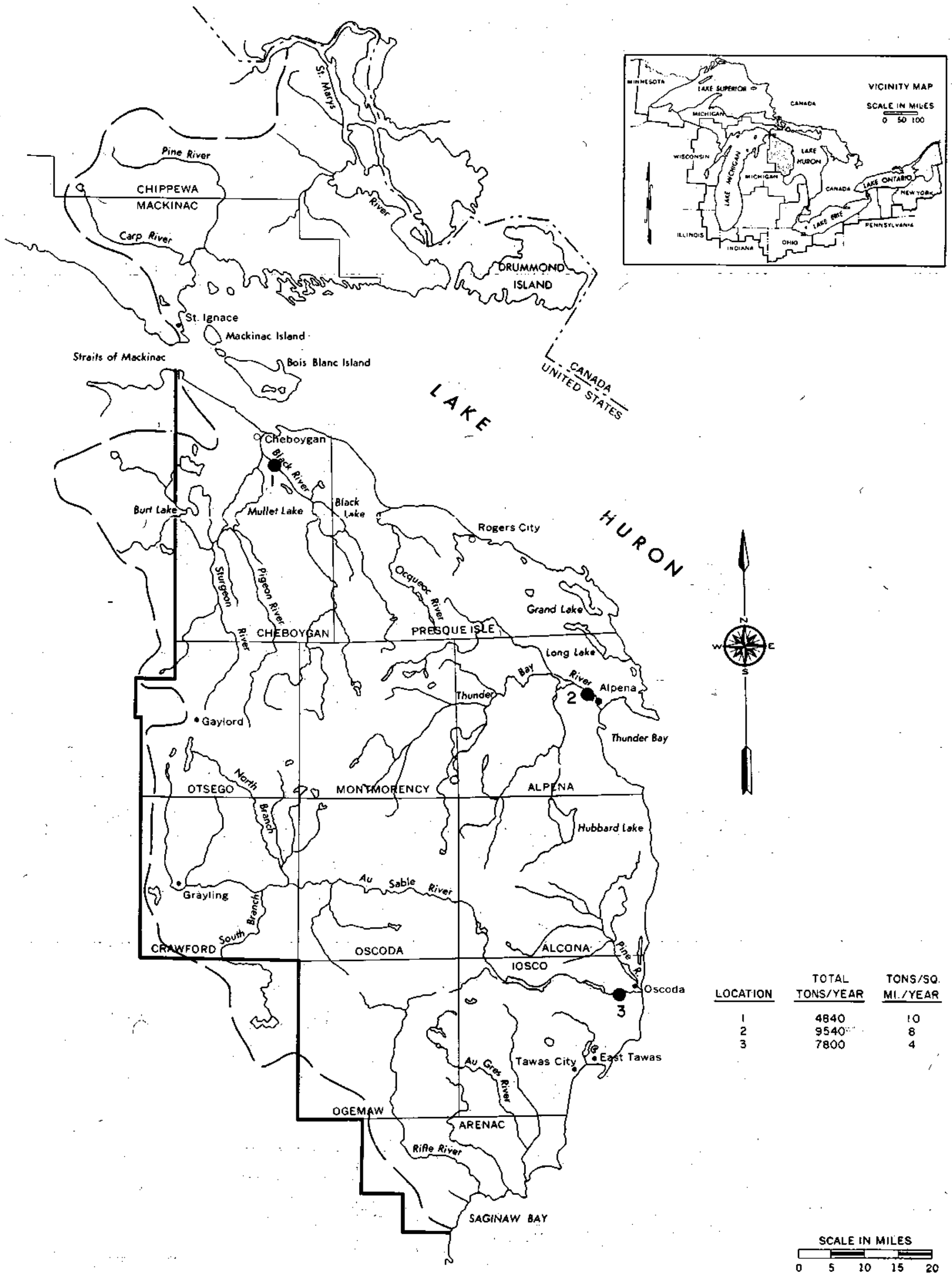
SCALE IN MILES
0 5 10 15 20 25

FIGURE 18–5 Estimated Sediment Production, Planning Subarea 2.3



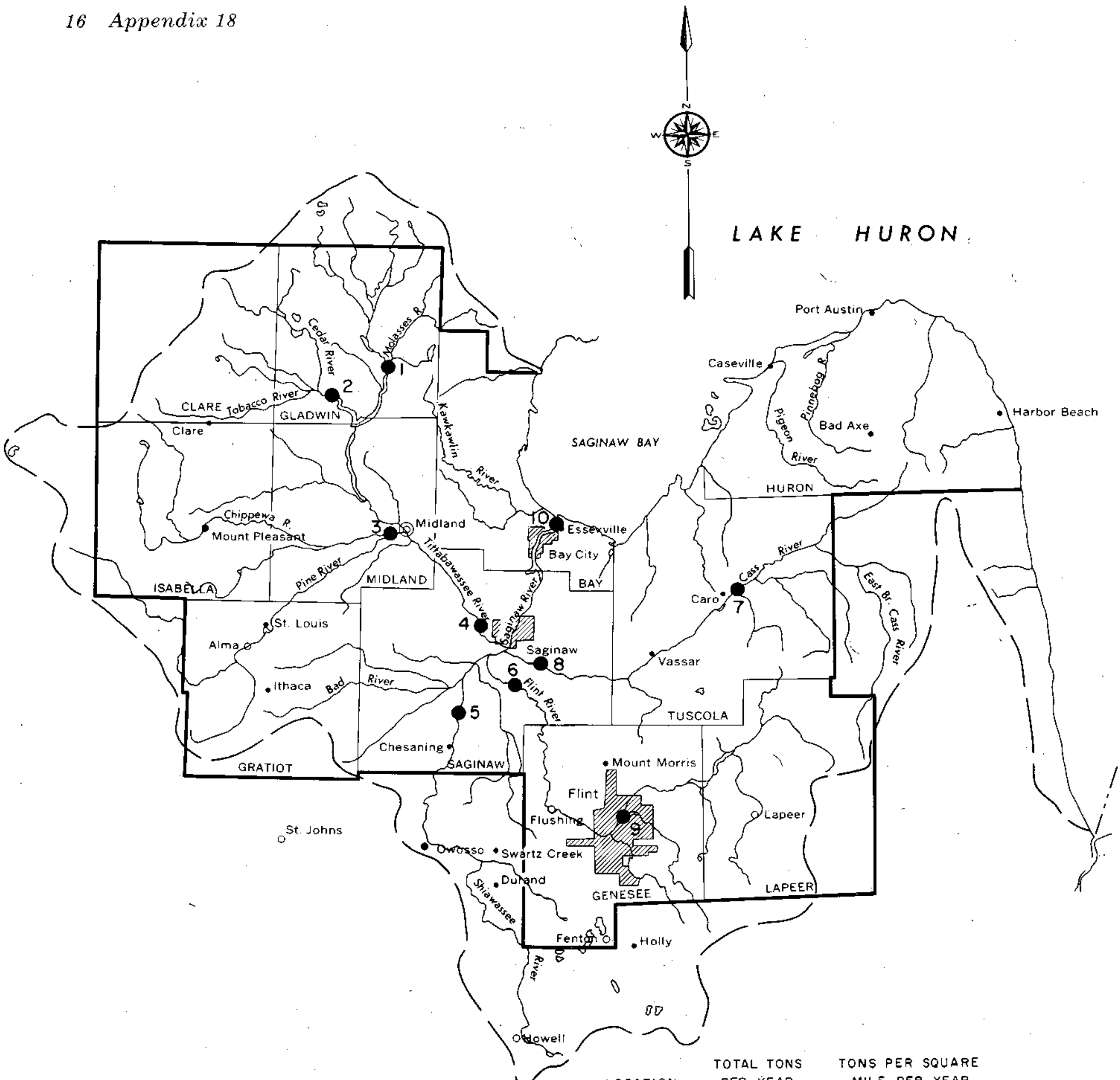
LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	7030	8
2	3250	2
3	26800	13
4	23600	41
5	48700	29
6	59300	22

FIGURE 18–6 Estimated Sediment Production, Planning Subarea 2.4



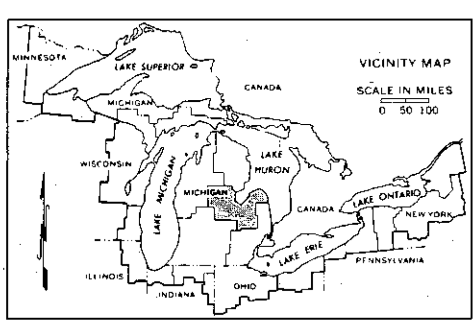
LOCATION	TOTAL TONS/YEAR	TONS/SQ. MI./YEAR
1	4840	10
2	9540	8
3	7800	4

FIGURE 18–7 Estimated Sediment Production, Planning Subarea 3.1



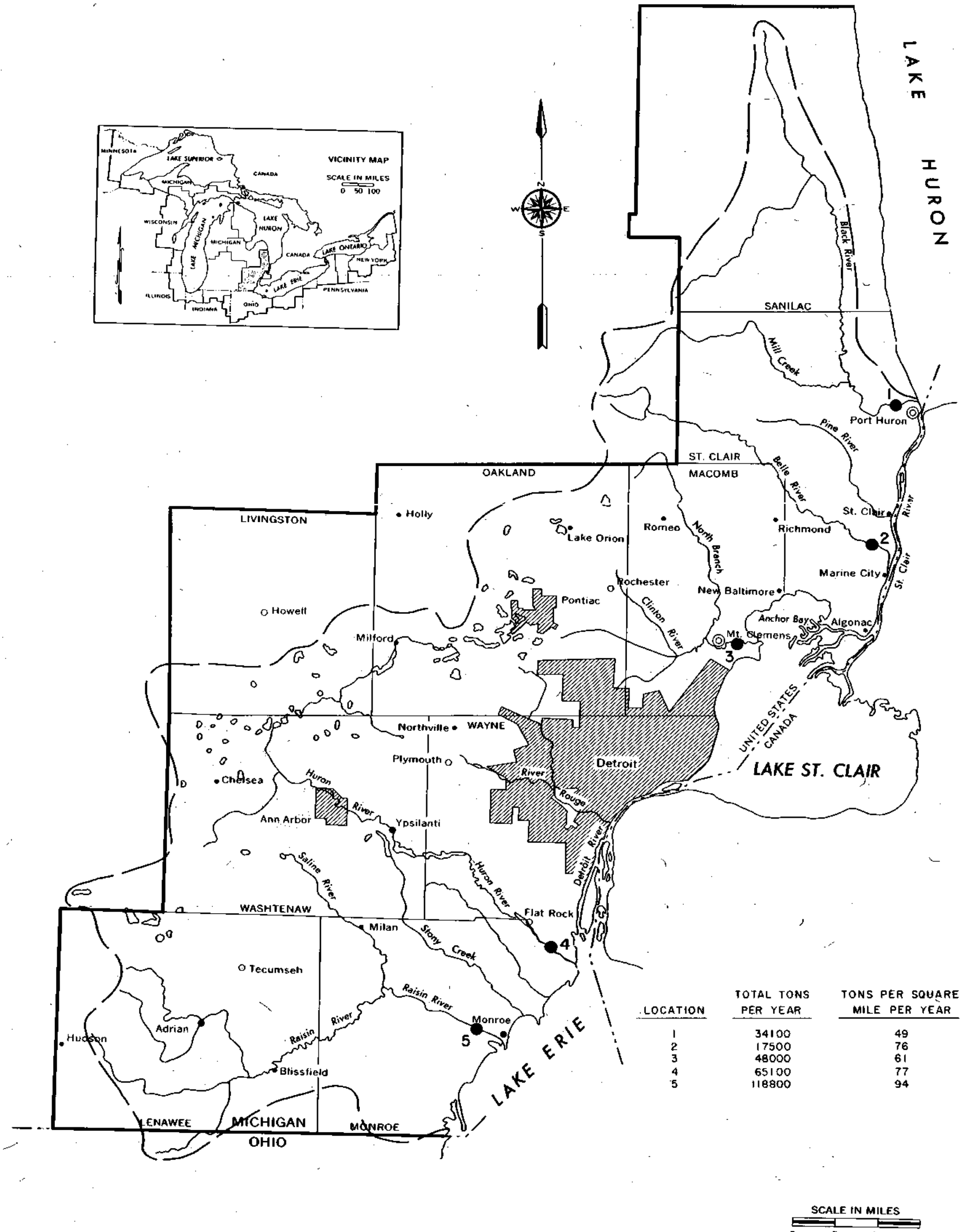
LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	6080	14
2	8650	19
3	60300	59
4	60000	31
5	41700	76
6	57300	45
7	36700	55
8*	52500	57
9	39600	57
10	135800	22

*MEASURED DATA BY U.S.G.S. BASED UPON LONG TIME RECORD.



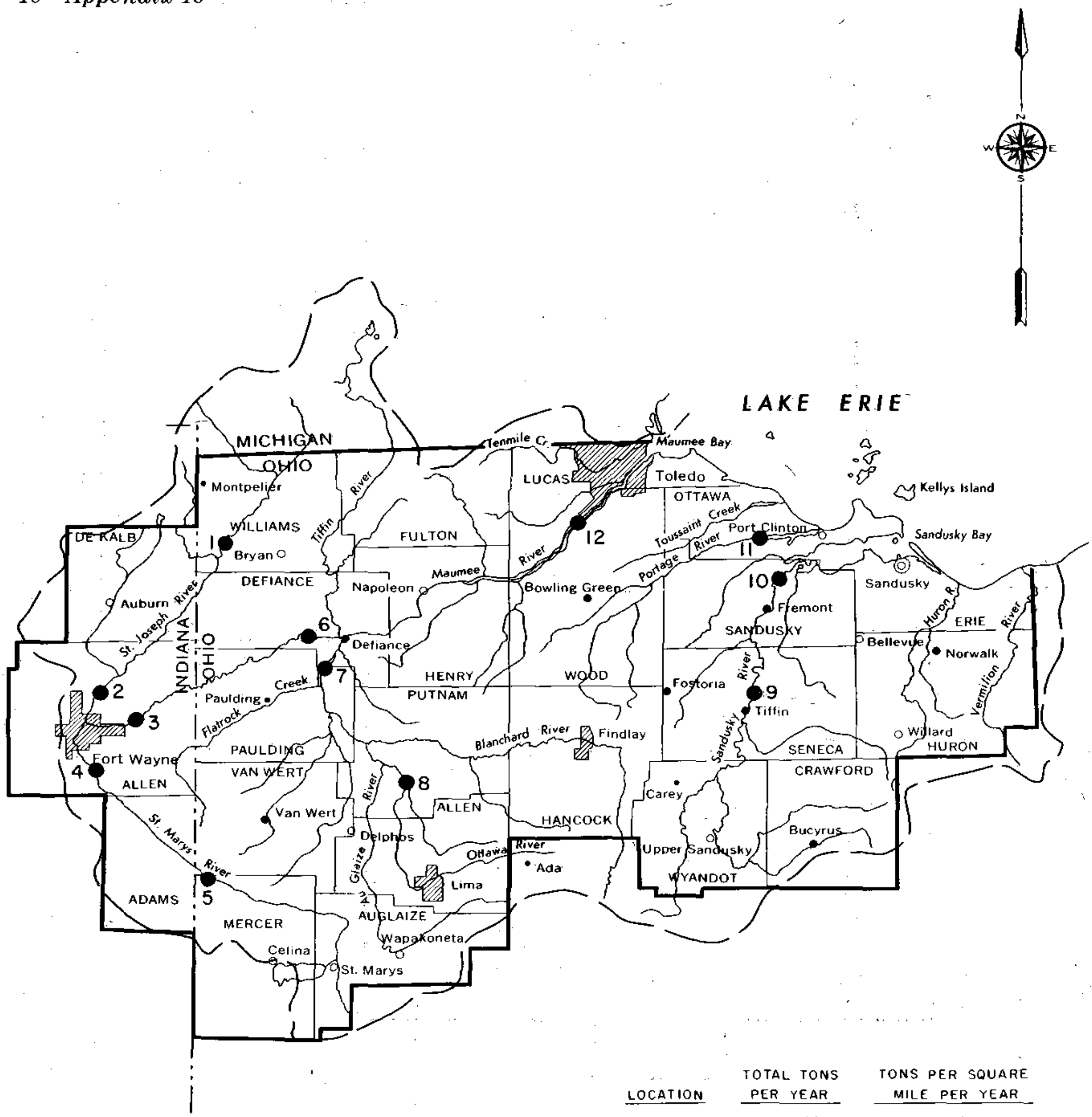
SCALE IN MILES
0 5 10 15 20

FIGURE 18-8 Estimated Sediment Production, Planning Subarea 3.2



LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	34100	49
2	17500	76
3	48000	61
4	65100	77
5	118800	94

FIGURE 18–9 Estimated Sediment Production, Planning Subarea 4.1



LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	62000	170
2	130000	125
3	240000	130
4*	139000	163
5	66000	190
6	440000	74
7	215000	90
8	96000	135
9	102000	102
10*	226000	161
11*	89000	180
12*	1179000	173

*MEASURED DATA BY U.S.G.S. BASED UPON LONG TIME RECORD.

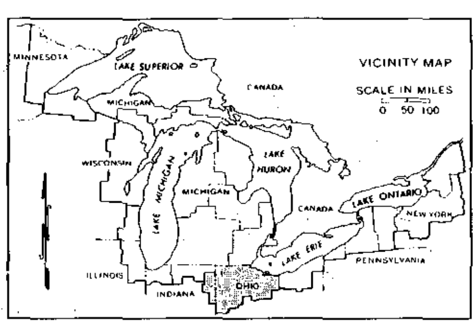
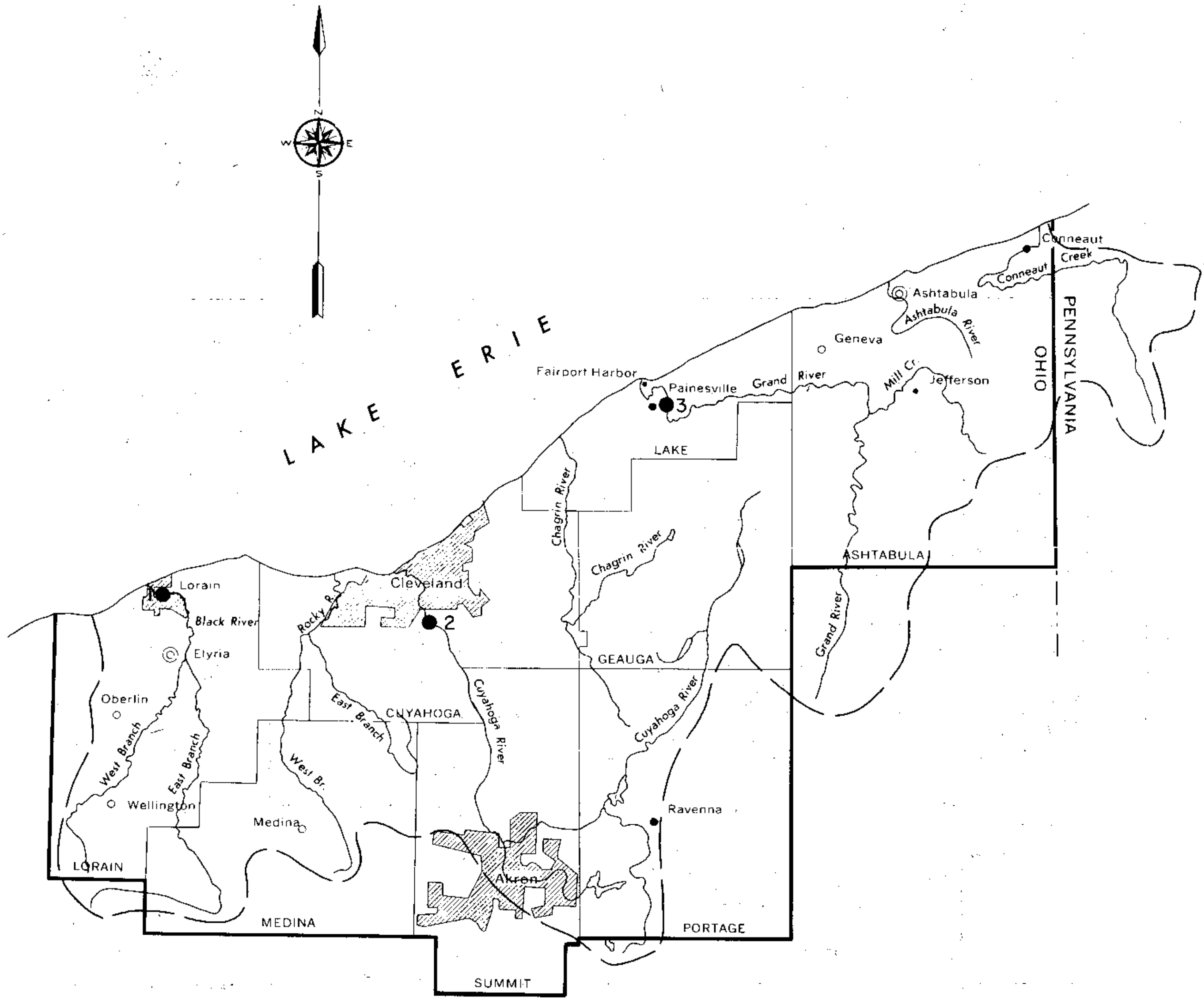
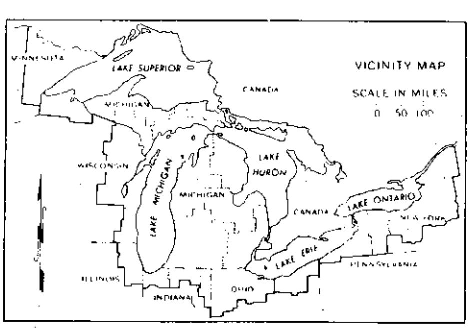


FIGURE 18–10 Estimated Sediment Production, Planning Subarea 4.2



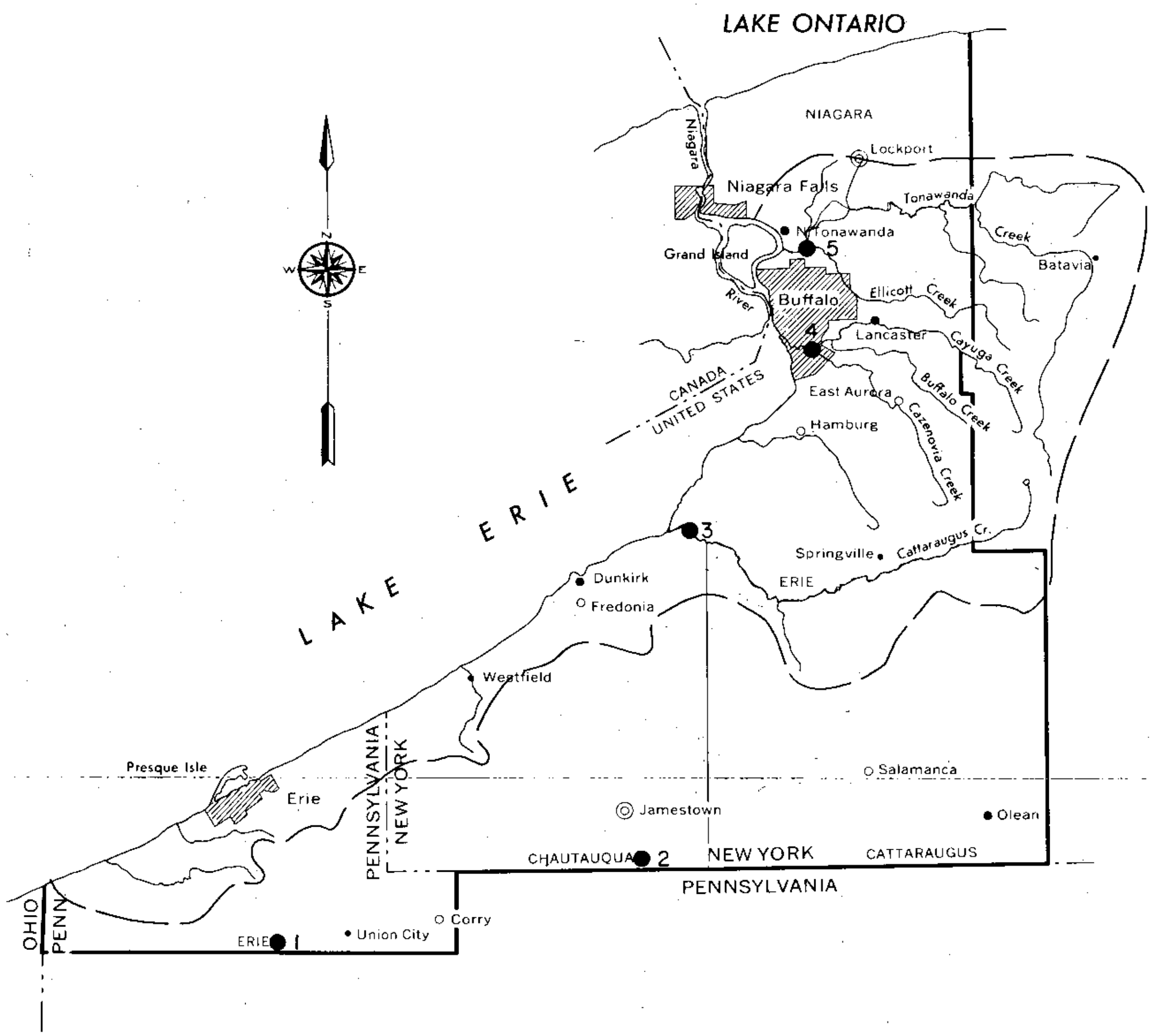


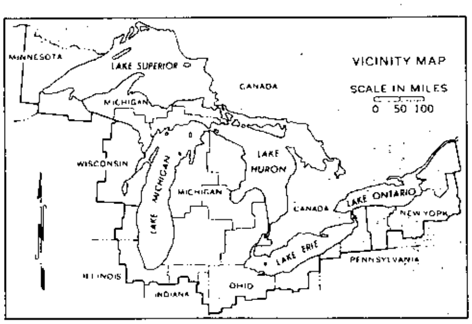
LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	67100	142
* 2	200600	254
3	22500	34

* MEASURED DATA BY U.S.G.S. BASED UPON LONG TIME RECORD

SCALE IN MILES
0 5 10 15

FIGURE 18–11 Estimated Sediment Production, Planning Subarea 4.3

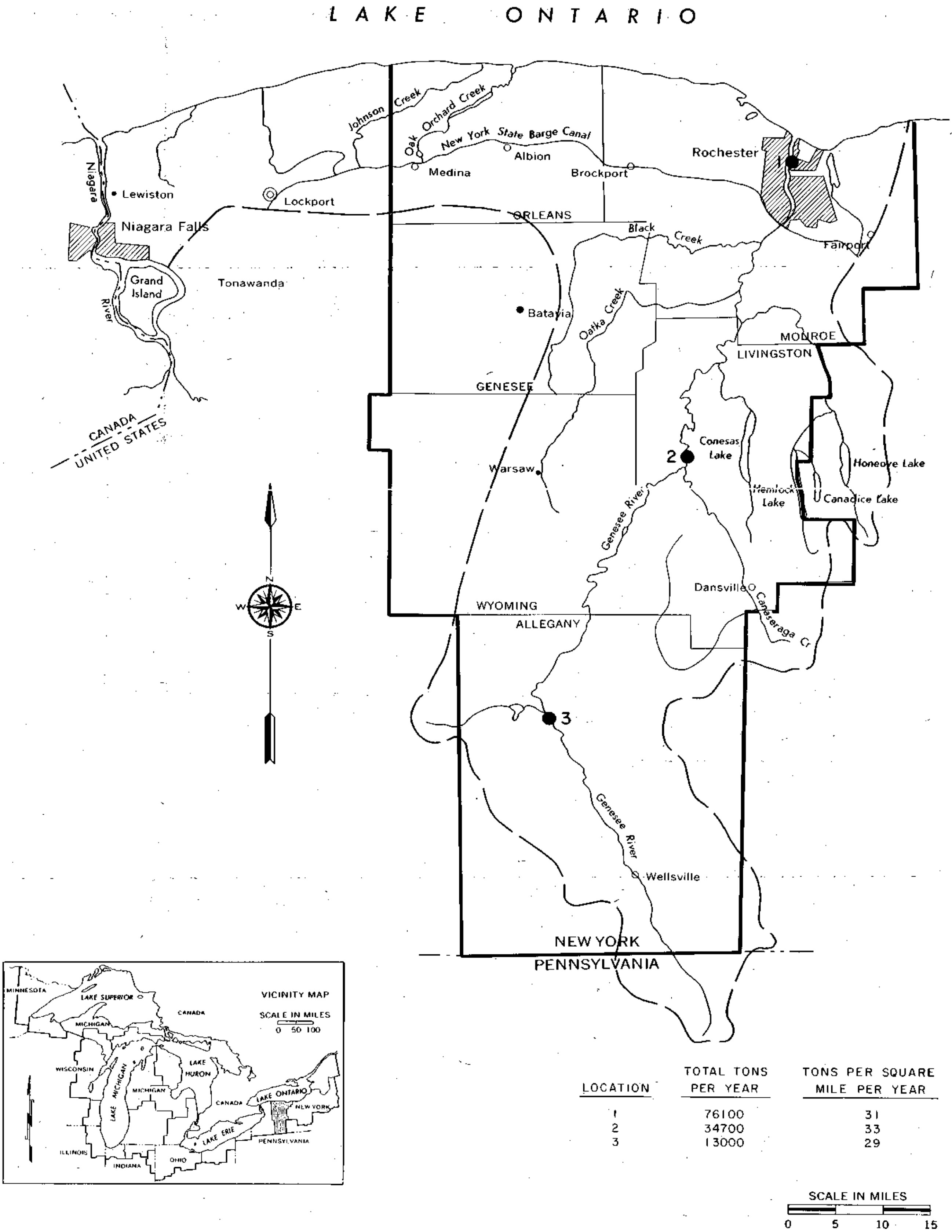




LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	17500	72
2	22500	40
3	18000	33
4	23000	65
5	24000	40

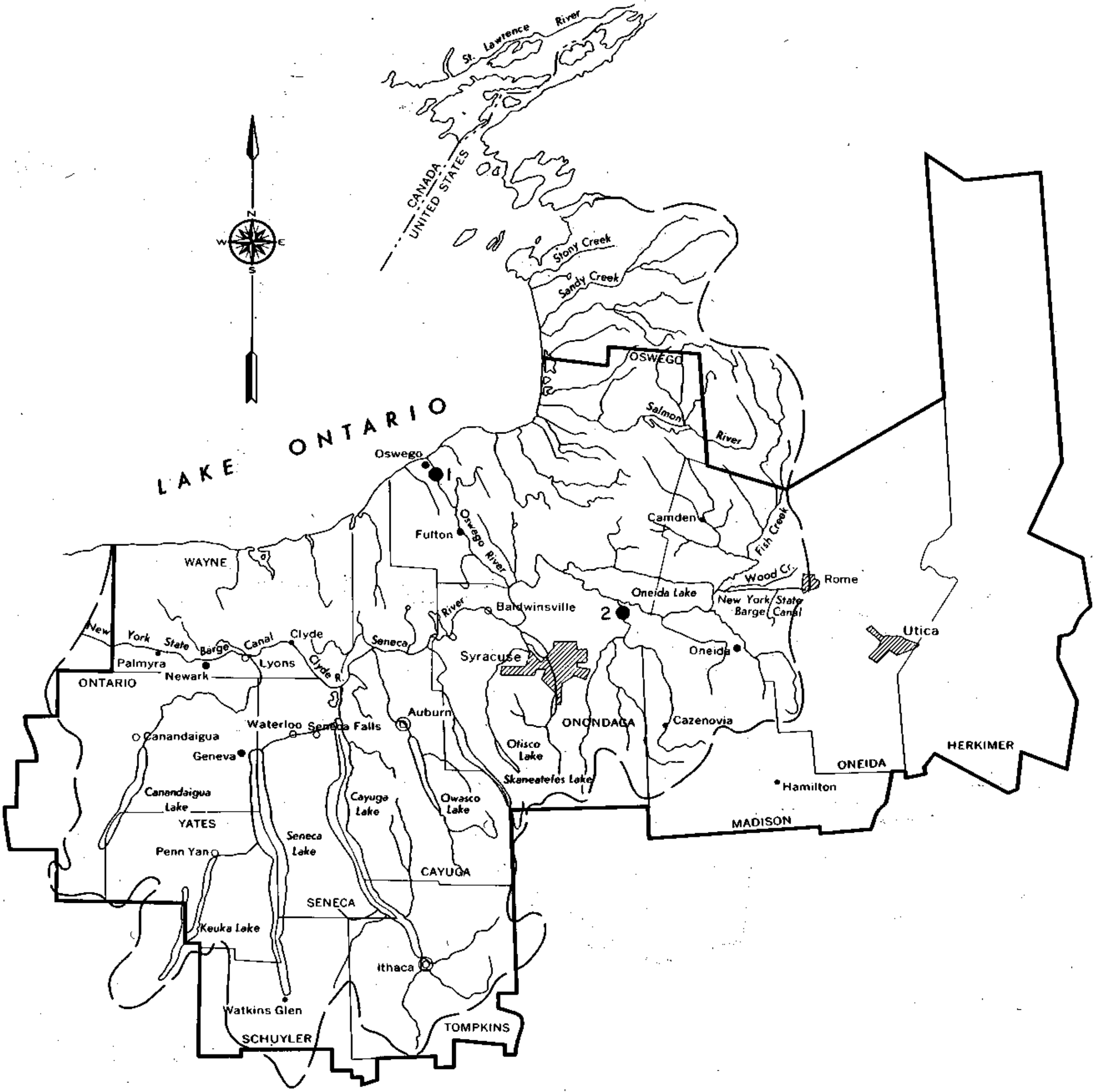
SCALE IN MILES
0 5 10 15 20

FIGURE 18–12 Estimated Sediment Production, Planning Subarea 4.4



LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	76100	31
2	34700	33
3	13000	29

FIGURE 18–13 Estimated Sediment Production, Planning Subarea 5.1



LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	136500	27
2	34700	80

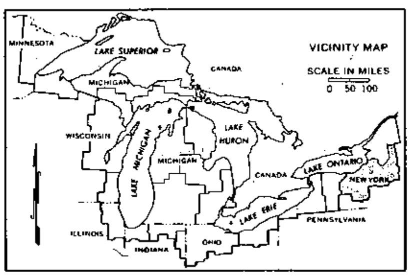
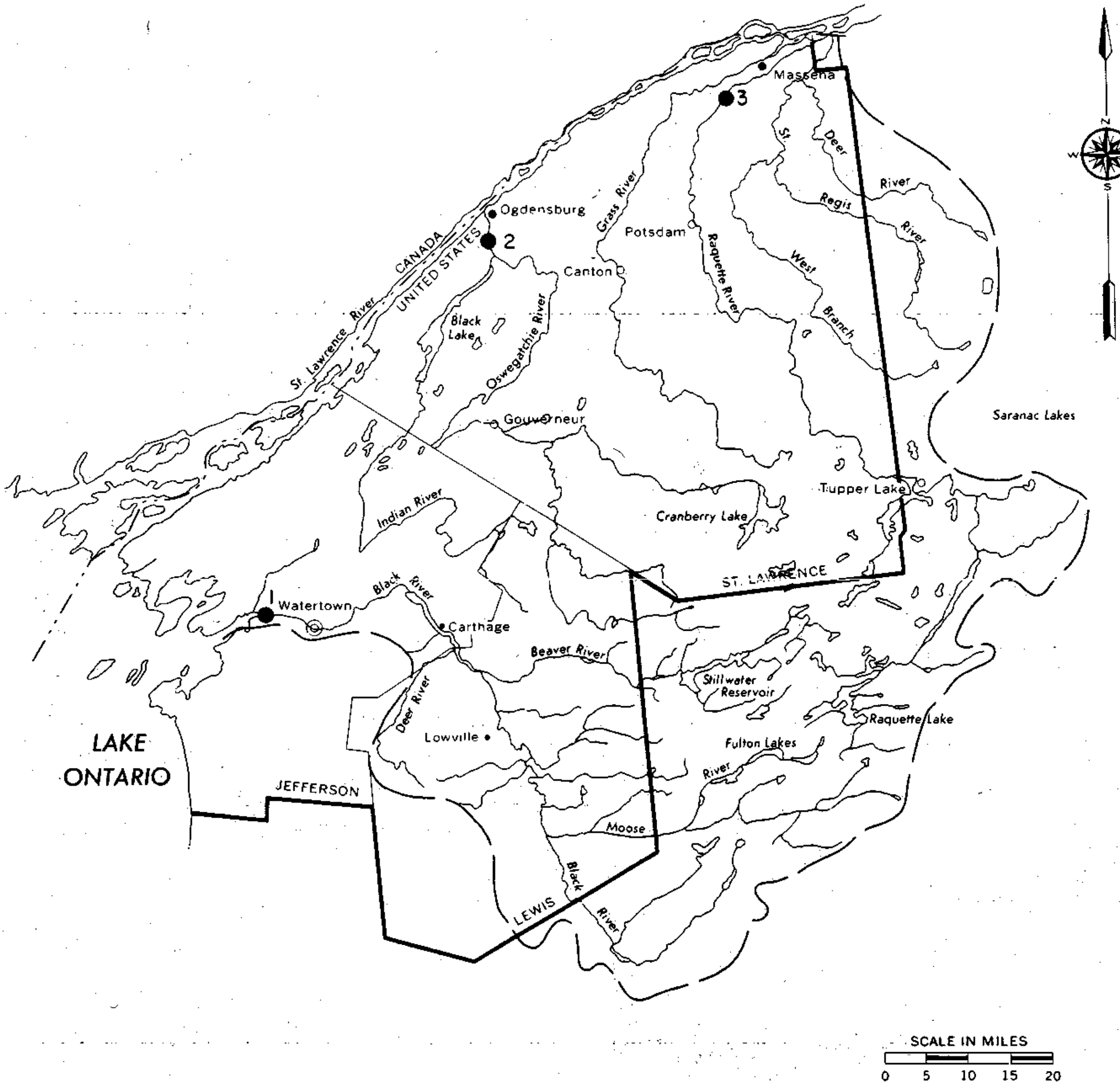
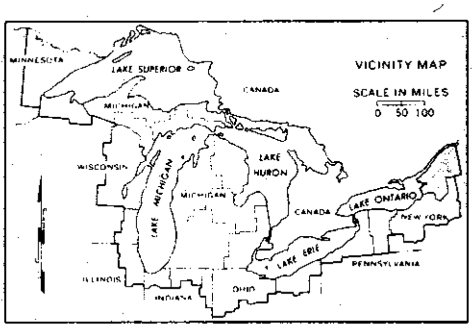


FIGURE 18–14 Estimated Sediment Production, Planning Subarea 5.2





LOCATION	TOTAL TONS PER YEAR	TONS PER SQUARE MILE PER YEAR
1	35500	18
2	25500	15
3	10300	9

FIGURE 18–15 Estimated Sediment Production, Planning Subarea 5.3

Section 3

GROSS EROSION RATES

Soil erosion occurs in many forms. Aspects of erosion have been covered in separate sections in this study. The erosion rates of these various forms are combined in this section and expressed as gross erosion rates. Included are sheet erosion rates, streambank and roadside erosion rates, and the erosion rates from urban construction in the major metropolitan complexes.

3.1 Components of Gross Rates

The present gross erosion rates for the Great Lakes Basin are presented in the maps of the 15 planning subareas in the Basin. The values were based on the following information:

(1) the base sheet erosion rates (present) for the various counties, as enumerated in Section 4, Intensity of Sheet Erosion Rates

(2) the value of 27 tons per square mile from streambank erosion developed in Section 7, Distribution and Intensity of Damage from Streambank Erosion

(3) the value of 5 tons per square mile from roadside erosion computed from data from the Special Roadside Erosion Study[8] made in Wisconsin and discussed in Section 5. Two assumptions were made: that the acres of roadside erosion found in Wisconsin would be representative on an acres-per-square-mile basis for the entire Great Lakes area, and that an erosion rate of 20 tons per acre of eroding area per year would also be representative.

(4) erosion rates from construction activity in the 18 metropolitan complexes, as evaluated in Section 6. The following values (Table 18–9) were used for the 18 metropolitan complexes in positioning the lines.

(5) the value of 5 tone per square mile, included for erosion from upland gully channel erosion. Gully erosion has not been evaluated in quantitative terms, but it has been presented in qualitative terms in Section 5. Much of the rill and minor gully erosion has been included in the values in Section 4, because of the nature of the erosion process. The erosion included in the 5 tons per square mile occurs in scattered upland channels that may be bare of vegetation or partially vegetated. These gully channels are largely older land scars, but a few recent and actively cutting channels are included. The total contribution of eroded soil material from these conditions is very minor and approximately of the same magnitude as erosion from roadside cuts and ditches.

Forested land, approximately 39.8 million acres, covers approximately 52 percent of the Great Lakes Basin. Total gross erosion from this forested land is nearly 5 percent of the total for the Basin, approximately 7.7 million tons per year. Approximately 75 percent is from sheet erosion and 25 percent from other sources such as streambank and roadside ero-

TABLE 18–9 Erosion Rates for Metropolitan Complexes

Metropolitan Complex	Erosion (T/sq mi)
Duluth-Superior	64
Green Bay-Oshkosh	19
Milwaukee	173
Chicago	556
South Bend-Elkhart	140
Kalamazoo-Battle Creek	77
Grand Rapids	128
Lansing-Jackson	45
Saginaw-Flint	58
Detroit	429
Toledo	58
Ft. Wayne	192
Lorain-Elyria	128
Cleveland-Akron	332
Buffalo	77
Erie	70
Rochester	116
Syracuse	58

sion. Erosion from exposed disturbed land undergoing urban development contributes some five percent of the gross erosion in the Basin. This urban erosion occurs on less than 0.1 percent of the land area in the Basin. The remaining 90 percent of the gross erosion in the Basin is derived from the open agricultural and nonagricultural lands, nearly 48 percent of the land area in the Basin.

3.2 Isograms and Isogreros Lines

The erosion from the five sources was combined and rates were expressed in terms of tons per acre per year. These rates are expressed by isograms. Lines of equal gross erosion are called isogreros on the following maps. These smooth out the abrupt changes that would appear by merely listing computed gross erosion rates for the individual counties. Computed erosion rates were placed in the geometric center of each county. The lines connect points of equal rates and were positioned by interpolating between the various point values of gross erosion rates.

Figures 18–31c through 18–45c show the gross soil erosion from the major erosion sources in estimated mean annual tons per acre per year. The isogreros lines smooth these values to reflect regional differences, local variation, and rate of change.

Section 4

THE INTENSITY OF SHEET EROSION RATES

The determination of the base sheet erosion rates in the Great Lakes Basin was a major task in the development of this appendix. The present and future sheet erosion rates are the crucial elements in the evaluation of the degree and intensity of erosion and sedimentation. Much of the damage to land and water resources, such as eutrophication and other water quality problems, capacity loss in channels and reservoirs, and productivity loss on farm lands, is directly related to these erosion rates.

Sheet erosion is distinct from other forms of erosion because it is the removal of a fairly uniform layer of surface soil by runoff water. Sheet erosion results from other erosion processes such as rill and splash erosion. The surface remains relatively uniform and is not indented with gully channels or other irregular removal areas. This form of erosion occurs on all land and ranges from very slow geological erosion to rapid accelerated erosion where the surface soil has been bared of cover.

The base or benchmark erosion rates were developed by counties within the planning subareas in the Great Lakes Basin. For each of these 190 counties, a weighted average annual sheet erosion rate was computed. The following few paragraphs briefly describe the procedures used to calculate these weighted erosion rates.

4.1 Method of Computing Sheet Erosion Rates

Three components are involved in computing sheet erosion rates on an average annual basis:

(1) soil and slope characteristics

(2) cropping patterns and other land cover conditions

(3) regional rainfall characteristics

The universal soil loss equation,[16] which incorporates these data, is used to estimate the average annual rate. The main source of the data used in this study was the National Conservation Needs Inventory,[18] updated to 1968. These data were available by counties and by soil resource groups. The soil resource groups combine soil categories of similar physical and management characteristics. The Conservation Needs Inventory provided cropping and other cover data by soil resource group.

Based upon the descriptions of the soil resource groups, the following interpretations

TABLE 18–10 Basic Erodibility and Slope Factors by Soil Resource Group

Soil Resource Group	K Value (Basic Erodibility)	SL (Slope % - Slope Length)
1	0.37	0.25
2	0.37	0.20
3	0.37	0.50
4	0.32	0.40
5	0.45	0.40
6	0.24	0.40
7	0.22	0.40
8	0.17	0.65
9	0.45	1.80[1]
10	0.32	1.80[2]
11	0.32	1.80[2]
12	0.22	1.80
13	0.32	3.80
14	0.37	4.20
15	--[4]	--
16	0.43	0.25[3]
17	0.43	0.40
18	0.43	0.40
19	0.32	0.40
20	0.43	0.40
21	--[4]	--
22	--[4]	--
23	0.24	2.60

[1]0.40 Illinois

[2]0.65 Michigan

[3]0.50 New York

[4]Soil Resource Groups 15, 21, and 22 include level mucks and swamps and steep rocky soil and were not used in the erosion rate evaluations.

were made to establish numerical values needed for application in the universal soil loss equation. The K values describe the basic erodibility of the soil resource groups. These values reflect the relative susceptibility to erosion of the predominant soil types within the soil resource group. The soil loss values reflect predominant slope characteristics of the soil resource group. Generally, steeper slopes are more susceptible to erosion than lesser slopes. This susceptibility is reflected numerically in the soil loss (SL) values.

The Conservation Needs Inventory enumerated a wide variety of crop cover conditions by the soil resource groups. These data were interpreted in terms of effectiveness of cover to reduce erosion rates. Four broad cover categories were adopted for the many crops, pasture, and woodland items on the CNI: row crops; small grains; pasture, hay land, and meadow (grasslands); and forest lands. These crop and cover data provided the basis for establishing the numerical values (C values) for use in the universal soil loss equation.

Another factor used in the soil loss equation to compute sheet erosion rates is the rainfall factor, R. Research data show that when factors other than rainfall are held constant, storm losses from erosion are directly proportional to the product value of two rainstorm characteristics. These are total kinetic energy of the storm times its maximum 30-minute intensity. These are called EI values. The rainfall erosion index at a particular location is the longtime average yearly total of the storm EI values. The factor R is the number of erosion index units in a normal year's rain. Figure 18–46c is a map showing lines of equal R values, called isoerodents. Values from this map are used directly in the soil equation.

4.2 Sheet Erosion Rates by County

A summarization table was made for each county in the Basin listing the acres in each cover category by soil resource groups. Generally, 10 to 15 soil resource groups were represented in each county. A program that contained the various numerical values for the soil resource groups and the cover categories was devised for a desk computer. The necessary multiplication procedures used in the universal soil loss equation and the various weighting procedures were also built into the program. A weighted average annual sheet erosion rate for each county was the output of the program sequence adjusted for the soil and cover characteristics of the individual county. These average annual sheet erosion rates are expressed in tons per acre per year.

TABLE 18–11 Values for Cover Conditions

Cover Category	C Value
Row Crops	0.500
Small Grains	0.200
Pasture, Hay, & Meadow	0.020
Woodland	0.005

The present computed average annual sheet erosion rates for counties in the Great Lakes Basin range from 0.1 ton per acre per year in Schoolcraft and Crawford Counties in Michigan to nearly 9.0 tons per acre in Will County, Illinois. The differences in these rates strongly reflect the differences in cover, soil and rainfall characteristics. Schoolcraft and Crawford Counties each have less than one-half of one percent row crop acreage and more than 90 percent woodland. Will County has more than 65 percent cropland and less than 10 percent woodland. In addition, the rainfall is approximately twice as erosive in Will County as it is in Crawford and Schoolcraft Counties. Soil characteristics are also a factor. Crawford County, Michigan, has sandy soil types covering approximately 90 percent of its surface. Will County, Illinois, has less than 5 percent sandy soil types. Sandy types have generally lower basic erodibility factors. Table 18–12 summarizes the current weighted average annual sheet erosion rates of the counties lying within the planning subareas.

4.3 Sheet Erosion Rates by Planning Subarea

Table 18–13 lists the weighted average annual sheet erosion rates for the planning subareas in the Great Lakes Basin. Shown are the present rates, as well as those projected to target years 1980, 2000 and 2020.

In many cases the sheet erosion rates shown on Table 18–13 are greater than the gross erosion rates summarized on Table 18–4. This is because the sheet erosion rates are computed only on rural lands, which include land in both agricultural and nonagricultural uses. The urban built-up land has been subtracted, and the erosion was computed separately for this urban land (as is shown in Tables 18–2 and 18–3). Rates of erosion on urban built-up land are generally far less than the average rates

TABLE 18–12 Current Weighted Average Annual Sheet Erosion Rates by County (Tons/Acre/Year)

State and County	Present Sheet Erosion
Illinois	
Cook	7.5
Du Page	8.0
Kane	7.8
Lake	5.6
McHenry	5.2
Will	8.7
Indiana	
Adams	5.7
Allen	5.7
De Kalb	5.5
Elkhart	5.9
Lagrange	5.3
Lake	8.3
La Porte	7.4
Marshall	6.5
Noble	6.6
Porter	7.4
St. Joseph	5.5
Starke	6.6
Steuben	4.6
Michigan	
Alcona	0.5
Alger	0.2
Allegan	3.9
Alpena	0.3
Antrim	1.3
Arenac	1.3
Baraga	0.1
Barry	3.6
Bay	2.2
Benzie	0.6
Berrien	5.8
Branch	3.8
Calhoun	3.7
Cass	5.6
Charlevoix	0.3
Clare	0.6
Clinton	3.9
Chippewa	0.2
Cheboygan	0.3
Crawford	0.1
Delta	0.2
Dickinson	0.4
Eaton	3.4
Emmet	0.6
Genesee	2.3
Gladwin	0.4
Gogebic	0.2
Grand Traverse	0.9
Gratiot	3.6
Houghton	0.2
Huron	2.1
Hillsdale	4.0
Ingham	3.7
Ionia	2.3
Iosco	0.2
Iron	0.2
Isabella	2.3
Jackson	2.6
Kalamazoo	3.6
Kalkaska	0.2
Kent	4.0
Keweenaw	0.1
Lake	0.5
Lapeer	1.8
Leelanau	1.0
Lenawee	4.9
Livingston	2.3
Luce	0.1
Mackinac	0.1
Macomb	3.4
Manistee	1.4
Marquette	0.2
Mason	1.3
Mecosta	1.7
Menominee	0.8
Midland	1.2
Missaukee	0.4
Monroe	3.7
Montcalm	2.9
Montmorency	0.2
Muskegon	0.9
Newaygo	1.1
Oakland	1.5
Oceana	2.0
Ogemaw	0.7
Ontonagon	0.3
Osceola	1.2
Oscoda	0.3
Otsego	0.3
Ottawa	2.3
Presque Isle	0.2
Roscommon	0.1
Saginaw	2.4
St. Clair	1.7
St. Joseph	4.2
Sanilac	1.8
Schoolcraft	0.1
Shiawassee	3.0
Tuscola	2.1
Van Buren	4.7
Washtenaw	3.3
Wayne	3.3
Wexford	0.4
Minnesota	
Carlton	0.4
Cook	0.2
Lake	0.2
St. Louis	0.2
New York	
Allegany	0.8
Cattaraugus	1.3
Cayuga	2.3
Chautauqua	0.9
Erie	1.2
Genesee	1.5
Herkimer	0.7
Jefferson	1.1
Lewis	1.2
Livingston	2.2
Madison	2.0
Monroe	1.7
Niagara	1.2
Oneida	1.6
Onondaga	2.7
Ontario	2.9
Orleans	2.0
Oswego	1.0
St. Lawrence	0.3
Schuyler	2.5
Seneca	2.3
Tompkins	1.9
Wayne	2.2
Wyoming	2.4
Yates	2.7
Ohio	
Allen	4.4
Ashtabula	0.9
Auglaize	4.9
Crawford	4.8
Cuyahoga	0.9
Defiance	5.2
Erie	4.0
Fulton	5.6
Geauga	1.5
Hancock	4.6
Henry	3.7
Huron	4.8
Lake	1.7
Lorain	3.7
Lucas	4.4
Medina	3.4
Mercer	4.9
Ottawa	4.8
Paulding	7.1
Portage	2.4
Putnam	6.7
Sandusky	5.0
Seneca	4.5
Summit	1.2
Van Wert	4.9
Williams	5.0
Wood	4.5
Wyandot	3.2
Pennsylvania	
Erie	1.2
Wisconsin	
Ashland	0.3
Bayfield	0.6
Brown	2.5
Calumet	2.7
Door	0.8
Douglas	0.2
Florence	0.8
Fond du Lac	3.6
Forest	0.2
Green Lake	2.7
Iron	0.3
Kenosha	4.3
Kewaunee	2.9
Langlade	1.0
Manitowoc	2.5
Marinette	0.3
Marquette	1.7
Menominee	---*
Milwaukee	2.4
Oconto	1.4
Outagamie	3.0
Ozaukee	5.1
Racine	4.4
Shawano	2.4
Sheboygan	2.9
Walworth	4.8
Washington	3.9
Waukesha	3.7
Waupaca	1.9
Waushara	2.0
Winnebago	2.8

*no information available

TABLE 18-13 Weighted Average Annual Sheet Erosion Rates by Planning Subarea

Planning Subarea	Sheet Erosion Rate (T/Ac/Yr) Current	1980	2000	2020
1.1	0.28	0.28	0.26	0.26
1.2	0.19	0.18	0.17	0.17
2.1	1.55	1.45	1.26	1.52
2.2	6.20	6.16	5.50	4.96
2.3	4.25	4.29	4.25	5.30
2.4	0.72	0.59	0.48	0.61
3.1	0.38	0.37	0.31	0.31
3.2	1.93	1.97	1.14	1.44
4.1	2.75	2.75	2.17	2.48
4.2	5.00	5.24	5.49	5.85
4.3	2.07	1.76	1.72	2.05
4.4	1.16	1.04	0.71	0.71
5.1	1.63	1.40	1.28	1.28
5.2	1.84	1.58	1.08	1.30
5.3	0.71	0.60	0.56	0.56

on the adjacent agricultural lands (unless the adjacent rural land is forest land). In many cases the amount of urban built-up land in the various planning subareas is large enough to reduce the gross erosion rate of the planning subarea below the mean sheet erosion rates for the rural land. Partial explanation for variations in mean sheet erosion rates between the planning subareas may be seen in the data in Table 18-14. Sheet erosion rates are related to a number of variables. The most pronounced are summarized in this table. There is a wide range of the values for these variables.

4.4 General Discussion

Potential sheet erosion rates on individual fields and parts of fields under the ranges of soil erodibility, slope, cover, and rainfall are listed in Tables 18-10 and 18-11 and in Figure 18-36c. Theoretically, the difference between sheet erosion rates on land with the most erosive combination of soil, slope, rainfall, and cover characteristics could be 10,000 times that on land with the least erosive combination.

It is very doubtful that the extremely high rates of sheet erosion exist on more than a small amount of land. These extreme rates (which would be 150 to 200 tons per acre per year) would very likely not occur as sheet erosion but as channel (gully) erosion. However, minimum rates probably occur on extensive areas in the northern forested, level, and sand areas with low rainfall intensities.

The effects conservation practices have on sheet erosion rates are mentioned in Section 1, Trends in Erosion Rates. Section 1 also points out that conservation measures applied for erosion control to date have probably reduced erosion rates by 20 to 25 percent. Much of this reduction has been due to shifts in crop rotations and land use changes. The reductions of only a few percent are directly due to the application of mechanical erosion control measures. However, reduction of sheet erosion rates on the land where these practices are applied ranges from 50 to 80 percent or more.

Future reductions in sheet erosion rates by the application of mechanical erosion control practices are shown in Table 18-15. These are based upon rates of application of past ongoing programs and on the needed accelerated program stated in Appendix 13, *Land Use and Management*. These reductions are 5 to 10 percent less than present planning subarea sheet

TABLE 18-14 Range of Mean Values of Major Variables by Planning Subarea

Planning Subarea	Mean Sheet Erosion Rate T/Ac/Yr	Relative Rainfall Intensity	Percent of Area in: Cultivated Crops	Slopes >5%	Sandy Soil Types
1.1	0.28	85	5	45	17
1.2	0.19	75	4	43	30
2.1	1.55	95	33	24	18
2.2	6.20	150	55	16	5
2.3	4.25	125	60	24	18
2.4	0.72	85	18	58	57
3.1	0.38	75	13	51	47
3.2	1.93	75	54	18	15
4.1	2.75	100	56	17	10
4.2	5.00	125	75	2	2
4.3	2.07	125	32	16	1
4.4	1.16	100	28	31	1
5.1	1.63	85	43	25	2
5.2	1.84	85	32	33	14
5.3	0.71	80	19	43	15

erosion rates. The values on Table 18–15 are average reductions in overall planning subarea erosion rates. Reductions on the individual fields where the practices are applied range from 50 to 80 percent or more.

Studies have been made by the U.S. Forest Service on erosion rates on forested land in the Great Lakes Basin. These studies indicate that, on the average, sheet erosion rates on well-forested land average approximately 0.16 tons per acre per year. Based upon the possible range of land cover and rainfall characteristics, this rate can theoretically vary from 0.2 tons per acre per year to 2.0 tons.

On forest land, high streambanks, logging roads, and other small disturbed areas usually produce much higher erosion rates of all other types.

TABLE 18–15 Projected Decrease in Mean Annual Sheet Erosion Rates (Tons/Acre/Year)

Planning Subarea	To Target Year 1980	2000	2020
1.1	--	0.01	0.02
1.2	--	0.01	0.01
2.1	0.03	0.06	0.10
2.2	0.12	0.28	0.35
2.3	0.09	0.21	0.37
2.4	0.01	0.02	0.04
3.1	0.01	0.02	0.02
3.2	0.04	0.06	0.10
4.1	0.06	0.11	0.17
4.2	0.10	0.27	0.41
4.3	0.04	0.09	0.14
4.4	0.02	0.04	0.05
5.1	0.03	0.06	0.09
5.2	0.03	0.05	0.09
5.3	0.01	0.03	0.04

Section 5

GENERAL SURVEY OF EROSION AND SEDIMENTATION PROBLEMS

Questionnaires were sent to personnel located in or near the counties lying within the planning subareas of the Great Lakes Basin. These people were district conservationists for the Soil Conservation Service, U.S. Department of Agriculture. They work in these counties and are familiar with local erosion and sedimentation problems.

The questions asked on these questionnaires required the conservationists' opinions on the degree of severity and the extent of various types of erosion problems other than those involving sheet erosion rates. The rates for sheet erosion were determined as described in Section 4.

In addition to questions on erosion damage, the conservationists' opinions on the degree and severity of damage in their counties from sediment derived from land erosion were also sought.

The purpose of these questionnaires was to survey the nature, extent, and severity of erosion and sediment damages that were not compiled or otherwise known except on a local basis. One hundred ninety questionnaires were sent out to be completed by local personnel in the field. Almost 100 percent of the questionnaires were completed and returned.

Data from these questionnaires were summarized in various ways and the results are presented on the pages that follow. Each major element of the questionnaire is presented separately in order to reflect the relative differences of each type of problem throughout the Basin.

5.1 Distribution and Intensity of Damages from Channel Erosion

Erosion from water flowing down upland slopes or drainageways in which the flow is incised in pronounced channels is broadly classed as channel erosion. Gullies and valley trenches in which the flow is intermittent in response to precipitation are also included, as are channels of this type that receive continuous low-volume base flow due to seep zones that the channel intercepts. A gully is distinct from a rill because it is not obliterated by ordinary tillage operations on cultivated land. Gullies, valley trenches, or other channel erosion will persist unless special grading or filling operations are performed. Reasons for channel erosion and the rate at which the channel will grow in length and width are related to the rate of surface runoff, channel slope, and to the resistance to erosion in the zone where flow becomes concentrated. When channel erosion occurs, the rate of concentration of surface runoff and its velocity of flow exceeds the ability of the soil and its cover to resist erosion.

Responses to a question about reasons for channel erosion indicate that approximately 30 percent of the conservationists believe channel erosion is due to lack of adequate grassed waterways on cultivated land. Twenty-five percent indicated that channel erosion was primarily due to traffic—vehicle lanes, livestock trails, logging skids, and pedestrian paths. Table 18–16 lists various opinions on channel erosion and the percent of questionnaire responses that indicated them as problems.

The questionnaires indicated that channel erosion is a rare occurrence in 18 percent of the counties in the Basin. Seventy-one percent of the counties have channel erosion that occurs occasionally to frequently. In 11 percent of the counties, channel erosion occurs frequently to very frequently. Table 18–17 summarizes the relative frequency of channel erosion occurrence in the Lake basins.

Channel erosion is widespread throughout the Basin. However, its intensity and damaging effects are quite diverse. The problem cannot be attributed to extreme topographic or climatic conditions. For example, Planning Subarea 4.2, which is predominantly gently-sloping to level land, has channel erosion that occurs on an occasional to frequent basis in 83

TABLE 18-16 Reasons for Channel Erosion

Reason		Percent of Responses
Inadequate grassed waterways		30
Traffic		25
Vehicle tracks	9	
Livestock trails	7	
Logging skids	7	
Pedestrian paths	2	
Soil problems		14
Problems with drainage outlets		13
Farming practice and carelessness		10
Miscellaneous		8
Torrential rains	4	
Natural geologic erosion	2	
Chemical sprays	1	
Pipelines	1	
		100

TABLE 18-17 Channel Erosion Problems (Percent of Counties)

Lake Basin	Rare	Occasional to Frequent	Frequent to Very Frequent
Total Great Lakes Basin	18	71	11
Superior	23	54	23
Michigan	19	76	7
Huron	14	86	0
Erie	13	75	14
Ontario	25	50	25

percent of the counties. Channel erosion is a local problem. It appears as a critical problem only if a local imbalance between runoff, flow velocity, and resistance to erosion exists. Channel erosion problems in the Basin can be controlled with proper land management.

5.2 Distribution and Intensity of Damages from Roadside Erosion

Roadside erosion is a collective term that describes a variety of erosion processes that occur along highways and other roadway rights-of-way. Sheet erosion, rill, gully, and other channel erosion and wind erosion on susceptible areas combine to form this general category.

Roadside erosion is associated with the disturbance of the land surface because of grading cuts and fills along the right-of-way. Responses from questions about roadside erosion indicate that the greatest cause is the lack of adequate vegetative cover. Fifty-one percent of the responses indicated this to be the major problem. The second-greatest problem indicated was the difficulty of establishing vegetation on steep cuts and slopes. Twenty-three responses indicated this to be the major problem. Table 18-18 summarizes opinions on the major cause of roadside erosion in the Great Lakes Basin.

TABLE 18-18 Reasons for Roadside Erosion

Major Causes of Roadside Erosion	Percent of Responses
Inadequate vegetative cover	51
Over-steep slopes	23
Improper drain outlets	14
Soil problems	7
Improper maintenance	5

Twelve percent of the counties in the Great Lakes Basin have severe roadside erosion problems, 54 percent have a moderate problem, and 34 percent have a minor or slight problem. The Lake Erie basin has the least severe problem from roadside erosion, perhaps due to the large level lake plain area within the basin. Table 18-19 summarizes the frequency of occurrence of roadside erosion by Lake basin.

TABLE 18-19 Roadside Erosion Problems (Percent of Counties)

Lake Basin	Rare	Occasional to Frequent	Frequent to Very Frequent
Total Great Lakes Basin	34	54	12
Superior	32	47	21
Michigan	29	58	13
Huron	27	64	9
Erie	46	45	9
Ontario	35	55	10

5.3 Special Roadside Erosion Study

Quantitative data are available from a special study made in the State of Wisconsin on roadside erosion. The report, entitled "Erosion on Wisconsin Roadsides," September 1969,[8] was cosponsored by the National Resource Council of State Agencies and the Wisconsin chapter, Soil Conservation Society of America. The report is based on a 100 percent survey of road cuts and fills in the State. The purpose of the survey was to ascertain the role of roadside erosion as a sedimentation problem. The study found 7,280 acres of active erosion on the 87,000 miles of rural roads in the State.

The four counties in Wisconsin that lie in Planning Subarea 2.1 have a combined total of 1,394 acres of active roadside erosion, which occurs on 791 linear miles of roadside. The six Wisconsin counties in Planning Subarea 2.2 have a total of 308 acres of active roadside erosion occurring on 391 miles of roadside.

This report on roadside erosion in Wisconsin goes into considerable detail, far beyond what is indicated by this briefly summarized data. In addition to the individual county data on acres and linear miles of roadside erosion, the report indicates the types of roads by percentages, the causes of erosion, and a brief history of the age of the eroded areas. The report also goes into control and treatment needs. It specifies by counties the square feet and percentages of the total that require: fertilizer, seed, and mulch; sloping, fertilizer, seed, and mulch; and structures, sloping, fertilizer, seed, and mulch.

TABLE 18–20 Active Roadside Erosion in Wisconsin Parts of Planning Subareas

Planning Subarea	Acres	Miles
1.1	448	178
2.1	1394	791
2.2	308	391
Total	2150	1360

5.4 Distribution and Type of Wind Erosion

Wind erosion occurs on expanses of open land subjected to winds of sufficient velocity to pick up soil particles or to cause them to drift. Soils that lack cohesive properties, such as sandy soils and organic soils, are susceptible to blowing. Clay and silt soils that are poorly aggregated are also susceptible. All soils are susceptible to wind erosion to some degree. Susceptibility is increased during dry periods because of the decrease of cohesive properties displayed by dry soils.

In the Basin, 8 percent of the counties indicated wind erosion to be a severe problem, 43 percent a slight problem, and 27 percent a negligible problem. Table 18–21 summarizes these responses by Lake basin.

TABLE 18–21 Wind Erosion Problems (Percent of Counties)

Lake Basin	Negligible Problem	Slight Problem	Moderate Problem	Severe Problem
Total Great Lakes Basin	27	43	22	8
Superior	82	18	0	0
Michigan	14	43	34	9
Huron	27	41	23	9
Erie	24	56	13	7
Ontario	45	30	15	10

The counties in the Lake Michigan basin appear to experience the greatest amount of wind erosion damage.

A question was asked as to what types of soil were most susceptible to wind erosion. The responses to this question are summarized in Table 18–22. A special wind erosion problem occurs in the counties in the Lake Superior basin, on mine waste areas. Nearly one-quarter of these counties indicated this to be the major wind erosion problem.

TABLE 18–22 Type of Soil on Which Major Wind Erosion Damages Occur (Percent of Counties)

Lake Basin	Mineral Soils	Organic Soils	Sand Dunes	Mine Waste
Total Great Lakes Basin	55	31	13	1
Superior	44	0	33	23
Michigan	54	34	12	0
Huron	80	15	5	0
Erie	56	29	15	0
Ontario	28	50	22	0

5.5 Other Erosion Damages

The questionnaire also attempted to determine if there were unusual erosion problems in the Great Lakes Basin. Thirty-three percent of the responses indicated that unusual problems exist, including the existence of soil classes on which erosion is difficult to control; irregular topographic features on which control practices are difficult to establish; and local farming practices, usually too many row crops and too much clean tillage in relationship to applicable control measures. These problems appear to be randomly scattered throughout the Basin.

Table 18-23 shows other erosion problems that were listed, and the number of times they were mentioned. Erosion on productive bottomland soil or bottomland scour is the most intense in Planning Subareas 2.3 and 4.2.

TABLE 18-23 Other Erosion Problems Mentioned

Problem	Times Mentioned
Bottomland scour, erosion or productive bottomland soil	48
Erosion on shorelines of inland lakes (exclusive of Great Lakes shoreline)	31
Erosion on mine spoil and other waste	18
Miscellaneous	7

5.6 Distribution and Intensity of Infertile Overwash

One form of sedimentation damage is the periodic deposition of infertile sediment on productive cropland—generally on bottomlands, but not necessarily restricted to bottomland. As the following data will show, infertile overwash is not a widespread, serious problem in the Basin as it is in other parts of the United States. There are probably several reasons for this:

(1) Much of the Great Lakes Basin has glacial topography on which extensive flood plains have not developed.

(2) Where cultivated flood plains are found, the contributing watershed does not feed large volumes of infertile sand and other materials to the streams.

(3) The combinations of cover, stream gradients, soils, and climatic conditions do not lend themselves to violent surges of overwash materials, which are characteristic of those areas that do receive sizeable damage from infertile overwash.

The most extensive areas of infertile overwash are in the Lake Erie basin. Tables 18-24 through 18-26 summarize the indicated severity of this problem throughout the Basin.

TABLE 18-24 Infertile Overwash Problems (Percent of Counties)

Lake Basin	Negligible Damage	Moderate Damage	Severe Damage
Total Great Lakes Basin	84	15	1
Superior	88	12	0
Michigan	85	14	1
Huron	95	5	0
Erie	67	33	0
Ontario	85	15	0

TABLE 18-25 Land Affected by Infertile Overwash (Percent of Counties)

Lake Basin	Less Than 10 Acres	10-100 Acres	100-500 Acres	More Than 500 Acres
Total Great Lakes Basin	41	44	12	3
Superior	72	17	11	0
Michigan	38	48	13	1
Huron	70	20	5	5
Erie	30	44	14	12
Ontario	30	60	10	0

TABLE 18-26 Recoverable Fertility after Infertile Overwash (Percent of Counties)

	Time Span			
Lake Basin	Short Time	Several Years	Long Time	Never
Total Great Lakes Basin	58	29	10	3
Superior	38	28	28	6
Michigan	52	36	11	1
Huron	65	15	10	10
Erie	63	31	3	3
Ontario	75	25	0	0

When infertile deposition occurs it tends to concentrate on the same land areas repeatedly. Thus the values in Table 18-25 should not be interpreted as new land being affected each year.

Another question was asked that involves the damage done to land by the deposition of infertile overwash. An opinion on how much time is needed to restore original fertility to the land after infertile overwash occurs was also obtained (Table 18-26).

5.7 Distribution and Intensity of Sediment Deposition in Channels

A widespread problem with sedimentation is the filling of various drainage and flood control channels, which must be periodically cleaned out in order to function properly. The responses to the questions on channel sedimentation revealed that this is recognized as one of the more severe erosion and sedimentation problems in the Great Lakes Basin. The first question about channel sedimentation asked how serious the problem was in individual counties.

Another question on channel sedimentation asked for an opinion on how many miles of channel were cleaned out each year in the individual counties. A question was also asked about the size of jobs in terms of cubic yards of sediment removed per mile of channel for maintenance purposes. The greatest mileages of channel clean-out are in Planning Subareas 2.3 and 4.2.

The largest volumes of channel clean-out are in Planning Subareas 2.2, 2.3, 3.2, 4.1, and 4.2. Intermediate volumes of clean-out occur in Planning Subareas 4.3, 4.4, 5.1, 5.2, and 5.3, and the smallest volumes are in Planning Subareas 1.1, 1.2, 2.1, 2.4, and 3.1. These generally parallel the levels and intensities of agricultural cultivation throughout the Basin.

TABLE 18–27 Problems from Sediment Deposition in Channels (Percent of Counties)

Lake Basin	Slight	Moderate	Severe
Total Great Lakes Basin	25	48	27
Superior	39	61	0
Michigan	30	44	26
Huron	32	55	13
Erie	9	39	52
Ontario	22	21	57

TABLE 18–28 Annual Channel Cleanout (Percent of Counties)

	Total Channel Cleanout		
Lake Basin	Less than 10 Miles/Year	10–50 Miles/Year	More Than 50 Miles/Year
Total Great Lakes Basin	75	23	2
Superior	100	0	0
Michigan	72	26	2
Huron	82	18	0
Erie	62	36	2
Ontario	84	16	0

TABLE 18–29 Annual Sediment Removal (Percent of Counties)

Lake Basin	Less Than 5,000 Cu Yd/Mi	5,000 to 15,000 Cu Yd/Mi	More Than 15,000 Cu Yd/Mi
Total Great Lakes Basin	78	19	3
Superior	97	3	0
Michigan	79	18	3
Huron	78	20	2
Erie	70	28	2
Ontario	79	20	1

5.8 Other Sediment Problems

A question was asked about other sediment problems that occur locally and are of sufficient severity to present management problems. The percent of the counties experiencing these problems is shown in Table 18–30.

The last question asked the conservationists to state their opinions on overall problems of erosion and sedimentation that occur in their counties. This was to include special conditions and problems not specifically addressed in previous questions. The following is a resume of these comments:

(1) The red clay areas of Minnesota and Wisconsin present special management problems and create abnormally severe sedimentation situations in connection with local resources.

(2) Changes in farm economics, particularly in dairy farming and cash grain farming, are creating more severe erosion and sedimentation problems.

(3) The movement of population into outdoor areas, more pedestrian traffic along streams, road improvements, etc., is creating more erosion and sediment problems.

(4) Sedimentation of major outlet streams is causing threats to drainage systems in agricultural lands.

(5) Increased local flooding occurs with the gradual fill of low areas with sediment deposition.

(6) Major land reshaping, e.g., orchards and major industrial installations (in outlying, nonmetropolitan areas), is creating more erosion and sedimentation problems.

(7) Intensive fertilization and spray programs in connection with sedimentation are creating increasing problems with eutrophication and other pollution.

(8) Streambank erosion, because of cleanout and changed hydrologic conditions, is becoming a greater source of sediment.

(9) Late season vegetable crops, too late to establish winter cover crops, add to sedimentation.

(10) Sediment from sand, gravel, and other mine spoil is becoming an increasing problem.

(11) Long row crop rotations in combination with complete spray weed control are leaving land more vulnerable to erosion.

TABLE 18–30 Other Problems from Sedimentation (Percent of Counties)

Problem	Superior	Michigan	Huron	Erie	Ontario	Overall GLB
Clogging of Storm Sewer	33	43	18	43	25	37
Filtration Costs, Sediment Removal	11	9	5	43	10	17
Turbidity in Recreation Lakes	6	47	18	50	25	43
Loss of Reservoir Capacity	33	38	18	39	60	38
Eutrophication	17	53	18	45	50	44
Damage to Fish and Wildlife	72	71	36	61	60	64
Miscellaneous	1	3	0	0	0	2

Section 6

EROSION FROM URBAN DEVELOPMENT IN THE MAJOR METROPOLITAN COMPLEXES

As yet, we are not adept at estimating quantities of erosion resulting from urban expansion activity. This is equally true of estimating the amount of the eroded material that goes downstream and the distance it travels. This section on urban erosion is the result of a compilation of existing technology and existing data. It has been undertaken to develop new evaluation techniques to utilize the available tools and information. This effort should begin to define, quantify, and place urban erosion in its proper perspective as a source of sediment in the Great Lakes Basin.

The problems associated with erosion and sedimentation generally follow hydrologic boundaries rather than economic or geographic boundaries. For this reason the metropolitan complexes studied in this section are treated in relation to their hydrologic boundaries. They do not necessarily follow the Standard Metropolitan Statistical Areas of the Census Bureau or the Economic Areas of the Office of Business Economics. The metropolitan complexes are deliberately aligned to the major watercourses that exist in proximity to the major urban centers (Table 18-32). This is to facilitate the association of erosion problems with the problems of pollution and water quality.

The Urban Erosion Index developed in this study fulfills a major purpose of a river basin framework study: to establish degree and intensity of problems. The index examines variations of climate, relief, and geologic materials throughout the Basin. When applied on a longtime basis in conjunction with economic projection, the index should point out problems of urban erosion in the various metropolitan complexes.

6.1 The Urban Erosion Index

A committee of soil survey personnel in the Great Lakes States grouped the soils of the Great Lakes Basin into 23 groups, called soil resource groups. The soils were grouped on the basis of similarity of internal drainage, permeability, texture, slope, and other physical and management characteristics. Only major soil characteristics were grouped and only minor variation remained within the soil resource groups. Further consultation with soil survey personnel established predominant soil erodibility factors and slope factors for the soil resource groups. Table 18-31 summarizes the erodibility factors (K values) and

TABLE 18-31 Predominant Erodibility Factors and Slopes by Soil Resource Group

Soil Resource Group	Erodibility (K)	Slope (%)
1	0.37	2
2	0.37	1
3	0.37	4
4	0.32	3
5	0.45	3
6	0.24	3
7	0.22	3
8	0.17	5
9	0.45	12
10	0.32	12
11	0.32	12
12	0.22	12
13	0.32	20
14	0.37	25
15	*	*
16	0.43	2
17	0.43	3
18	0.43	3
19	0.32	3
20	0.43	3
21	0	0
22	*	*
23	*	*

* Indeterminable - group not used

the predominant slopes (percent) that were established. Soil resource groups 15, 22, and 23 have broad characteristics from which predominant erodibility and slope characteristics cannot be determined. These groups generally involve small acreages. When they occurred, they were subtracted from total acreage figures and were not used in determining weighted averages.

Summary printouts were obtained from the Conservation Needs Inventory (CNI) data,[18] updated to 1967. Acres of land by soil resource groups, summarized by counties, were obtained from these data. Generally 10 to 15 soil resource groups are represented in each county. Weighted average erodibility factors and slope were computed for each of the 18 metropolitan complexes by summarizing the data for the counties lying within each of the complexes.

Table 18–32 lists the metropolitan complexes and the county data used in each to determine the weighted erodibility and slope factors. The land included in the computations excludes existing urban development and includes the surrounding land into which urbanization will ultimately expand. Approximate 1960 populations of the complexes and the major tributary rivers are also shown in this table.

A third factor used in computing the Urban Erosion Index is the rainfall factor, R. R is the summation of the longtime average yearly total of storms as reported by Wischmeir.[22] This R factor is the same as described in Section 4.

Table 18–33 summarizes the Urban Erosion Index values computed from the weighted erodibility factor, the slope factor, and the rainfall factor taken from Figure 18–46. The index is the product of these three factors. Regional soil and topographic conditions are noticeable in the weighted K and S values. The larger K values generally indicated concentrations of fine-textured soils that tend to be more erosive than coarse-textured soils. The gently sloping lake plain topography is reflected in the low S values for the Bay City and Toledo complexes. These values contrast the high S values for the Grand Rapids complex, which lies on strongly rolling glacial drift plains.

The reasoning behind the Urban Erosion Index is that the three factors of soil erodibility, slope, and rainfall energy are powerful and affect rates of erosion; the data on these three factors are readily available from existing sources; and the numerical index, as a product of these factors, is a convenient comparative tool that reflects relative difference in potential erosion rates.

TABLE 18–32 Metropolitan Complexes Evaluated in the Urban Erosion Study

Metropolitan Complex	Counties Included	Approximate Population	Tributary River
Duluth-Superior	Carlton (Minn) Douglas (Wis)	300,000	St. Louis
Green Bay-Appleton-Oshkosh	Brown Outagamie Winnebago Fond du Lac	500,000	Fox River
Milwaukee	Milwaukee Waukesha Racine	1,500,000	Milwaukee Root
Chicago	Lake (Ill) Cook Du Page Will Kane Lake (Ind) Porter (Ind)	6,000,000	Des Plaines Calumet
South Bend-Elkhart	St. Joseph Elkhart	350,000	St. Joseph
Kalamazoo-Battle Creek	Kalamazoo Calhoun	300,000	Kalamazoo
Grand Rapids	Kent	400,000	Lower Grand
Lansing-Jackson	Ingham Jackson Eaton Clinton	400,000	Upper Grand
Bay City-Saginaw-Flint	Bay Saginaw Genesee	800,000	Saginaw
Detroit	Macomb Oakland Wayne Washtenaw	4,000,000	Clinton Rouge Huron
Toledo	Lucas Wood	500,000	Lower Maumee
Fort Wayne	Allen	300,000	Upper Maumee
Lorain-Elyria	Lorain	300,000	Black River
Cleveland-Akron	Cuyahoga Medina Summit Lake Geauga	2,200,000	Cuyahoga
Erie	Erie (Penn)	250,000	Several small tributaries
Buffalo	Erie (NY) Niagara	1,100,000	Tonawanda Buffalo
Rochester	Monroe	600,000	Genesee
Syracuse-Rome	Onondaga Oneida	600,000	Oswego

6.2 Erosion Rate Estimates

It is necessary to connect the Urban Erosion Index to existing benchmark urban erosion

TABLE 18–33 Urban Erosion Index Values for the Major Metropolitan Complexes

Metropolitan Complex	Urban Erosion Index (K)x(S)x(R)	Weighted Erodibility (K)	Weighted Slope (S)	Rainfall (R)
Duluth-Superior	1.86	0.27	0.069	100
Green Bay-Oshkosh	0.96	0.30	0.032	100
Milwaukee	1.37	0.34	0.035	115
Chicago	2.85	0.38	0.047	160
South Bend	2.75	0.36	0.051	150
Kalamazoo-Battle Creek	2.35	0.33	0.057	125
Grand Rapids	2.41	0.33	0.073	100
Lansing-Jackson	1.62	0.32	0.046	110
Bay City-Saginaw-Flint	0.93	0.38	0.027	90
Detroit	1.92	0.31	0.062	100
Toledo	1.04	0.41	0.023	110
Fort Wayne	2.45	0.43	0.038	150
Lorain-Elyria	1.87	0.41	0.038	120
Cleveland-Akron	2.62	0.39	0.054	125
Erie	2.10	0.39	0.049	110
Buffalo	0.89	0.39	0.027	85
Rochester	1.44	0.37	0.052	75
Syracuse-Rome	2.46	0.36	0.076	90

date to utilize it in making quantitative estimates. Urban erosion data usable as benchmark values are limited and sketchy. The recent study by Schmidt and Summers[11] on urban erosion in the Clinton River basin, Detroit metropolitan area, provides the best quantitative data yet available.

Schmidt and Summers studied nine building sites in the Clinton River basin in 1967. They made detailed and refined measurements to determine erosion rates and employed a variety of techniques to accomplish this including a measurement of land voided by gullies. Figure 18–47 was developed using these data. The purpose of developing this curve was to provide a working tool to estimate urban erosion rates on individual development sites in an evaluation of urban erosion in the entire Detroit metropolitan area. The products of the same three factors used in the Urban Erosion Index plus a fourth, cover, were used for the abscissa values in Figure 18–47. The products of the four factors were computed for the nine sites in the Schmidt and Summers study. The erosion rates for the nine sites determined by Schmidt and Summers (Y values) were plotted against the products (X values) described above. The arrangement of points on Figure 18–47 resulted, and a curve was drawn to average these points. By using four variables that are relatively easy to determine, the curve provides a method to approximate average tons per acre per year without going into a detailed study.

The values along the X axis of Figure 18–47 differ from the Urban Erosion Index values only in having a cover factor in addition to erodibility, slope, and rainfall. The cover factor is a percentage value indicating the percent of urban development area actually denuded of cover. A site completely denuded had a cover value of 1.0, or 100 percent, in the Schmidt and Summers study. The Urban Erosion Index values have been established as-

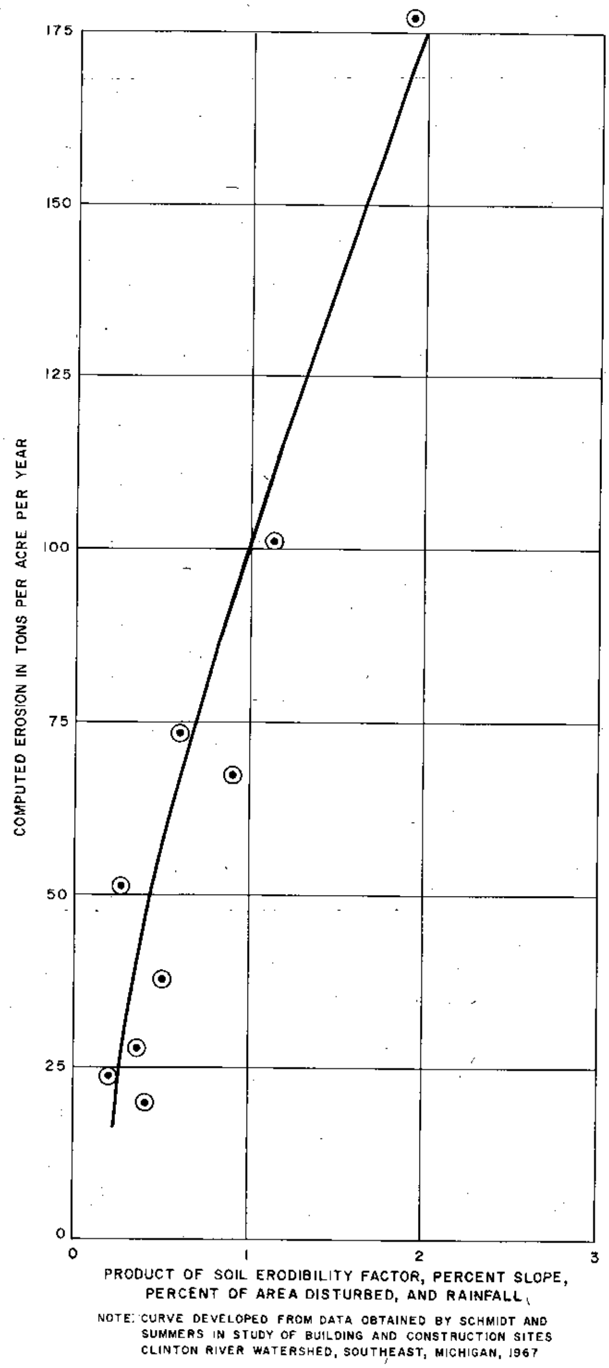


FIGURE 18–47 Urban Erosion Curve

suming a unity value for cover, or 1.0. This gives the indexes a uniform base.

The Urban Erosion Index values may be read along the X axis of Figure 18–47 to obtain corresponding average annual tons per acre from the Y axis. For example, the Urban Erosion Index for the Erie, Pennsylvania, metropolitan complex is 2.10. This value yields a rate of 170 tons per acre per year. This is the longtime average annual erosion rate for land undergoing urban development assuming 100 percent denudation of the land cover during development. If only 80 percent of the cover were denuded during development (this is a more realistic figure in practice), then the index would be adjusted to 0.8 x 2.1 or 1.68. This value yields a rate of approximately 150 tons per acre per year.

Table 18–34 summarizes the estimated longtime average erosion rates from urban development areas assuming 100 percent cover denudation. The 100 percent figure is used because of the large number of values that could be assumed for cover. The urban erosion evaluation in the Southeastern Michigan Water and Land Resources Study, Type IV study, revealed that in the Detroit metropolitan area the average denudation rate was 85 percent. This was based upon 100 current (1968) building and construction sites. The range was from 40 percent to 100 percent.

TABLE 18–34 Estimated Longtime Average Erosion Rates from Land Undergoing Urban Building and Construction

Metropolitan Complex	Urban Erosion Index[1]	Longtime Average[2]
Duluth-Superior	1.86	160
Green Bay-Oshkosh	0.96	90
Milwaukee	1.37	125
Chicago	2.85	200
South Bend-Elkhart	2.75	200
Kalamazoo-Battle Creek	2.35	185
Grand Rapids	2.41	190
Lansing-Jackson	1.62	140
Bay City-Sag.-Flint	0.93	90
Detroit	1.92	165
Toledo	1.04	100
Fort Wayne	2.45	190
Lorain-Elyria	1.87	160
Cleveland-Akron	2.62	195
Erie	2.10	170
Buffalo	0.89	85
Rochester	1.44	130
Syracuse	2.46	190

[1]Cover Assumed to be 100% Denuded

[2]Tons/Acre/Year

6.3 Estimates of Total Land Exposed and Total Erosion

Erosion rate estimates for the metropolitan complexes were developed in the previous section. Total tons of erosion from urban development activity may be estimated. Levels of building activity were combined with the values of tons per acre per year in Table 18–35 to do this. Census data for 1950 and 1960[21] were used to assemble data on housing units. Housing units were translated into average annual acreages of land developed in the metropolitan complexes.

The census data revealed the total number of housing units built between 1940 and 1960. Also, the number of single family units and that of multiple family units could be determined. From these figures, the average annual number of new single and multiple dwelling units was determined. The assumptions were made that four single dwelling units require one acre of land and 12 multiple units require one acre of land. By dividing the average annual number of single and multiple dwelling units by 4 and 12 respectively, the average annual acres of land used for new housing was determined. There was confusion as to what constitutes multiple dwelling units, but this was partly cleared up. A large number of duplex houses could have been multiple units, which would have caused an underestimate of the acres of land used for multiple units. However, reference to the 1968 residential construction[12] in the Detroit region reveals that only one-half of one percent of the housing units built in 1967 in the Detroit region were duplexes. Therefore, duplexes do not involve a large enough segment of the total residential construction to cause significant error in the estimates of acres.

For an example of how the acreage figures for new housing units were computed, let us use Grand Rapids. The census data showed Grand Rapids had 34,060 new single dwellings and 10,357 multiple units between 1940 and 1960. These figures divided by 20 give an average annual rate of 1,703 single units and 518 multiple units for this period. These figures divided by 4 and 12 respectively, give a total of 469 acres of land developed for housing as an average for each year between 1940 and 1960.

Urban development not only involves new housing, but also new associated urban facilities such as shopping centers, schools, industrial parks, and roads. Areas developed with these associated facilities are stripped, graded, and generally denuded of cover similarly to the housing developments. An attempt was made to determine a realistic ratio between acres of housing development and associated facilities. Several land use studies of urban areas were consulted. Land use is reported in different ways by different studies, and it is difficult to relate one study to another. Generally the studies consulted indicated ratios between acres of housing to acres of associated facilities of 1.0:0.65 to 1.0:1.0. For this study of urban erosion, a conservative approach was used and the value of 0.65 was chosen to estimate the present and future acres involved in associated facilities.

Table 18–35 summarizes the computations made for the metropolitan complexes. Estimated average annual acres of land developed for housing and for associated facilities are shown. The acreage figure in column 6 of the table, multiplied by the average annual tons per acre shown in column 3, Table 18–34, gives an estimate of the past average annual tons of erosion from urban development activity. The Office of Business Economics, U.S. Department of Commerce has supplied indexes of projected population growth through the Economic and Demographic Studies Work Group.[4] These are summarized in Table 18–36. The OBE Economic Areas vary geographically to some extent from the metropolitan complexes, but realistic projections still should be similar.

The projections shown in Tables 18–37 and 18–38 are based upon the OBE projections of population growth (OBE Indexes, Table 18–36). A direct relationship was assumed to exist between population growth and the need for urban land for the development of housing and associated facilities. This relationship is based upon the historical period 1940 to 1960.

The values in column 6 of Table 18–35 are estimates of the average annual number of acres of currently developed housing, street, school, commercial, and industrial uses in the 18 metropolitan complexes. These uses normally undergo development that exposes large areas of land to accelerated erosion. Thus, values in column 6 are the acres on which erosion control practices are needed. Currently, 42,000 acres of land are exposed annually to this erosion. Table 18–37 gives projections of the annual rate of new land exposed for 1980, 2000, and 2020. This rate of exposure more than doubles by the year 2020. Thus, the need for design techniques and erosion control practices will need to be applied to ever-increasing acreage to help control downstream sedimentation damage.

Table 18–38 summarizes the current estimated average annual erosion from urban development activity in the metropolitan complexes. This average annual erosion (in tons) is the product of the figures in column 3 of Table 18–34 and column 6 of Table 18–35. Based upon this approach, the total potential for eroded material will more than double for the Great Lakes Basin by the year 2020.

The information developed in this study indicates that approximately 7.0 million tons of soil material erode each year from current building and construction activity within the major metropolitan complexes of the Great Lakes Basin. If 80 to 90 percent of the economic growth of the Region is around these complexes, then another 10 to 20 percent should be added to these figures to include all urban development activity in the Basin. Urban area development will produce an increasing amount of sediment and ever-increasing hazards to downstream resources. Therefore, there is a crucial need for effective erosion control practices.

6.4 The Disposition of Eroded Soil Material

The disposition of the soil material downstream from the urban development sites is complex. Much of the material is trapped locally on streets, in streams, and in ponds and lakes. Much of the material moves farther downstream and is deposited on flood plains, in channels, and in the Great Lakes themselves. Damages are then incurred from the sources of the sediment to the Lakes themselves. The percentage of eroded material delivered to downstream points (delivery ratios) is treated in the section on sediment production. The general guidelines of sediment delivery apply to sediment from both urban lands and open rural lands.

6.5 Solids from Sources Other than Erosion

Waste solids come from other sources than erosion. For example, storm water picks up various wastes from established urban areas, ranging from settled dust and ash to solid debris. Solids from municipal treatment plants and other waste disposal from municipal and industrial sources are also picked up. Recent studies have shown that dust is deposited from the atmosphere at rates ranging from 10 to 3,600 pounds per acre monthly in the area east of the Rocky Mountains. Much of this dust is carried off with runoff water in the urban areas.

The quantities of solids from these various urban nonerosion sources appear to be quite significant. Fly ash from steel mills is abundant enough to require dredging in adjacent navigation channels in some instances. Dust from other industrial processes, such as cement making and certain chemical processes, is also abundant. Dust settling from the burning of organic fuels also contributes solids. Solids in sizeable quantities result from a wide variety of sources ranging from mud carried on automobiles and organic debris from tree leaves and grass trimmings, to children's backyard sand boxes and discarded litter.

There are no research data available on the quantity of solids resulting from these other nonerosion urban sources that reach the local water resources. Some indication of the volume of solids may be illustrated by data from the Cleveland and Detroit areas. The discrepancies between both measured suspended sediment and estimated sediment production and annual dredging quantities are pointed out in Section 8.

Measured data at Independence, Ohio, on the south side of Cleveland, show an average annual load of approximately 200,000 tons of suspended solids carried by the Cuyahoga River. Dredging rates along the Cuyahoga below this point are far greater than this. The dredging rates on the lower River Rouge in the Detroit area are also far greater than estimated erosion and sediment delivery rates would indicate.

These two situations illustrate the phenomenon that maintenance dredging rates in harbor and other navigation channel facilities located within concentrated industrial and municipal environments reflect the influx of solids at a much higher rate than sedimentation from erosion would indicate. This area, solids in water resources derived from urban waste, needs research and evaluation in order to place the magnitude, sources, and control needs into perspective.

TABLE 18–35 Average Annual Acres of Land Developed for Housing and Associated Facilities (1940–1960)

Metropolitan Complex	Average Annual Housing Units		Acres of Housing	Acres of Assoc. Facilities	Total Acres
	Single	Multiple			
Duluth	1,036	381	291	189	480
Green Bay-Oshkosh	1,687	460	460	300	760
Milwaukee	4,890	3,593	1,522	990	2,512
Chicago	15,259	16,591	8,010	5,204	13,214
South Bend-Elkhart	1,914	349	507	330	837
Kalamazoo-Battle Creek	1,645	412	445	289	734
Grand Rapids	1,703	518	469	305	774
Lansing-Jackson	2,213	448	590	384	974
Bay City-Saginaw-Flint	4,176	733	1,105	718	1,823
Detroit	20,483	9,107	5,880	3,822	9,702
Toledo	1,876	673	525	341	866
Fort Wayne	1,216	260	325	211	536
Lorain-Elyria	1,274	273	341	222	563
Cleveland-Akron	8,432	5,178	2,539	1,650	4,189
Erie	989	409	281	183	464
Buffalo	3,581	3,257	1,166	758	1,924
Rochester	1,772	982	525	341	866
Syracuse-Rome	2,079	1,136	515	335	850
TOTAL	77,225	44,760	25,496	16,572	42,068

TABLE 18–36 OBE Indices of Population Expansion Index in Percent (1960 has a value equal to 100)

Metropolitan Area	1970	1980	1990	2000	2010	2020
Duluth	97	101	107	114	121	128
Green Bay-Oshkosh	109	119	133	147	165	187
Milwaukee	120	140	165	188	216	249
Chicago	116	129	144	159	175	196
South Bend-Elkhart	112	122	135	147	163	181
Kalamazoo-Battle Creek	122	143	167	194	223	258
Grand Rapids	113	126	141	158	177	201
Lansing-Jackson	122	143	167	194	223	258
Bay City-Saginaw-Flint*	116	131	150	184	209	211
Detroit	119	137	158	175	198	225
Toledo	111	123	138	153	171	192
Fort Wayne	120	140	165	192	224	262
Lorain-Elyria	110	121	136	151	168	188
Cleveland-Akron	110	121	136	151	168	188
Erie	103	113	124	135	148	165
Buffalo	105	115	127	139	152	168
Rochester	115	129	146	165	186	210
Syracuse	110	122	137	153	170	190
GREAT LAKES BASIN	114	128	146	162	181	205

*Average of Bay City and Detroit OBE Economic Areas

TABLE 18-37 Estimated Acres of New Land Exposed Annually by Construction Activity and Needing Erosion Control

Metropolitan Complex	New Acres of Land Exposed Annually			
	Present	1980	2000	2020
Duluth-Superior	480	485	548	615
Green Bay-Oshkosh	760	904	1,117	1,421
Milwaukee	2,512	3,517	4,144	6,255
Chicago	13,215	17,050	21,010	25,900
South Bend-Elkhart	837	1,021	1,230	1,515
Kalamazoo-Battle Creek	734	1,050	1,424	1,894
Grand Rapids	774	975	1,223	1,555
Lansing-Jackson	971	1,389	1,884	2,506
Bay City-Saginaw-Flint	1,822	2,386	3,353	3,844
Detroit	9,696	13,284	16,970	21,818
Toledo	866	1,065	1,325	1,663
Fort Wayne	537	752	1,030	1,406
Lorain-Elyria	562	680	849	1,057
Cleveland-Akron	4,190	5,070	6,326	7,876
Erie	465	525	628	767
Buffalo	1,923	2,211	2,674	3,231
Rochester	866	1,117	1,429	1,819
Syracuse-Rome	850	1,036	1,300	1,615
GREAT LAKES BASIN	42,060	53,481	68,464	86,758

TABLE 18–38 Estimated Potential Total Erosion from Urban Development Activity (through the year 2020)

Metropolitan Complex	Average Annual Tons Per Year (1000s)			
	Present	1980	2000	2020
Duluth-Superior	76.8	77.6	87.6	98.5
Green Bay-Oshkosh	68.4	81.4	100.5	127.9
Milwaukee	314.0	439.6	590.3	781.9
Chicago	2,642.8	3,409.2	4,202.0	5,179.9
South Bend-Elkhart	167.4	204.2	246.0	303.0
Kalamazoo-Battle Creek	135.8	194.2	263.4	350.4
Grand Rapids	147.0	185.2	232.3	295.5
Lansing-Jackson	136.0	194.5	263.8	350.9
Bay City-Saginaw-Flint	164.0	214.8	301.8	346.0
Detroit	1,600.0	2,192.0	2,800.0	3,600.0
Toledo	86.6	106.5	132.5	166.3
Fort Wayne	102.0	142.8	195.8	267.2
Lorain-Elyria	90.0	108.9	135.9	169.2
Cleveland-Akron	817.0	988.6	1,233.7	1,536.0
Erie	79.0	89.3	106.7	130.4
Buffalo	163.5	188.0	227.3	274.7
Rochester	112.6	145.2	185.8	236.5
Syracuse-Rome	161.5	197.0	247.1	306.9
GREAT LAKES BASIN	7,064.4	9,159.0	11,552.5	14,521.0

Section 7

DISTRIBUTION AND INTENSITY OF DAMAGE FROM STREAMBANK EROSION

The information on streambank erosion was developed in a special study on the extent and intensity of streambank erosion made during March and April 1969.[13] The study in the Great Lakes water resource region was the responsibility of the Erosion and Sedimentation Work Group and was part of a nationwide study of the nature and scope of streambank erosion damages. The overall study was the responsibility of the U.S. Army Corps of Engineers, and it came about by a directive in the Rivers and Harbors Act of 1968. The Corps of Engineers invited other Federal and State agencies to participate in the study.

7.1 Nature of Streambank Erosion

Streambank erosion is a hydraulic process by which soil material is eroded from the sides of a channel either by direct abrasion, undercutting, or sloughing, or by a combination of these. Streambank erosion is a natural geologic phenomenon by which valley development occurs as a result of gradual lateral widening. Existing flood plain land, and land along the valley sides, is lost or otherwise altered by lateral cutting and undermining. Damage results from accelerated streambank erosion which hastens the loss of existing land and the natural resources, agricultural improvements, or the urban improvements on this land. Damage also results from the sedimentation process on downstream improvements and on fish, wildlife, water supply, and recreational resources.

7.2 Study Procedure

The streambank erosion study utilized a procedure in which streambank erosion was classified as slight, moderate, or severe damage. Measurement of the degree of serious damage immediately raises questions of interpretation. To some interests, a certain level of streambank erosion may be considered serious, while to other interests the same level may appear to be slight or moderate. Types of resources being damaged by streambank erosion vary, and levels of damage to these resources also vary. Fish habitat and water quality are sensitive to relatively small quantities of sediment derived from eroding banks. Navigation facilities can stand much higher quantities.

The term serious streambank erosion is used in the summaries that follow as a working term to separate those areas which appear to have damages of sizeable proportions, i.e., damages detrimental to one or more of a wide variety of interests. Furthermore, damage by serious streambank erosion warrants further study to determine if some form of streambank erosion protection is justifiable. Moderate streambank erosion includes those areas that have some damage but under present conditions do not appear to warrant further study because the installation of protective measures will not produce sufficient benefits.

The U.S. Army Corps of Engineers and the U.S. Department of Agriculture agencies were the principal contributors to the study. The Corps' operations were mainly on the larger rivers, those draining more than 400 square miles. The Department of Agriculture compiled the information on smaller watersheds and streams draining less than 400 square miles.

Streams with one-square-mile drainage areas were the lower limit of stream size evaluated for streambank erosion damage. Miles of stream were determined by the use of drainage density values of the various land resource areas within the Basin. A land resource area is a broad geographic zone in which soil and physiographic conditions are very similar. There are 20 of these land resource areas within the Great Lakes Basin. Rates of streambank erosion and damage determinations were made on the basis of local knowledge and the results of some project evaluations.

7.3 Summary of Damages

The tables that follow summarize the streambank erosion estimates for the Great Lakes Basin arrived at in the study. The erosion is summarized in bank miles (a bank mile of streambank erosion would be erosion continuous for one mile on only one side of a stream channel), moderate or severe damage, and dollar damages from land loss, sedimentation and other damages. The tables also separate this damage by the two major categories of rivers: those draining more than 400 square miles, and the rivers and streams draining less than 400 square miles. Further separation of the data is by States and by planning subareas.

Various estimates of bank erosion throughout the Basin indicate that this erosion affects less than one percent of the banks in some areas, and as much as 15 percent of the banks in other areas. Analysis of original computations was made for the various segments in the Basin. It revealed that estimates ranged from an average of 7 tons per square mile from streambank to as high as 45 tons per square mile for streams draining less than 400 square miles. An average of 27 tons per square mile for the entire Great Lakes Basin was found. This value was used in another section of this appendix as a quantity contributing to gross erosion values.

Total average annual damage from streambank erosion in the Great Lakes Basin is $1,709,600. This occurs on 10,394 bank miles, of which 2,945 bank miles are considered seriously damaged and 7,989 miles are considered moderately damaged.

The figures on streambank erosion indicate that nearly 125 acres of land in Michigan are gnawed away by this erosion yearly. The Wisconsin part of the Basin loses 30 acres each year, and the Ohio part loses 65 acres. Streambank erosion contributes more than 600 acre-feet of sediment to the streams in Michigan each year, 170 acre-feet in Wisconsin, and 325 acre-feet in Ohio. These land losses, plus those from the other States, are the acreage loss values upon which the dollar damages shown in Land Loss in Tables 18–39 through 18–42 were based. These values were arrived at by economic evaluation procedures.

TABLE 18–39 Streambank Erosion Along Rivers and Streams Draining Less Than 400 Square Miles—by State

State	Bank Miles of Damage		Annual Damage--Dollars		
	Moderate	Severe	Land Loss	Sedimentation	Other
Minnesota	131	33	1,900	500	1,300
Wisconsin	987	229	37,500	7,400	40,400
Michigan	3,166	2,018	262,300	120,500	123,200
Illinois	36	7	13,800	600	13,800
Indiana	277	49	40,700	29,900	4,600
Ohio	898	126	21,900	44,800	5,700
Pennsylvania	180	3	500	1,300	---
New York	1,398	170	14,700	19,100	7,900
Total	7,073	2,635	393,300	224,100	196,900

TABLE 18–40 Streambank Erosion Along Rivers and Streams Draining More Than 400 Square Miles—by State

State	Bank Miles of Damage	Annual Damage--Dollars		
		Land Loss	Sedimentation	Other
Minnesota	0	---	---	---
Wisconsin	160	102,000	34,200	---
Michigan	720	14,700	43,700	---
Illinois	3	1,100	---	---
Indiana	---	---	---	---
Ohio	190	13,800	346,300	---
Pennsylvania	---	---	---	---
New York	153	71,700	230,000	38,000
Total	1,226	203,300	654,000	38,000

TABLE 18–41 Streambank Erosion Along Rivers and Streams Draining Less Than 400 Square Miles—by Planning Subarea

Planning Subarea	Bank Miles of Damage		Annual Damage--Dollars		
	Moderate	Severe	Land Loss	Sedimentation	Other
1.1	313	154	13,300	3,500	15,900
1.2	591	315	112,300	95,200	12,400
2.1	1,104	109	27,000	4,700	28,000
2.2	70	18	15,000	800	15,300
2.3	481	272	35,700	13,400	15,900
2.4	592	540	34,900	10,900	32,800
3.1	368	224	24,800	7,600	22,700
3.2	582	388	41,500	8,600	21,700
4.1	496	316	34,700	6,900	16,200
4.2	651	82	27,100	34,100	5,400
4.3	276	45	11,900	18,000	2,300
4.4	291	28	2,000	2,700	1,300
5.1	244	25	3,000	3,800	1,600
5.2	674	67	7,600	9,600	3,800
5.3	340	52	2,500	4,300	1,600
Total	7,075	2,635	393,300	224,100	196,900

TABLE 18-42 Streambank Erosion Along Rivers and Streams Draining More Than 400 Square Miles—by Planning Subarea

Planning Subarea	Bank Miles of Damage	Annual Damage--Dollars Land Loss	Sedimentation	Other
1.1	15	---	---	---
1.2	42	300	900	---
2.1	145	102,000	34,000	---
2.2	3	1,100	---	---
2.3	312	6,600	19,800	---
2.4	144	2,900	8,700	---
3.1	50	1,900	5,700	---
3.2	97	1,900	5,800	---
4.1	75	1,100	2,800	---
4.2	155	6,300	44,300	---
4.3	35	7,500	302,000	---
4.4	44	22,000	10,000	20,000
5.1	42	26,200	200,000	---
5.2	42	18,000	20,000	10,000
5.3	25	5,500	---	8,000
Total	1,226	203,300	654,000	38,000

7.4 General Discussion of Damages

Research on the Pine River,[5] a tributary to the Manistee River in Michigan, shows a total of 16,000 bank feet of streambank erosion occurred at 200 locations along a 26-mile reach of river. This is one of the highly susceptible areas. It is an example of a stream in a forest, a sport fishing and other recreation center. The sediment damages fish habitat and has detrimental effects on wildlife. The detrimental effects of sediment on fish and their habitat involve: reduced survival of fish eggs; poor bottom-spawning types; reduced aquatic fauna; less fish shelter because holes are filled in; and harmful effects of prolonged turbidity. The natural beauty of the stream is defaced by the raw bank cuts, which affect the aesthetic value of the stream to canoeists and others who view these areas. To date, no economic value has been placed upon this aesthetic aspect.

This form of erosion decreases the capacity of reservoirs and contributes to overflow sediment damage to crops and cropland, urban installations, and other facilities. Although the overall contribution of sediment derived from streambank erosion is a minor part of the total sediment resulting from all types of erosion in the Basin, there is an important aspect that should be considered. This is the role that streambank erosion plays in present levels of water quality and its potential future role in this area.

The effects on water quality are particularly noticeable in the developing urban areas. Urban development leads to increasing runoff from housetops, parking lots, streets and other hard surfaces. These conditions are different than agricultural runoff and erosion conditions. The increased runoff could lead to degrading channels with increased bank cutting and sloughing. This increase of sediment from eroding streambanks in the urban environment could become a major source of sediment in the streams and a serious pollution threat as a carrier of contaminants.

Section 8

SEDIMENT CONCENTRATION IN HARBOR, PORT, AND NAVIGATION CHANNEL FACILITIES

Dredging is done periodically in 115 harbors within the Great Lakes Basin. Approximately 10.8 million cubic yards of sedimentary mud, sludge, and other materials are dredged annually to maintain these harbors and port facilities. These materials may be classed in three major categories of origin:

(1) those materials that are deposited directly by inflow from contributing rivers and streams and are the product of soil erosion and the collection of other waste in runoff water

(2) those materials that are redistributed from bottom areas within the harbors and deposited in channels or turning basins

(3) those materials originating as waste from inflow or dumping from municipal and industrial sources. Lake Erie ports require the greatest amount of dredging, 6.7 million cubic yards annually. Lake Michigan harbors require 1.9 million cubic yards; Lake Huron, 1.0 million; Lake Ontario, 0.5 million; and Lake Superior, 0.4 million cubic yards of maintenance dredging annually.

8.1 Role of Sediment Inflow

The analysis of the role of direct sediment inflows and their influence on maintenance costs of navigation facilities can only be expressed in general terms. Rivers and surrounding land areas contribute substantial quantities of solids to the harbor areas annually. This sedimentary material is transported by the streams and rivers both as a suspended load and as a bed load.

Land erosion in the Great Lakes Basin produces approximately 165 million tons of eroded soil materials annually. The distribution of this eroded soil is complex, and variable quantities are deposited at downstream locations. A considerable quantity is deposited into the Lakes each year. It is not known how much eroded soil material reaches the Lakes each year, how much is deposited in the harbor areas, or how much redistribution of older sedimentary materials adds to maintenance dredging costs. Each harbor will vary depending on its characteristics of currents, flows, size and depth, and the influence of littoral drift. In the long run, the accumulation of waste products of erosion and other solid discharge is the total source of new materials in the harbors that must be removed in order to maintain shipping.

8.2 Dredging Costs

The determination of maintenance dredging costs is complicated by many factors. The presence of sedimentary materials in the harbor areas which are redistributed by currents, cross gravity flows, and by littoral drift make it extremely difficult to analyze sources. Changing port facilities such as enlarged and extended navigation channels or turning basins may require a greater amount of maintenance dredging. This complicates longtime analysis of harbor sedimentation.

Quantities of dredging depend upon volume of shipping and draft requirements of the individual harbor. Large volume harbors generally have more channels to maintain. Sometimes only partial dredging jobs are done at one time, and these may be confined to certain parts of the harbor. Records of individual dredging jobs could give misleading impressions as to the amount of harbor sedimentation.

Dredging costs vary widely in cost per cubic yard of material. The size of the individual dredging job is a factor in cost per cubic yard. The length of haul and the method of disposal are also important factors in costs. Records of dredging costs on 35 major harbors on the Great Lakes indicate an average cost of maintenance dredging of approximately $0.60 per cubic yard under present dredging methods. An analysis of longtime average annual costs of maintenance dredging requires an extensive search in order to relate these costs to other factors.

8.3 Cleveland Harbor

Cleveland Harbor, Ohio, receives the greatest amount of maintenance dredging of any of the navigation facilities on the Great Lakes, with average annual maintenance dredging amounts of 1,220,000 cubic yards. Approximately 60 percent of the material dredged comes from channels along the Cuyahoga River upstream from its mouth. The remainder comes from the outer harbor. The dredged material is expressed in terms of cubic yards, but no data are available on the average dry density of this material. If the density of this material were 45 to 50 pounds per cubic foot (a reasonable volume-weight for material deposited in this environment), then the 1.22 million cubic yards would weigh approximately 800,000 tons.

The longtime measured data on sediment carried by the Cuyahoga River (USGS station at Independence, Ohio) is approximately 200,000 tons per year. On this basis, the dredged material would amount to four times the annual sediment inflow. This illustrates the discrepancies that emerge in attempting to relate sediment yield to dredging volume. Reasons for this discrepancy can only be speculated upon. The assumed density of the dredged material could be far too high; the readings may not be representative because the station at Independence is several miles above the main harbor area, or large quantities of industrial and municipal waste such as fly ash from the steel mills in this harbor area could be introduced to the Cuyahoga River.

8.4 Toledo Harbor

Toledo Harbor, Ohio, receives the second largest amount of annual maintenance dredging of the Great Lakes harbors, 1,120,000 cubic yards. An average dry volume weight of 50 pounds per cubic foot would make this amount of dredged material weigh approximately 750,000 tons. The longtime measured sediment load of the Maumee River at Waterville, Ohio, is 1,179,000 tons. These figures indicate that average dredging figures approximate sediment yield, considering that all the sediment load would not be deposited in the harbor, but some of the fine-grained sediment would be carried farther out into Lake Erie. However, this is only speculation and the reasons for the relative closeness of the dredged values and the measured sediment yields could be merely coincidental.

8.5 River Rouge

The River Rouge, Michigan, navigation facilities have average annual maintenance dredging of 300,000 cubic yards per year. With an assumed dry weight of 50 pounds per cubic foot, this volume of dredged material would weigh approximately 200,000 tons. This is several times the estimated yield of sediment from land erosion in the River Rouge watershed. The River Rouge harbor, like the Cleveland harbor, has an intense concentration of heavy industry and other urbanization within its contributing area, and could show the influence of large quantities of waste solids from municipal and industrial sources, in addition to soil materials from land erosion. This is a possible explanation for the discrepancy between dredge quantities and estimated sediment source. It illustrates further the lack of knowledge and understanding of the actual amount of solid material that originates from highly developed urban-industrial watershed areas.

The records show that 126,000 cubic yards were dredged from the River Rouge harbor in 1948. This increased to 259,000 cubic yards in 1958, and to 342,000 cubic yards in 1967. Several speculative explanations could be given for the gradual increase to an average annual figure of 300,000 cubic yards. Harbor facilities could have been enlarged and deepened, and maintenance dredging requirements may have increased. The increase could be due to the gradual increase of inflow of solid waste because of extensive urbanization and increased industrial activity in the watershed.

8.6 Monroe Harbor

Monroe Harbor, Michigan, is dredged of 176,000 cubic yards annually. The watershed above this harbor is largely agricultural and has an estimated sediment production of approximately 100,000 tons per year. The annual dredging would amount to approximately 120,000 tons per year. The effects on sediment deposited in Monroe harbor from the City of Monroe and the industry concentrated in this area are unknown. The percentage of the inflow of sediment that deposits in the harbor from land erosion upstream is also unknown. The harbors that have contributing rivers that reflect predominantly agricultural runoff characteristics show correlation between dredging quantities and sediment production, but this again is merely a general statement, subject to much variation.

8.7 Other Harbors

The following table (Table 18–43) lists the various harbors and ports where significant dredging is done periodically for maintenance. This list is included with discussion of the role of sedimentation in dredging operations to illustrate both the amounts of sediment that accumulate in navigation facilities and the wide scope of dredging needs within the Great Lakes Basin.

The dredging data, in cubic yards, are expressed as average annual cubic yards where this information was available. However, for many harbors only data on occasional, periodic dredging were available.

8.8 Dredging and Water Quality

Contemporary concerns for problems of environment preservation and pollution of water have raised questions about past dredging practices. In the past U.S. Army engineers have deposited the 10.8 million cubic yards of annual dredged material in open-lake disposal areas. These areas are located near enough to the various Great Lakes harbors to be convenient and to minimize hauling costs, yet they

TABLE 18–43 Maintenance Dredging in Great Lakes Harbors

Harbor or Other Navigation Facility	Average Annual Cubic Yards	Periodic Cubic Yards and Year	Harbor or Other Navigation Facility	Average Annual Cubic Yards	Periodic Cubic Yards and Year
Duluth-Superior	---	150,000 (1948)	Frankfort, Mich.	10,000	---
	70,000	126,000 (1958)	Leland, Mich.	15,000	---
	---	87,000 (1967)	Traverse City, Mich.	1,000	---
Port Wing, Wisc.	5,000	17,000 (1948)	Charlevoix, Mich.	30,000	---
Cornucopia, Wisc.	---	3,000 (1948)	Manistique, Mich.	40,000	---
	---	9,800 (1958)	Mackinaw City, Mich.	4,000	---
Ashland, Wisc.	---	20,000 (1948)	Cheboygan, Mich.	10,000	---
Ontonagon, Mich.	30,000	41,000 (1948)	Alpena, Mich.	8,000	---
Menominee, Mich.	---	7,000 (1948)	Saginaw River	600,000	---
Keweenaw Channel	55,000	54,000 (1948)	Bay Port, Mich.	6,000	---
	---	37,000 (1958)	Port Austin, Mich.	8,000	---
Grand Marais, Mich.	16,000	---	Harbor Beach, Mich.	35,000	---
Oconto, Wisc.	---	16,600 (1948)	Lake St. Clair		
Sturgeon Bay, Wisc.	---	30,000 (1948)	(channels)	200,000	---
Green Bay, Wisc.	137,000	---	St. Clair River	200,000	---
Kewaunee, Wisc.	---	24,000 (1948)	Black River	3,000	---
		12,000 (1967)	Belle River	1,000	---
Two Rivers, Wisc.	51,000	---	Clinton River	20,000	---
Manitowoc, Wisc.	43,000	---	Detroit River	800,000	---
Sheboygan, Wisc.	23,000	---	River Rouge	300,000	---
Milwaukee, Wisc.	70,000	---	Monroe, Mich.	176,000	---
Racine, Wisc.	30,000	---	Toledo, Ohio	1,120,000	---
Kenosha, Wisc.	29,000	---	Sandusky, Ohio	600,000	---
Waukegan, Ill.	32,000	---	Huron, Ohio	200,000	---
Chicago River			Lorain, Ohio	300,000	---
& Harbor	108,000	---	Cleveland, Ohio	1,220,000	---
Calumet R. & H.	200,000	---	Fair Port, Ohio	400,000	---
Indiana Harbor	151,000	---	Ashtabula, Ohio	220,000	---
Michigan City, Ind.	48,000	---	Conneaut, Ohio	100,000	---
St. Joseph, Mich.	100,000	---	Erie, Penn.	300,000	---
South Haven, Mich.	16,000	---	Dunkirk, N.Y.	---	9,000 (1958)
Saugatuck, Mich.	55,000	---	Buffalo Harbor &		
Holland, Mich.	40,000	---	Black Rock Channel	625,000	---
Grand Haven, Mich.	50,000	---	Rochester, N.Y.	360,000	---
Muskegon, Mich.	105,000	---	Oswego, N.Y.	80,000	---
Pentwater, Mich.	70,000	---			
Ludington, Mich.	55,000	---			
Manistee, Mich.	60,000	---			
Portage Lake, Mich.	20,000	---			

are removed sufficiently to avoid interference with water intakes, beaches, and other facilities.

The material being dredged from channels and harbors is becoming increasingly noxious as population and industrial activity increase. Many contend that the removal of the polluted dredgings from the navigation channels and harbors and disposal in open-lake areas constitutes a moving of polluted material into hitherto uncontaminated sections of the Lakes. However, many questions remain as to what effect the polluted material has on lakewater quality, and what the limnological effects are.

In 1966, the U.S. Army Corps of Engineers proposed to build diked enclosures at the 15 most polluted harbors in the Great Lakes. Prior to further consideration of this proposal, a broad-based pilot study was undertaken in cooperation with other agencies to investigate the whole dredge disposal problem on the Lakes.[14] The study took approximately two years.

This pilot study was done under the general supervision of the Buffalo District, Corps of Engineers, and included a variety of approaches. A board of consultants was engaged to advise, and to evaluate results. Extensive sampling studies were made, methods of treating dredged material were studied, methods of flocculating suspended solids were investigated, and possible sites for diked disposal areas were located and evaluated.

The following are some of the findings and conclusions of the pilot study:

(1) As in all problems of this complex nature, no single solution to dredge-disposal can be laid down for all the Lakes and their harbors.

(2) The removal and stirring up of sediment in harbors has little significant effect on the environment of the harbor. Removal of this material may occasionally be beneficial to the bottom environment.

(3) The effect of open-lake dredge dumping remains in question. The board of consultants acknowledges that in-lake disposal of heavily polluted dredgings must be presumed undesirable because of long-term effects on the ecology of the Great Lakes, as evidenced by the results of bioassay tests.

(4) Treatment of dredged material may be effective, but it is costly in relation to conventional open-lake disposal.

(5) Disposal in diked areas is also very costly. In 35 harbors studied, the cost of diked disposal was 3½ times the cost of conventional open-lake disposal.

(6) Diked disposal areas are effective in preventing sediments from reaching open waters. However, diking raises other problems such as damage to wildlife in marshy areas or to the environment of other areas selected for disposal sites.

(7) The benefits of halting open-lake disposal are not measurable and remain intangible.

(8) Dredgings form only a small part of the sediment and pollution problem. It is estimated that only eight percent of the sediment and dissolved solids that enter Lake Erie reach the Lake by dredge. Presumably, if this dredged material were placed in diked areas, pollution to Lake Erie would be reduced by approximately the same magnitude. This value is less in the other Lakes.

(9) Dredging equipment and procedures can be improved to mitigate some of the adverse effects of open-lake disposal. Turbidity can be minimized by improved dumping techniques.

The general conclusions from the pilot study on dredging and water quality problems say that a 10-year program to deposit polluted dredgings in diked areas may be desirable in 35 harbors where polluted sediment exists. Also, present knowledge indicates that open-lake disposal of nonpolluted dredgings can be safely continued. Finally, studies should be continued to explore a number of areas where research is needed.

Section 9

MEASURED SEDIMENTATION DATA

9.1 Survey of Available Data on Suspended Sediment

A common technique for measuring sediment concentration and movement uses water samples collected at stations located along the watercourses. These stations have gauged cross-sections in which flow in cubic feet per second can be determined by use of flow depth measurements. Concentrations of sediment in parts per million can be determined from analysis of the water sample. This concentration can then be related to flow rates. If sufficient data are collected, relations can then be worked out using flow duration data to rate the particular stream or river for total sediment transport.

The above method is the most reliable means of determining total sediment yields. However, reliability is a function of the accuracy of the cross-section rating, the frequency of sampling, and the method of collecting samples. It is costly to obtain these data on a continuous or even frequent basis. For this reason, continuous data collection is generally confined to key study locations where data are collected for specific purposes. Much of the suspended sediment data in the Great Lakes Basin are collected on a periodic, occasional, and infrequent basis. For this reason, longtime average sediment concentrations have only been worked out at a few locations to date. These locations are indicated in Figures 18–2 through 18–15 in Section 2.

Most of the sampling of suspended sediment in the Great Lakes Basin has been done by the U.S. Geological Survey, the Federal Water Pollution Control Administration (now the Environmental Protection Agency), the Bureau of Commercial Fisheries (now the U.S. Fish and Wildlife Service), and the U.S. Army Corps of Engineers. Streams in the Great Lakes Basin range from a few parts per million concentration of suspended solids up to several hundred parts per million. At some locations, the concentration of suspended solids occasionally rises to much higher levels where flash runoff conditions remove soil from bare cultivated land or from local construction sites where cover has been removed.

The concentration of suspended solids also reflects the presence of upstream surface inflow of waste solids, solids from municipal sewage treatment plants, other municipal and industrial waste, and mine washings. Table 18–44 lists the locations of sites where suspended sediment sampling is currently being done. The frequency of sampling and the length of record are also shown.[6]

TABLE 18–44 Sediment Sampling Locations

Stream or River	Location	Length of Record	Frequency of Sampling
St. Lawrence R.	Massena, N.Y.	---	---
Lake Erie	Buffalo, N.Y.	---	---
Cuyahoga R.	Independence, Ohio	Since 1950	Continuous
Portage R.	Oak Harbor, Ohio	---	---
Sandusky R.	Fremont, Ohio	---	---
Maumee R.	Waterville, Ohio	Since 1950	Continuous
St. Marys R.	Fort Wayne, Ind.	Since 1953	Continuous
Raisin R.	Monroe, Mich.	Since 1966	Daily
Detroit R.	Detroit, Mich.	Since 1957	Weekly
Detroit R.	Gibraltar, Mich.	Since 1966	Continuous
Clinton R.	Fraser, Mich.	Since 1966	Periodic
St. Clair R.	Port Huron, Mich.	Since 1966	Weekly
Black R.	Fargo, Mich.	Since 1966	Periodic
Cass R.	Frankenmuth, Mich.	Since 1966	Periodic
Shiawassee R.	Owosso, Mich.	Since 1966	Periodic
Rifle R.	Sterling, Mich.	Since 1966	Continuous
St. Marys R.	Sault Ste. Marie, Mich.	Since 1959	Weekly
Michigamme R.	Witch Lake, Mich.	Since 1964	Daily
Pine R.	Hoxeyville, Mich.	Since 1966	Weekly
Popple R.	Fence, Wis.	Since 1963	Continuous
Brule R.	Florence, Wis.	Since 1964	Occasional
Menominee R.	Pembine, Wis.	Since 1964	Occasional
Little Wolf R.	Royalton, Wis.	Since 1963	Occasional
Sheboygan R.	Sheboygan, Wis.	Since 1963	Occasional
Milwaukee R.	Milwaukee, Wis.	Since 1963	Occasional
Root R.	Franklin, Wis.	Since 1964	Occasional
Root R.	Racine, Wis.	Since 1964	Occasional
Elkhart R.	Goshen, Ind.	Since 1963	Continuous

In addition to these sampling stations, the Soil Conservation Service conducted a study of suspended sediment in southeast Michigan (Planning Subarea 4.1). This study, a part of the Southeast Michigan Water Resources Study, was made at 18 sampling points on south Michigan tributaries. Sampling was done monthly and sometimes semimonthly for a two-year period. Locations of the sampling points are listed in Table 18–45.

9.2 Rates of Sedimentation in Reservoirs

Water impoundments located along watercourses receive inflow of solids through sedimentation. The rates of accumulation of these solids are related to many factors such as the size of the drainage area above the impoundment, the rates of soil erosion, input of other solids, and shape, slope, and other relief characteristics. Another important factor is the amount of inflow and its relationship to the capacity-inflow ratio (see Glossary).

Rates of sedimentation in reservoirs vary widely throughout the United States. The wide variations in erodibility of soils and climatic conditions plus variations in land cover demand versatility in reservoir design to provide for sediment accumulation. Generally, climate, soils, relief, and other characteristics of the Great Lakes Basin maintain lower sedimentation rates than in other regions of the United States. However, these lower rates do not minimize the problem of reservoir sedimentation. The reasons involve the effects of sedimentation on water quality and the chemical and biological factors involved, as well as the physical loss of capacity in the reservoir. Thus, loss of capacity is only one aspect of damage to reservoirs from sedimentation. Nutritional qualities of inflow affect the rate of growth of organic matter. Organic sediment is a prominent problem throughout the Great Lakes, and it is a major source of capacity loss of impoundments.

TABLE 18–45 Sampling Locations—Southeast Michigan Water Resources Study

Stream or River	Michigan Location
Raisin R.	Near Adrian
Raisin R.	At Dundee
Saline R.	Near Azalia
Stony Creek	Near Monroe
Huron R.	Near Flat Rock
Rouge R.	Inkster
Rouge R.	Near Garden City
Rouge R.	Near Livonia
Mill Creek	Near Dexter
Huron R.	Hudson Mills
Clinton R.	Yates
Clinton R.	Near Mt. Clemens
North Br. Clinton R.	Near Mt. Clemens
Belle R.	Near Adair
Pine R.	Near St. Clair
Mill Creek	Near Ruby
Black Creek	Near Fargo
Black Creek	Near Applegate

Reservoir sedimentation surveys are made by use of sampling techniques. All methods involve systematic measurement of water and sediment depth either on ranges or by some random distribution of sampling locations. The end result of a survey is the expression of loss of original reservoir capacity in terms of acre-feet or percentages. A commonly used technique is described in a technical guide prepared by the U.S. Soil Conservation Service.[19]

Periodic resurveys are made on many reservoirs to keep up to date on total loss of capacity, the changing rates of accumulation, and the distributions and densities of the sediment in reservoirs. Many reservoir sedimentation surveys are made on a scattered, random basis in order to determine sedimentation rates for different physiographic regions under varied climatic, soil, cover, and relief conditions.

Table 18–46 summarizes 1970 data on reservoirs located within the Great Lakes Basin. These data were obtained from a published source,[15] a special study made recently in southeast Michigan, and from personal communications updating surveys made since 1965. The last four columns in these tables give the net sediment-producing area in square miles, the current storage capacity in acre-feet, total sediment accumulation in acre-feet, and the average annual accumulation of sediment in acre-feet.

Table 18–46 indicates the total original water capacity of the 49 surveys listed was 262,000 acre-feet. Approximately 37,500 acre-feet of capacity have been lost to sediment to date. This represents an average capacity loss of approximately 14 percent on all reservoirs which range in age from a few years to more than 100 years. The average rates of sediment accumulation vary from a fraction of one percent to several percent per year.

TABLE 18-46 Reservoir Sedimentation Surveys in the Great Lakes Basin—To 1970

Reservoir	Nearest Town - State	Date of Survey	Net Drainage Area Sq. Mi.	Storage Capacity Ac.-Ft.	Total Sediment Accum. Ac.-Ft.	Avg. Sediment Accum. Ac.-Ft.
Lake Rockwell	Kent, Ohio	Aug. 1914	124.1	7,423		
		Aug. 1950		6,887	536	14.88
Babb Pond	Richfield,	1932	0.02	0.245		
	Ohio	Apr. 1951		0.189	0.056	0.003
Basom Pond	Hudson, Ohio	1944	0.32	3.87		
		Apr. 1951		3.24	0.63	0.096
Christener Pd.	Parma, Ohio	1940	0.09	3.40		
		Apr. 1951		2.79	0.61	0.055
Schoenbeck Pd.	Richfield,	1940	0.03	1.48		
	Ohio	Apr. 1951		1.29	0.19	0.017
East Branch	Burton, Ohio	1939	16.88	4,659		
		Jun. 1949		4,535	124	12.4
Centerville	Aurora,	1855	10.38	86.3		
Mills	Ohio	1949		38.3	44	0.468
Grand	Celina, Ohio	1844	93	130,175		
		Aug. 1940		106,605	23,570	245.5
Goller Pd.	Defiance,	Mar. 1945	0.024	9.5		
	Ohio	Aug. 1951		9.4	0.1	0.015
Auglaizer	Defiance,	1912	2,326	14,400		
Power	Ohio	1951		11,600	2,800	71.75
Eagle Creek	Defiance,	1912	5.2	129		
	Ohio	Jul. 1951		74	55	1.41
Beetree Creek	Defiance,	1912	1.91	148		
	Ohio	Aug. 1951		104	44	1.13
Batt Pond	Defiance,	Apr. 1947	0.012	2.6		
	Ohio	Jul. 1951		2.5	0.1	0.023
Harrison Lake	Fayette,	1941	37.0	991		
	Ohio	Jun. 1949		929.1	61.9	7.47
		Jul. 1951		902.4	26.7	12.7
Allmandinger	Ohio City,	Jan. 1945	0.035	5.08		
Pond	Ohio	Jul. 1951		4.71	0.37	0.055
Bucyrus #2	Bucyrus,	1919	2.79	242		
	Ohio	Jun. 1949		218	24	0.8
Contris Pond	Lafayette,	1947	0.13	9.2		
	Ohio	1951		7.9	1.3	0.325
		1954		7.4	0.5	0.167
Sixmile Creek	Defiance,	1912	21.4	995		
	Ohio	Jul. 1951		696	299	7.67
Burt Lake	Oakwood,	Sep. 1948	0.74	59		
	Ohio	Jul. 1951		57	2	0.714
Kohart Pond	Grover Hill,	Sep. 1943	0.019	2.4		
	Ohio	Jul. 1951		2.1	0.1	0.013
Van Buren Lake	Findlay,	1939	22.72	248		
	Ohio	Nov. 1948		205	43	4.52
		Aug. 1951		186	19	6.78
Lake Rushford	Coneadea,	1925	60.7	28,000		
	NY	1951	60.7	27,426	574	22.1
Mt. Morris	Mt. Morris,	1951	1,011	338,010		
	NY	1957		336,611	1,389	231
		1963		335,393	2,517	218
Orchard Park	Buffalo, NY		1.7			0.23

TABLE 18–46(continued) Reservoir Sedimentation Surveys in the Great Lakes Basin—To 1970

Reservoir	Nearest Town - State	Date of Survey	Net Drainage Area Sq. Mi.	Storage Capacity Ac.-Ft.	Total Sediment Accum. Ac.-Ft.	Avg. Sediment Accum. Ac.-Ft.
Saline Mill	Saline, Mich.	Mar. 1969	63	240.1	110.5	3.56
Bridgeway	Ann Arbor, Mich.	Mar. 1969	7.5	76.7	28.8	0.70
Franklin Mill	Franklin, Mi.	Apr. 1969	7.8	97.8	84.7	0.64
Tecumseh (Evans)	Tecumseh, Mich.	Apr. 1969	26.3	227.8	133.1	0.94
Sharon Hollow	Manchester, Mich.	May. 1969	25	258.1	114.2	2.7
Norvell	Norvell, Mich.	May. 1969	25.3	717.6	215.3	2.15
Brooklyn	Brooklyn, Mich.	May. 1969	6.2	249.3	63	3.0
Manchester (Power)	Manchester, Mich.	May. 1969	6.4	288.9	29.4	1.28
Manchester (Mill)	Manchester, Mich.	May. 1969	17	21.3	10.5	0.17
Kent Lake	Milford, Mi.	Jun. 1969	44	12,204	2,136	118.7
Stony Creek N.	Mt. Vernon, Mich.	Jun. 1969	56	996	113	17.95
Stony Creek S.	Mt. Vernon, Mich.	Jun. 1969	56	3,929	268	42.54
Oakwoods Metro	Flat Rock, Mich.	Jun. 1969	31.6	941.2	301.5	6.85
Belleville	Belleville, Mich.	Jul. 1969	20.3	19,945	1,965	49.2
Ford Lake	Ypsilanti, Mich.	Jul. 1969	11.2	17,926	1,841	51.1
Barton Pond	Ann Arbor, Mich.	Jul. 1969	183	3,150	549	10.17
Iron Mill	Manchester, Mich.	Aug. 1969	5.2	1,551	393	3.93
Tecumseh (Mill)	Tecumseh, Mich.	Aug. 1969	25.9	677	341	3.41
H.N. Fry	Onsted, Mich.	Aug. 1969	12.5	121.3	5.3	0.76
Newburgh	Plymouth, Mich.	Sep. 1969	54.3	667.8	104.9	2.91
Adrian	Adrian, Mi.	Sep. 1969	59	1,000	149	5.32
Waterford	Northville, Mich.	Sep. 1969	54	173	72	0.72
Phoenix	Plymouth, Mich.	Sep. 1969	56.8	225	53.3	0.53
Fenton Mill	Fenton, Mi.	Jan. 1970	45	445	192	1.44
Elsie	Elsie, Mich.	Nov. 1964	192	111	58.9	
Rockford	Rockford, Mich.		225	89	44.6	
Fish Creek	Carsonville, Mich.		123	99	29.3	
Stronach	Wellston, Mich.	Jan. 1953	233	640	613	14.95

Section 10

THE ROLE OF ORGANIC MATTER IN SEDIMENT ACCUMULATION

The role of organic sediment in the Great Lakes Basin water resources is vast and related to both the quality and the permanence of these resources. At the same time, little is known about the sedimentary aspects of organic materials. Literature on aquatic growth is profuse and the subject of lake aging and eutrophication has received widespread attention. The effects of the inflow of sediment rich in chemical nutrients have long been recognized as a major source of lake enrichment and consequent organic growth and accumulation.

10.1 Organic Material as a Sediment

The concept of organic rich materials as an accumulant analogous to the accumulation of predominantly mineral sediment has received little attention. Little is known about rates of accumulation, location of accumulation, and the factors that encourage or inhibit accumulation. However, sedimentary accumulation of organic sediments affects the rates of capacity loss in Great Lakes reservoirs and other water resources. This accumulation occurs both as a nearly pure organic material and as an organic fraction in combination with mineral sediment, which can make the deposited sedimentary material bulky.

10.2 Role of Chemical Nutrients

There are a number of elements known to be essential for plant growth. The most important are nitrogen, phosphorus, potassium, magnesium, calcium, manganese, iron, silicon, sulphur, oxygen, and carbon. Nitrogen and phosphorus influence growth in plants. Sources of phosphorus in water bodies include natural geologic sediments on the bottom of the lake or reservoir. In most areas phosphorus enters with runoff water. This phosphorus is largely associated with the solid fraction in the runoff water and is not dissolved. This solid fraction is derived from many sources such as sewage effluent, animal and plant water, and industrial effluents. The major source in many areas is the solid particles derived from soil erosion on fertilized farm land.

High levels of nutrients in water bodies are a major cause of the development and accumulation of organic sediment. This organic debris is generated largely from planktonic vegetation. Algae often account for 80 percent or more of the total biomass in a body of water. This organic material settles in combination with mineral inflow to form sediments rich in organic content.

10.3 Factors That Control Rates of Accumulation

Large rates of organic sedimentary accumulations can be associated with low concentrations of mineral sediments. Intense turbidity of the water and the resulting opaqueness inhibits planktonic growth by eliminating sunlight energy. Thus, the rates of accumulation are in balance with the nature of inflow and its concentration of suspended solids. Resulting organic rich sediments may have very low dry-weight densities. Samples taken in lakes and reservoirs in southeast Michigan during sediment surveys showed dry-weight densities, in some cases, of less than 15 pounds per cubic foot. Normal densities of fine-grained sediments, low in organic content, are on the order of 65 pounds per cubic foot.

Rates of organic sediment accumulation appear to be related to the dimensional or shape characteristics of the water body in which they are formed. A large percentage of the biomass in water bodies is of the planktonic type. These floating types of plants live near the surface in a few feet of water. Thus the rate of organic accumulation will vary with the amount of surface. For example, two reservoirs with the same total volume could have greatly different rates of organic sediment accumulation. If one reservoir was narrow but deep, and the other was wide and shallow, the second would have much more water exposed to sunlight and therefore a greater area favorable to planktonic growth.

In summary, the amount of organic sediment in a water body is based upon the level of nutrients (particularly phosphorus and nitrogen) in the water, and the amount of available energy from sunlight. Turbidity levels from suspended sediment and the water depth variations influence rates of accumulation. The chemical variations and climatic conditions are also modifying factors.

10.4 An Organic Sediment-Surface Area Relationship

Figure 18–48 illustrates a relationship found to exist in southeast Michigan lakes and reservoirs. Data on average annual sediment deposition are plotted against the original reservoir surface area. The sediment in these 23 reservoirs (data shown in Table 18–46, Section 9) is generally rich in organic material. The plotted relationship in Figure 18–48 shows a general correlation between the surface area (exposed to sunlight) and the average annual sediment accumulation. These reservoirs, which all lie in a relatively low mineral sediment-producing area, reflect the effects of

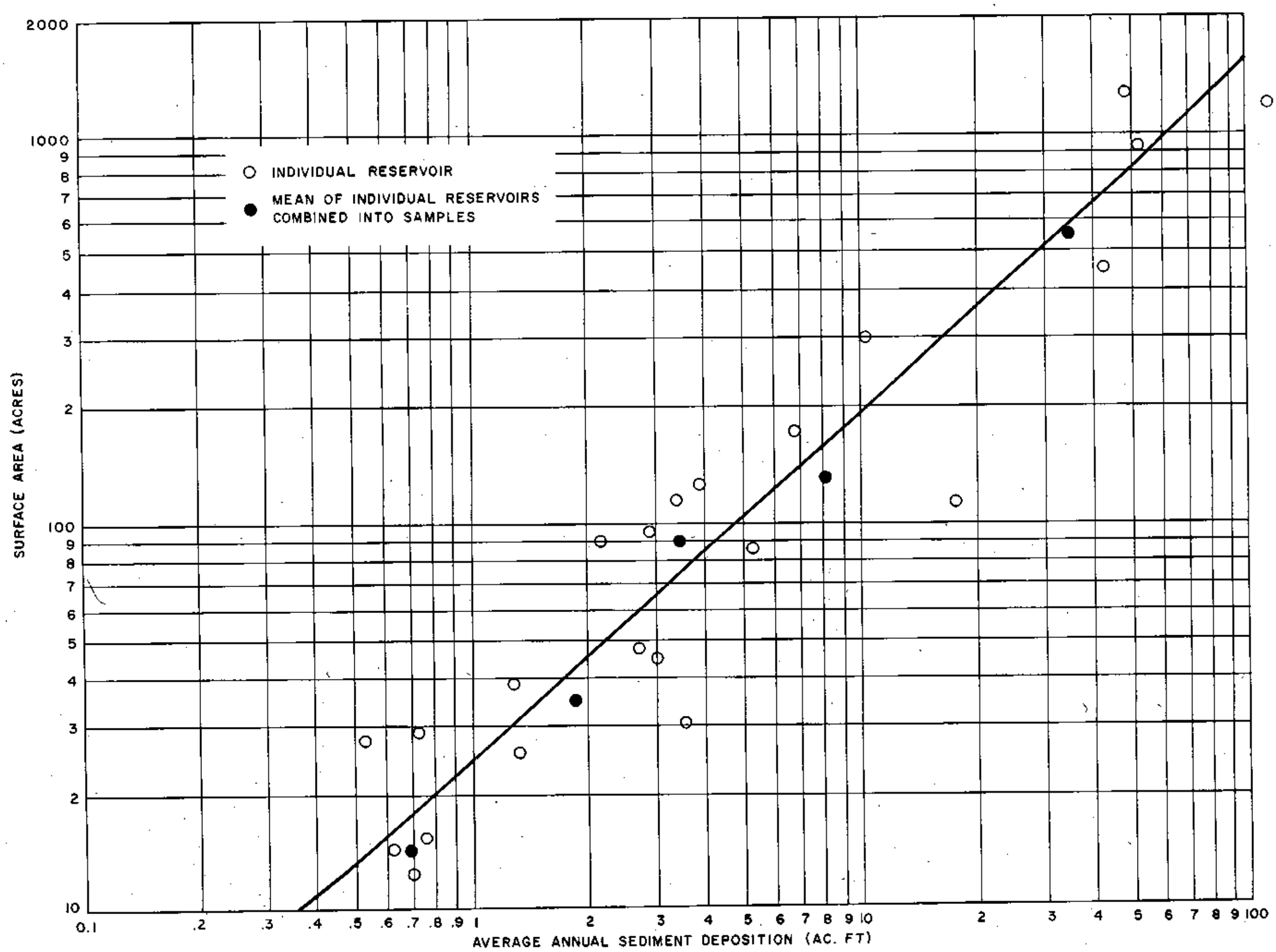


FIGURE 18–48 Average Annual Sediment Accumulation Versus Surface Area of Reservoirs

organic sediment accumulation. The impoundments, which have all been exposed to extensive nutrient enrichment through the years, illustrate the points discussed above. The basic nutrient sunlight energy requirements for organic sediment accumulation are shown.

10.5 General Comments and Summary

The discussion of sedimentation in the Great Lakes Region cannot be confined to classical mineral particle depositional relationships. Deposits in water are sediments regardless of their origin. It has been pointed out in the sections on urban erosion and dredging of harbors and again in this section that urban, domestic, and industrial waste, and organic growth are significant sedimentation factors in this Region. This discussion of organic sediments is included for three reasons:

(1) Organic sedimentary deposits have very significant effects on the capacity of water impoundments and their quality.

(2) The amount and extent of organic accumulation is closely related to the mineral soil material found in sediments derived from erosion sources.

(3) Little is known about the whole problem. The scope and intensity of the problems associated with organic sediment need investigation and extensive research.

Section 11

PHYSICAL CHARACTERISTICS OF THE BASIN RELATING TO EROSION AND SEDIMENTATION

The physiography of the Great Lakes Region was first described by J. Wesley Powell in a paper published in 1895 entitled "Physiographic Regions of the United States." In Powell's classification, most of the Basin was called "Lake Plains." Part of southwest Michigan fell in his division called "Ice Plains," and much of the western part of New York, lying in the Great Lakes Basin, was in his divisions called "Allegheny Plateaus and New England Plateaus." During the following 20 years, a number of attempts at regional physiographic classification were made. In 1914, at a meeting of the Association of American Geographers, a committee was appointed to devise a systematic division of the United States into physiographic units. This committee, later known as the Fenneman Committee, devised the classification which is now generally recognized. This classification of the physiography of the United States is presented in Fenneman's volumes, *Physiography of the Western United States* (1931) and *Physiography of the Eastern United States* (1938).

11.1 General Physiography and Relief

The Great Lakes Basin fits broadly into the Central Lowlands, the Appalachian Plateau, and the Superior Upland and Adirondack extensions of the Laurentian Upland. Bedrock in the Adirondack area and the Superior Uplands is Precambrian age with an area of younger Cambrian and Ordovician rock in the Adirondack area. This province is commonly known as the Canadian Shield. The Appalachian Plateau, locally the Allegheny Plateau, is bordered on the north by the Allegheny escarpment, which runs parallel to Lake Ontario on its south side. The Plateau area is largely Devonian age rocks. The Central Lowlands Province includes bedrock ranging in age from Cambrian through the younger Pennsylvanian. These rocks overlap the Canadian Shield along an extensive contact band and generally dip toward the Michigan Basin, which is centered in the central part of the Lower Peninsula of Michigan.

Elevations in the Great Lakes Basin range from 250 feet in the vicinity of Lake Ontario to as high as 3,000 feet in the Adirondacks and 2,000 feet in the Superior Upland. Most of the Basin ranges from 600 feet to 1,000 feet elevation. Elevation reaches more than 1,000 feet in south-central Michigan and in the northern part of the Lower Peninsula. Much of the western part of the Upper Peninsula of Michigan is 1,500 feet or more.

11.2 General Glacial and Glacial Lake History

The entire Basin was glaciated and left with drift thickness generally sufficient to obliterate most surface evidence of the preglacial topography. However, preglacial highlands such as the Marshall Upland in both northern and southern Michigan, the Superior and Duluth Uplands, the Niagara Cuesta, and certain lowland scoured areas still have outcrops of preglacial bedrock. Glacial drift as thick as 1,100 feet has been reported in Michigan. Vast areas have 100 feet or more of thickness. Scattered thin drift areas are found throughout the Basin.

The glaciation of the Great Lakes Basin, the influence of the various highland and lowland areas upon this glaciation, and the sequence of events in the retreat of the Wisconsin Stage are the dominant factors in the make-up of the present-day landscape. The recessions of the ice fronts and their readvances, the outwash from melting ice, and deposition of ground and terminal moraines, and the pooled lake water from the melted ice, left the complex land surface found in the Basin.

The land surface was molded by the advance and recession stages of the Tazewell, Cary, Port Huron (Mankato), Two Creeks, and Valders substages of the Wisconsin Stage during Pleistocene times. The advance of the ice front during these substages and the resulting terminal and recessional moraines left the variety of materials in which the soils developed and upon which the topography is based. An intricate pattern of spillway channels and other outwash melt deposits are associated with this moraine topography.

Recession and melting of ice during the various substages blocked drainage, giving a complex early history to the Great Lakes. This early history involved many levels of the Lakes, both higher and lower than present-day levels, and the existence of a number of major spillway-discharge points for meltwater. The earliest of these lake levels were Lakes Maumee and Chicago which discharged through the Wabash River and the Des Plaines-Illinois Rivers. Following lake stages included Lakes Arkona and Whittlesey, drained by the Ubly-Grand River Channel, Lake Wayne, which discharged eastward to the Mohawk Valley, and Lake Warren, which again discharged through the Grand River.

At the time Lake Whittlesey was forming, a lake was forming in front of the receding glacier in the Lake Superior basin. This lake, known as Lake Duluth, discharged through the valley of the St. Croix River. Later glacial recession and changes in levels created Lake Algonquin which, during four stages, discharged both eastward and westward. A later stage, known as Lake Nipissing, discharged eastward through the North Bay-Ottawa River and the St. Clair-Lake Erie outlet. The Finger Lakes in New York State had their own history. The high water level during the early recessional period of the ice front spilled over into the Susquehanna River drainage basin.

The existence of these early lake stages was important to the relief and soil characteristics of the Great Lakes Basin as they relate to problems of erosion and sedimentation. The resulting lake plains and outwash zones, both of which are extensive in the Basin, have slope and soil characteristics that are different from the non-impoundment, morainal portions of the glacial topography.

The importation of soil materials by the glaciation process and mixing and sorting of these materials forms the basis of the erodibility characteristics of the soils throughout the Basin. The variety of slopes and gradients left by glaciation and the preglacial topography form the relief patterns upon which erosion and sedimentation rates are based.

11.3 Planning Subarea 1.1

Planning Subarea 1.1 has a topographic relief of approximately 1,400 feet. The stream gradients are steep, averaging 100 feet per mile from the uplands to Lake Superior. The uplands are broad, rounded ridges with deep valleys. There are few flood plains along the streams. Cover conditions are generally good, made up of timber vegetation. The soils include well-drained sandy loams, sandy clay, and sandy clay loam tills of the Milaca-Hibbing soil association.

The land south and east from Duluth to the northern part of Ashland County, Wisconsin, is largely a plain dissected by long, canyon-like stream valleys. The interfluves are level and broad. This plain is the former lakebed of Lake Duluth, which existed in the post-Valders substage. The topographic relief of the area is approximately 400 feet, and the stream gradients range from 5 to 10 feet per mile. The predominant soils are red-brown clays and silty clays developed in calcareous lacustrine clays. This is locally called the "red-clay area," and belongs to the Ontonagon-Pickford-Bergland association. They are very erosive soils. Erosion rates on these soils are among the highest in the Lake Superior basin because of the agricultural use, steep slopes, and high erodibility factors of the soils. Sedimentation rates are high for this region, and local sediment damage to cropland and other land use is common. This area is broken by a north-south trending zone of sandy glacial drift extending through Bayfield County, Wisconsin, up to the Apostle Islands at the north end of the Bayfield Peninsula.

The part of Planning Subarea 1.1 lying west and northwest from Duluth, the upper St. Louis River watershed, is largely a level to gently rolling plain with channel gradients of three feet per mile or less. The soils include extensive areas of peat and muck that are very poorly drained and acid. The rolling portions of this area have soils similar to the Milaca-Hibbings soils on the Superior slopes. Although the muck soils are farmed extensively in some places, this area generally has low erosion and sedimentation rates.

11.4 Planning Subarea 1.2

The western part of Planning Subarea 1.2 is largely a mixed area of rock knobs, rolling to steep glacial drift plains, and intermittent boggy areas. It lies on the Superior Upland

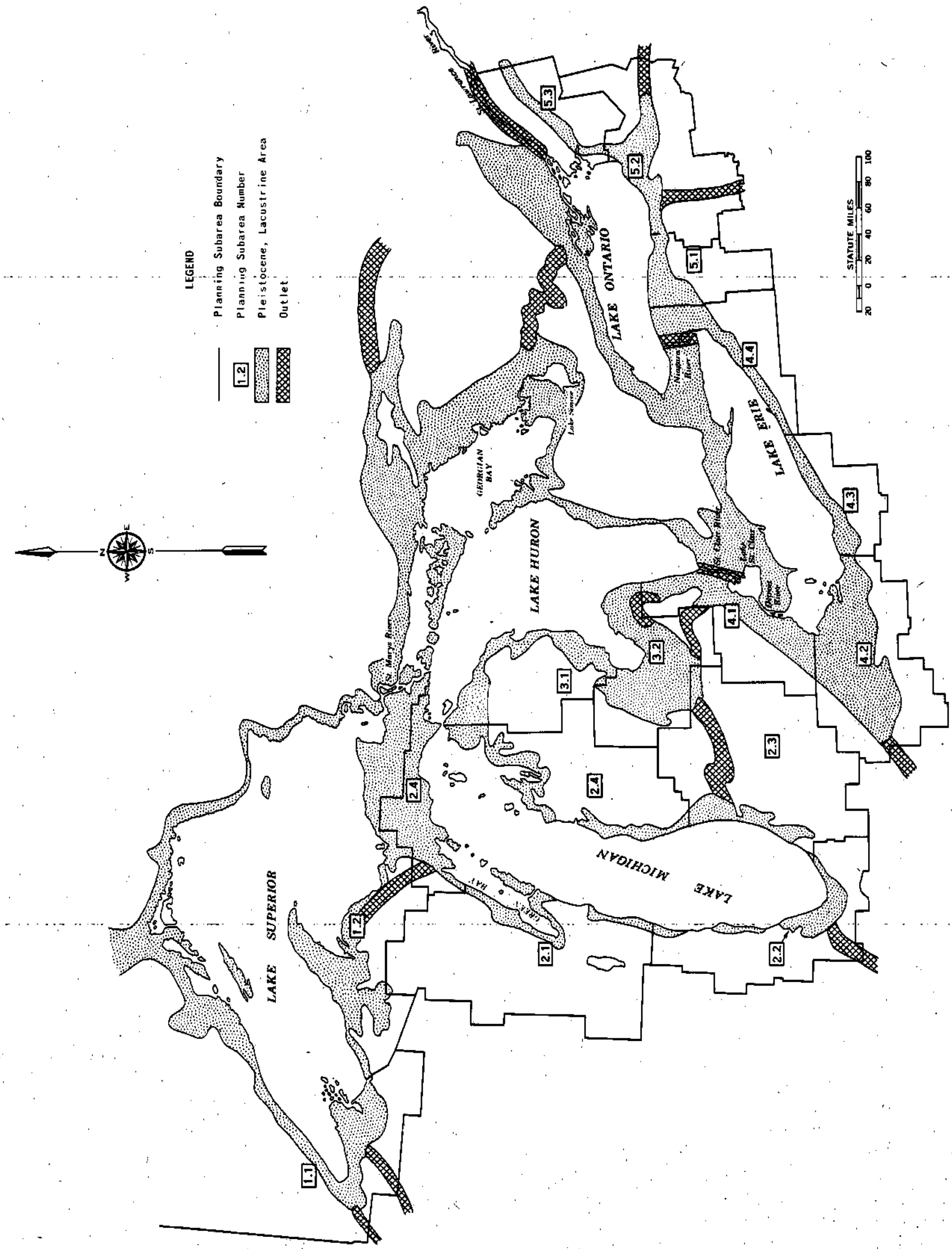


FIGURE 18–49 Pleistocene Lacustrine Areas and Main Outlets Used During Their Evolution

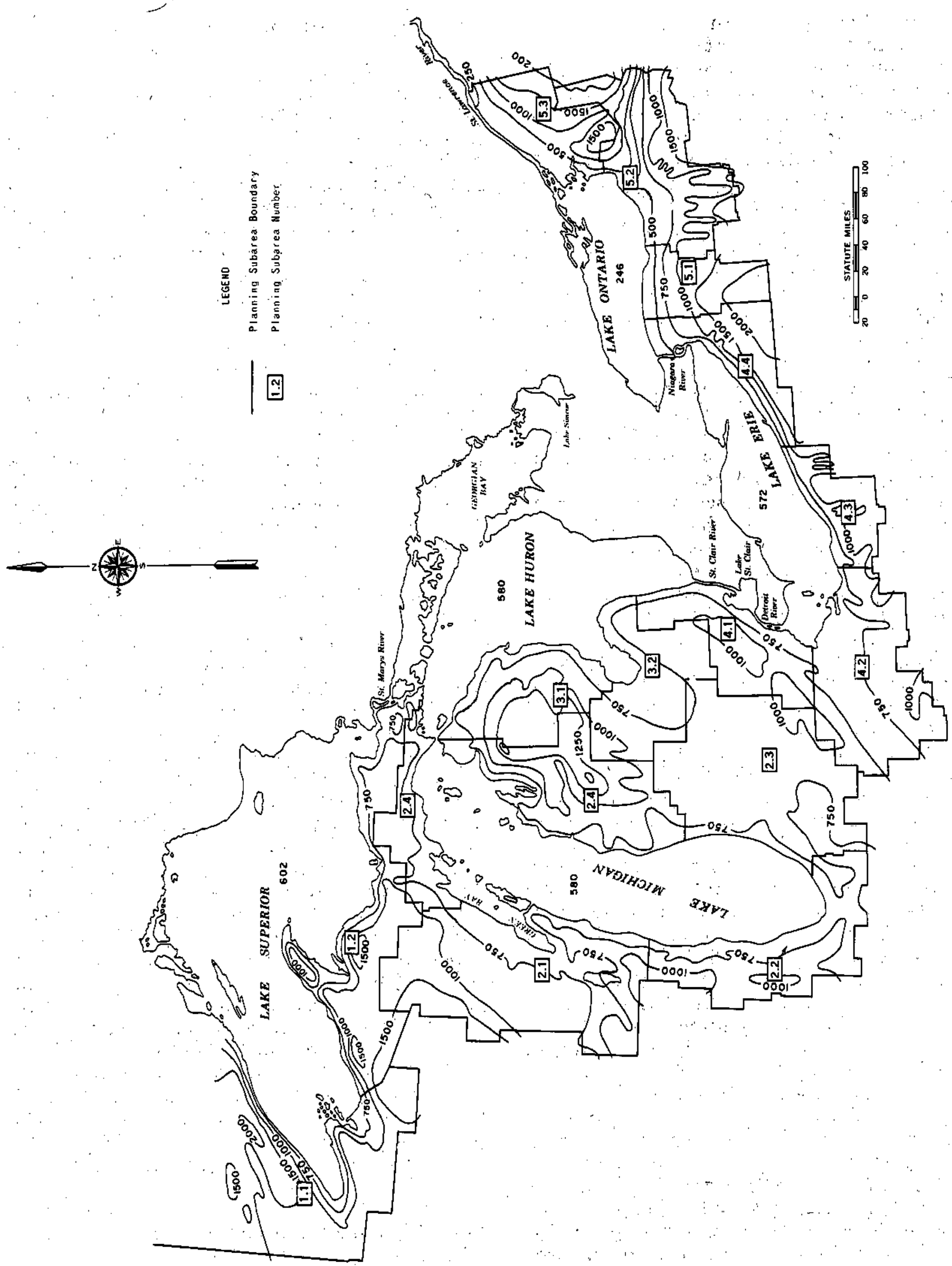


FIGURE 18–50 Generalized Relief (Elevation in Feet Above Sea Level)

extension of the Canadian Shield. The Porcupine Mountains are near the western end of the planning subarea where the topographic relief is 1,300 feet. East of the Porcupine Mountains is a gently sloping plain that extends to the base of the Keweenaw Peninsula. The stream gradients on this plain are 30 to 40 feet per mile. Flood plains along the streams are narrow, and the valley side slopes are moderately steep. The soils are poorly drained with slowly permeable subsoils, and they are developed in calcareous clay loam till and lacustrine silts and clays. These soils belong to the Walton-Ontonagon-Bohemian soil association and to the Ontonagon-Pickford-Bergland soil association.

The remainder of the western part of Planning Subarea 1.2 is a predominantly sloping to steeply sloping area with soils developed in glacial drift and in Precambrian bedrock. Predominant soils include the Baraga-Champion, the Marenisco-Munising-Hiawatha, the Goodman-Gogebic, and the Iron River soil associations. Topographically, the area is full of irregular rock outcrops, irregularly sloping hill and valley gradients, and relief ranging from 600 to 1,400 feet.

The eastern part of Planning Subarea 1.2, from Marquette, Michigan, eastward, has a very marked change in relief from the western part of this planning subarea. Although scattered areas have elevations that rise to 400 or 500 feet, the relief predominantly ranges from 150 to 300 feet above Lake Superior. The topography is gently rolling with extensive level peat and muck areas and nearly level poorly drained sandy soils. The soils come from a mixed glacial drift that is largely sand. Stream gradients are variable, but tend to be only a few feet per mile. The area south of Sault Ste. Marie has heavy textured clay and silt soils. However, the relief in this area is similar to the rest of the eastern part of Planning Subarea 1.2. Soils in the eastern part of Planning Subarea 1.2 include the Rubicon-Vilas-Grayling, Longrie-St. Ignace, Moran, Montcalm-Kalkaska-Emmet, Roscommon-Au Gres-Angelica, and Ontonagon-Pickford-Bergland soil associations.

The land cover in Planning Subarea 1.2 is predominantly woodland, permanent swampland vegetation, and grass and brushland. Cultivated cropland is found on a very small portion of the area. Because of the cover, the predominance of sandy soil types, and slough-like conditions on much of the land, the erosion rates on this planning subarea are low, and rates of sedimentation are minimal.

11.5 Planning Subarea 2.1

The northern part of Planning Subarea 2.1 is a highland that rises from 600 to more than 1,000 feet above Lake Michigan. The surface is irregular glacial drift and rock outcrop mixed with outwash plains and boggy areas. Stream gradients range from 5 to 25 feet per mile. Soils are developed in glacial tills ranging from clay loams and silty loams to sandy and gravelly materials. Major soil associations include the Onaway-Emmet-Guelph, the Goodman-Iron River, the Gogebic-Trenary-Hiawatha, and the Rubicon-Vilas-Grayling. The erosion rates and sediment yields from this area are low due to scattered agricultural activity and the predominance of woodland, brush, and swamp type vegetation.

The central part of Planning Subarea 2.1 is largely a rolling glacial drift plain consisting of calcareous silty and clayey glacial till. There are occasional sandy zones, but the predominant soils are the heavier textured soils of the Kewaunee-Oshkosh-Poygan soil association. The topographic relief of this part of the planning subarea is 150 to 300 feet above Lake Michigan, becoming 400 feet or more in the more western parts. The stream gradients on this rolling and undulating topography average five feet per mile or less. Because of intensified agriculture and more intense rainfall characteristics, the erosion rates and sediment production rates increase rapidly in a southerly direction in spite of the gentle relief.

The southern part of Planning Subarea 2.1 is similar to the central part, but the topographic relief is greater, rising to 600 feet at many points. Slopes are steeper but shorter. An unusual feature of the landscape is the concentration of drumlin topography in this part of the planning subarea. The erosion rates continue to increase in a southerly direction, reflecting more intense relief. Stream gradients increase to 10 feet per mile or more. Soils in the southern part of Planning Subarea 2.1 include the Miami-Dodge-Conover soil association and the Casco-Rodman-Fox soil association. A small area of prairie soils (Mollisols) are found in the southwest part of the area. These are included in the Saybrook-Parr-Drummer soil association.

11.6 Planning Subarea 2.2

The topographic relief in the northern part of Planning Subarea 2.2, on the land west of Milwaukee, is 400 feet or more above Lake

Michigan. The surface elevation decreases in a southerly direction where it becomes 100 to 150 feet above the Lake over broad areas in the southern parts of the planning subarea. The relief becomes less hilly in a southerly direction. Stream gradients throughout the planning subarea average less than 10 feet per mile.

Soils throughout much of the planning subarea are developed on calcareous glacial drift. In the north, west from Lake Michigan, the soils are developed on loam and silt loam till with scattered sandy till acres. In the north and toward the Lake, the soils are developed in less permeable and heavier textured clay tills. The better drained soils include the Miami-Dodge-Conover soil association. The more poorly drained soils include the St. Clair-Blount-Pewamo soil association.

The soils in the southern part of the planning subarea are dark-colored, prairie types (Mollisols). These are developed in clay and silty clay as well as loams and sandy loams and are generally poorly drained. Included are the Elliot-Ashkum soil association and the Brenton-Martinton-Rensselaer soil association. Many of the soils in the southern part of this planning subarea belong to the plastic till group of soils of northeastern Illinois.

Erosion and sedimentation rates in this planning subarea are the highest in the Great Lakes Basin. Relief characteristics are moderate, but much of the land is intensely cultivated. This high concentration of cultivated crops and the intense rainfall characteristics of the area (Figure 18–36c) are the reasons for these higher rates of erosion and sedimentation. Much of this planning subarea does not contribute hydrologically to the Great Lakes, but to the Mississippi River system.

11.7 Planning Subarea 2.3

The present land surface configuration in Planning Subarea 2.3 was formed during the advance and recession of the Cary substage of the Wisconsin Stage of glaciation. The influence of the Lake Michigan lobe, the Saginaw lobe, and to some extent, the Lake Erie lobe are evident in the orientation of the recessional moraines. It was in the post-Cary period that Lake Chicago and Lake Whittlesey came into existence. The Allendale delta, in west-central Michigan west of Grand Rapids, resulted from the high water levels in Lake Chicago (Glenwood Stage). The discharge of water through the glacial Grand River spillway was voluminous. Its load of sand and gravel was also heavy. Extensive sand and gravel deposits in the Allendale delta accumulated where the velocity of the Grand River decreased upon entering Lake Chicago.

The topographic relief in this planning subarea is more than 350 feet. The greatest elevation is along the eastern side of the area where the land rises on the southern Michigan Marshall highland. The topography rolls irregularly in a swell and swale fashion with rounded, gently to steeply sloping uplands with numerous depressional areas that lack outlets. Stream gradients are less than 10 feet per mile. Flood plains are generally narrow. The topography is geologically youthful and has a drainage network that is only beginning to become incised.

The soils in Planning Subarea 2.3 are developed in glacial drift and outwash sands, silts, and clays. The soils developed in the sandy materials include the Fox-Oshtemo-Warsaw soil association and the Fox-McHenry-Spinks soil association. Those soils which developed on heavier textured clay till materials include the Miami-Dodge-Conover soil association. The soils in the more northern part of the planning subarea become very sandy and are included in the Montcalm-Kalkaska-Emmet soil association.

The topography and relief in Planning Subarea 2.3 have been strongly influenced by early Great Lakes history. Lake Chicago began at about the same time as Lake Maumee, behind the Valparaiso moraine during the late Cary substage. Drainage was through the Des Plaines-Illinois Rivers. The Glenwood phase was the highest stage, and the lake surface was 60 feet higher than present Lake Michigan levels. A large segment of the western part of Planning Subarea 2.3 was inundated by this high water, as were parts of Planning Subarea 2.2. This high level led to the formation of the Allendale delta on the swamped lower Grand River near Grand Rapids.

Lake Chicago receded, but the water rose again after the Port Huron retreat. The Calumet phase was approximately 40 feet above present Lake Michigan levels and again inundated part of Planning Subareas 2.3 and 2.2. Later water level rises occurred in post-Valders time when Lake Algonquin and Lake Nipissing were 25 feet above present Lake Michigan. The former shorelines (strandlines) from the various lake levels are important dividers in the types of drift and water-laid materials on which the soils are developed.

The presence of a number of erosive soil types, slopes and other relief characteristics, relatively intense rainfall, and extensive cultivation of cropland in this planning subarea result in significant amounts of erosion and sedimentation. Estimated gross erosion rates range from two tons per acre per year in the northern edge of the area to more than six tons in the southwestern part.

11.8 Planning Subarea 2.4

The surface of Planning Subarea 2.4 has been influenced by three substages of the Wisconsin glaciation. Much of the surface of the southern part of the area was formed by recessional moraines and by meltwater from the Cary substage. The ice advanced over much of the northern part of the planning subarea during the Port Huron (Mankato) substage. A large part of the northern portion was again covered by ice during the Valders advance. The Valders drift has a reddish or pink cast against the blue-gray color of the Port Huron drift. The shorelines along Lake Michigan have been strongly influenced by the post-Port Huron and the post-Valders lake levels. Lake Nipissing and Lake Algonquin shorelines, standing 25 to 30 feet above the present lake level, are extensive.

The topographic relief in this planning subarea is 700 to 800 feet above the level of Lake Michigan throughout much of the area. This pronounced relief is due to a combination of thick glacial drift and the elevation of the Marshall Upland, which is a preglacial highland area centered in the northern part of the Lower Peninsula of Michigan. The topography of much of this planning subarea is strongly rolling to steep, but extensive sloping sandy outwash areas and lowland bogs are present. Stream gradients of 25 feet per mile are common on smaller tributary streams and gradients as much as five feet per mile are common along the larger rivers and streams. There is a concentration of drumlin topography in the region around Grand Traverse Bay.

The soils in this planning subarea are predominantly sandy but become loamy in some areas. These soils belong to the Rubicon-Vilas-Grayling and the Montcalm-Kalkaska-Emmet soil associations. Erosion and sedimentation rates are highest in the western parts of this planning subarea. The reason for this is the concentration of fruit farming along the western shore area which disturbs the surface cover.

11.9 Planning Subarea 3.1

The topographic relief in Planning Subarea 3.1 rises 700 to 800 feet above Lake Huron. Thick glacial deposits and the preglacial Marshall highland centered in the northern part of the Lower Peninsula are the cause of this pronounced relief. The topography of the area is a combination of strongly rolling highlands and broad, gently sloping sand outwash plains. Stream gradients average 10 feet per mile and gradients of 25 feet per mile or more are common on smaller tributaries.

The surface of this planning subarea was developed by the Cary, Port Huron, and Valders glacial advances and recessions. Algonquin and Nipissing shorelines are found 25 to 30 feet above Lake Huron. In addition, earlier lake levels, associated with Lakes Saginaw and Warren, left shorelines noticeable in the southeast part of the planning subarea facing the Saginaw Bay. These shorelines are found at approximately 100 feet above the present Lake Huron levels.

The soils are predominantly sands belonging to the Rubicon-Vilas-Grayling and the Montcalm-Kalkaska-Emmet soil associations. However, there are extensive areas of heavier textured soils in Alpena, Ogemaw, and Arenac Counties. These soils are included in the Nester-Kawkawlin-Selkirk soil association. There are also extensive lowland peat and muck soils throughout the planning subarea.

Cover conditions throughout much of the planning subarea are good, and erosion and sedimentation rates are generally low. However, these rates increase sharply in the southeast part of the area where clay soils occur and the amount of cultivated land increases.

11.10 Planning Subarea 3.2

The Saginaw lobe and its recessional moraines in combination with the late Cary and post-Cary levels have left the surface of this planning subarea with its present features. The topographic relief in the north and west parts of the planning subarea rises to 400 feet above Lake Huron. The surface also reaches this height in the east and southeast parts of the area near Flint. The intervening area, across the northeast-southwest trending axis of the Saginaw Valley, is a gently-sloping plain with a surface elevation that averages 100 to 200 feet above Lake Huron. Stream gradients average 5 to 10 feet per mile.

An important feature of the topography of this planning subarea is the extensive Saginaw lake plain, which is nearly level and covers much of the planning subarea. The strandlines at former lake levels are important dividing points for soil parent materials. The history of this lake plain begins during the late Cary melt period when a lake developed in front of the Saginaw lobe. Lake Maumee water came north through the Imlay Channel into early Lake Saginaw and spilled out through the Grand River into Lake Chicago. The final melt of Cary ice resulted in the large Lake Arkona level, which stood 120 to 130 feet above present Lake Huron. The second Lake Saginaw began to develop when the Port Huron ice reached its maximum. Water again flowed north from the successor to Lake Maumee, Lake Whittlesey, by way of the Ubly Channel and into Lake Saginaw. The succeeding lower lake levels, Lake Warren and its three stages, which occurred during the Valders retreat, and postglacial Lake Nipissing, influenced the lake plain topography in this planning subarea.

The western extension of Planning Subarea 3.2 is very sandy and the soils are included in the Rubicon-Grayling-Vilas soil association. The eastern area, in Tuscola and Lapeer Counties, is also very sandy and includes the Montcalm-Kalkaska-Emmet and Onaway-Emmet-Guelph soil associations. The soils throughout the lake plain include somewhat poorly to poorly drained soils ranging from clay loam, silty clay loam, to sandy loam, and loamy sands. The Brevort-Iosco-Sims, and Sims-Kawkawlin-Capac are the dominant soil associations. Much of Genesee and Lapeer Counties lie on rolling silt loam, clay loam, and sandy loam glacial drift. The Miami-Dodge-Conover and St. Clair-Blount-Pewamo soil associations are found here.

Erosion and sedimentation rates are relatively high in this planning subarea. The relief is generally mild, and the slopes are gentle in most of this area. However, because cultivation of crops is intense, cover conditions are insufficient to prevent erosion on the soils, many of which are highly erosive.

11.11 Planning Subarea 4.1

The preglacial Marshall Upland of southern Michigan is parallel to the northwestern side of this planning subarea. This highland, extending in a northeast-southwest direction, formed the divide that separated the Saginaw lobe from the Lake Erie lobe during the glacial period. Strongly rolling drift plains cover this highland. These drift plains rise more than 400 feet above lake levels. Much of the eastern part of this planning subarea lies on former lake plain and rises 100 to 200 feet above lake levels. Stream gradients on the drift plains average more than 10 feet per mile, and those on the lake plains average five feet per mile or less.

Early Lake Maumee was formed during the retreat of the Cary ice. Its lake level stood more than 200 feet above present Lake Erie, and its drainage was southwest through the Wabash River. As the Saginaw lobe retreated, an outlet for the waste water opened to the north through the Imlay Channel-Grand River-Lake Chicago route.

Lake Arkona formed at a lower elevation during the final wasting of the Cary ice. Lake Whittlesey was formed during the advance of the ice front of the Port Huron substage. As this ice front receded, drainage shifted to the east as an outlet through the Syracuse Channel to the Mohawk Valley opened. The lowering of the Lake Whittlesey surface resulted in the formation of Lake Wayne. Beach line traces, formed during stabilized periods of Lake Wayne, are found along the lake plains in this planning subarea.

The soils in the northwestern side of the planning subarea are strongly rolling predominantly sandy soils belonging to the Fox-McHenry-Spinks soil association. To the east and southeast of these sands there are soils that are less steeply sloping and are developed predominantly in loams, silt loams, silty clay loams, and clay loams. These soils are included in the Miami-Dodge-Conover and St. Clair-Blount-Pewamo soil associations. The soils on the lake plains include those developed in clay loams, silty clay loams, and clay and belong to the Sims-Kawkawlin-Capac, Toledo-Colwood-Fulton, and Hoytville-Nappanee-Wauseon soil associations. There are also banded areas of soils developed on sandy and loamy sands. These soils are included in the Plainfield-Granby-Zimmerman and Berrien-Wauseon-Coloma soil associations.

There is a great variability in relief and cover characteristics in this planning subarea as they relate to erosion. Many areas in the gently sloping lake plains are intensely cultivated, and even though the slopes are gentle, erosion rates are high. Relatively low erosion rates are found in the steep, sandy areas because of generally good cover conditions and low basic erodibility of the soils. Much of the rolling land on the more erosive soils is cultivated, and relatively high erosion rates are found.

11.12 Planning Subarea 4.2

Most of this planning subarea is included in the Erie lake plain. The western and southern reaches of the area rise into gently undulating glacial till plains. The topographic relief of the area rises as much as 500 feet above Lake Erie. The great majority of the planning subarea, however, lies 100 to 200 feet above the Lake. The surface of the area is nearly level to gently sloping. Stream gradients average one or two feet per mile along the major streams and in much of the tributary area. Gradients of the streams reach 10 feet per mile or more in the rolling drift fringe areas.

The soils in Planning Subarea 4.2 are developed in silty clay loam, silty clay, and clay. These soils are poorly to moderately well drained and generally slowly permeable. Included are the St. Clair-Blount-Pewamo, Blount-Pewamo-Morley, Toledo-Colwood-Fulton, Hoytville-Nappanee-Wauseon, and Paulding soil associations.

The topography in Planning Subarea 4.2 was controlled by the advance and recession of the Huron ice lobe and the subsequent drainage of meltwater from the glacial ice in the entire Great Lakes Region during the post-Cary glacial phases. Lake Maumee began to form behind the Ft. Wayne moraine, a recessional moraine of the late Cary substage. At its highest Lake Maumee stood 200 feet above present Lake Erie, and its drainage spilled into the Wabash River outlet. When the ice in the Saginaw lobe retreated, the drainage from Lake Maumee shifted to the Imlay-Grand Channel cutting off its flow through the Wabash outlet.

Lake Maumee and Lake Saginaw coalesced forming Lake Arkona. Lake Whittlesey formed after the advance of the Port Huron ice front. This drained through the Ubly-Grand spillway. Melting of the ice to the east opened an outlet through the Syracuse Channel and the Mohawk River and later through the Niagara River. This led to lower lake levels, and Lake Wayne, Lake Warren, and early Lake Erie followed. The source rock of most of the glacial till in this planning subarea is Devonian shale. This presumably accounts for the clayey glacial drift in the area. Soil differences are related to the location of strandlines from the various lake levels.

The erosion and sedimentation rates in this area are among the highest in the Great Lakes Basin. Relief characteristics are mild, and slopes are generally very gentle. However, cover conditions, because of intense cropping of the land, are poor. This, in combination with relatively intense rainfall characteristics, results in high erosion rates.

11.13 Planning Subarea 4.3

The transition between the Central Lowlands Province and the Allegheny Plateau section of the Appalachian Plateaus Province occurs in this planning subarea. This transition, which goes in a southerly direction from Cleveland, Ohio, changes the relief from 200 or 300 feet above Lake Erie in the western part of the area, to 500 or 600 feet in the eastern part. This transition is not an escarpment, but a smooth change where the land surface becomes more rolling and the slopes become steeper. Stream gradients are approximately 10 feet per mile in the western part and as much as 25 feet or more per mile in the eastern part of the planning subarea.

The soils in Planning Subarea 4.3 are developed in medium textured to heavy textured glacial till and are predominantly poorly to moderately well drained. Included are the Mahoning-Ellsworth, Canfield-Wooster-Chili, and Conneaut-Elnora-Tyner soil associations. Erosion and sedimentation rates show a steady decrease from a west-to-east direction through the planning subarea. Although relief characteristics become more intense in an easterly direction, there is a decrease in the amount of cultivated cropland in the same direction. Generally cover conditions are better, with more forest and grassland, in the eastern part of the area, and erosion rates are less than in the western part.

11.14 Planning Subarea 4.4

This planning subarea lies within the Allegheny Plateau section of the Appalachian Plateaus Province. There are three distinct physiographic features in this area. The first is the high, unglaciated Allegheny Plateau lying in southern Cattaraugus County, New

York, rising to approximately 1,800 feet above Lake Ontario. The second feature is the glaciated section of the Allegheny Plateau that rises 1,000 to 1,200 feet above Lake Erie and 1,300 to 1,500 feet above Lake Ontario. This slopes sharply into the lake plain section, the third feature of the planning subarea, which includes the northern part of Erie and Niagara Counties, New York. The Niagara Cuesta divides the lake plain through the middle part of Niagara County. This break marks a change in the elevation of the lake plain: it is approximately 300 feet higher on the south side of the Cuesta.

The slopes range from very steep on the plateau section, with stream gradients of 25 feet per mile and more, to gentle slopes with stream gradients of a few feet per mile on parts of the lake plain. The soils are developed largely from clays and silty clays and are for the most part somewhat poorly to moderately well drained. The lake plain soils, which include the Collamer-Fulton-Williamson and Odessa-Schoharic-Fulton soil associations, are formed in lake-laid silts and clays. The soils on the Allegheny Plateau sections are formed in clayey glacial till and shale bedrock. They include the Erie-Langford, Lordstown, and Volusia-Mardin soil associations.

The history of the lake plain in this planning subarea dates back to the time of Lake Arkona when early ponding began during the retreat of the Cary ice front. Ponding again occurred during the Port Huron substage (Lake Whittlesey and Lake Warren) and again during the Valders substage (Lake Lundy, Lake Grassmere, and early Lake Algonquin). These lakes, which stood at elevations ranging from 600 to 700 feet, were the source of the lake-laid silts and clays.

Erosion and sedimentation rates are relatively low in much of Planning Subarea 4.4. Cover conditions throughout most of the Allegheny Plateau are good. Although the land is strongly sloping, erosion rates are low because of the cover. The rates increase in the northern reaches of the planning subarea where the intensity of cultivation increases. However, slope and relief characteristics are gentle on the lake plain topography in this area, and they tend to minimize the erosion rates.

11.15 Planning Subarea 5.1

This planning subarea rises gradually from Lake Ontario, where there is a narrow lake plain, to the highland in the Allegheny Plateau. Immediately south of the lake plain is a rolling belt of medium textured, permeable glacial drift with a surface ranging from 300 to 700 feet above Lake Ontario. This belt is 20 to 30 miles in width and contains some of the best soils in New York State. Beyond this belt the land rises into the Allegheny Plateau regions where elevations average 1,700 to 2,000 feet above Lake Ontario and the soils are developed in a heavy textured glacial drift and in shale and sandstone bedrock. Slopes are strongly rolling to steep. Stream gradients range from a few feet per mile on the lake plain to more than 25 feet per mile in the Allegheny Plateau.

The soils include the Collamer-Fulton-Williamson association on the lake plains, and the Honeoye-Lima and Ontario-Hilton soil associations on the rolling drift plain. The Volusia-Mardin, Lordstown, and the Oquaga soil associations predominate in the strongly rolling Allegheny Plateau section.

Erosion and sedimentation rates become relatively high on the productive, rolling drift plains in the belt south of Rochester. Erosion rates become less in the southern part of the planning subarea because of the good cover on this steep land.

11.16 Planning Subarea 5.2

This planning subarea rises from the Lake Ontario lowland extension of the Central Lowlands Province to the highland of the Allegheny Plateau, a rise of approximately 1,250 feet above Lake Ontario. A wedge of hilly, sandy, and stony glacial drift lies immediately south and east of Lake Ontario. This area, which widens to the east, culminates in a large, very stony, oval-shaped zone that rises to the east on the back slopes of the Tug Hill Cuesta to an elevation of approximately 1,500 feet. Drumlins are common throughout this sandy area.

South of this sandy zone is a wide band of rolling land lying on medium textured, permeable glacial drift. Drumlins are found extensively in the northern half of this belt (within the Ontario soil association). The southern half of this belt contains very productive Honeoye-Lima soils. The southern fringes of Planning Subarea 5.2 lie on the Allegheny Plateau where soils are developed in heavy textured glacial till and shale rock. Soil associations in this planning subarea include the Sodus-Ira, Worth-Empeyville, Ontario, Honeoye-Lima, Langford-Eire, Lansing-Conesus, and Lordstown-Mardin-Volusia soil associations.

The erosion and sedimentation rates are among the highest in the eastern part of the Great Lakes Basin. This is due to the intensive agricultural use made of the medium-textured glacial drift soils in the middle belt of this planning subarea. Other parts of the area are less intensely used, and although relief conditions are more severe, erosion rates are less.

Much of the Finger Lakes region of western New York lies within this planning subarea. These lakes lie in the trough valleys of west-central New York. This complex valley system cuts across the Allegheny Plateau from its northern escarpment into the drainage of the Susquehanna River. These preglacial valleys were smoothed, widened, and deepened by glacial ice and glacial meltwater.

The filling of the Finger Lakes began during the recession of the Cary substage, when the outlets to the Susquehanna River had been blocked by end moraines. The subsequent history of the lakes during the Port Huron and Valders substages included drainage both to the east (Mohawk-Hudson) and to the west (Grand-Lake Chicago).

11.17 Planning Subarea 5.3

This planning subarea lies within both the Adirondack extension of the Canadian Shield and the lowlands of Lake Ontario and the St. Lawrence River. The topographic relief rises nearly 3,000 feet from the St. Lawrence River to the vicinity of Tupper Lake in the core area of the Adirondack Mountains. The Tug Hill Cuesta, which parallels the Black River on its west side, rises approximately 1,000 feet. The back slopes of this cuesta have very rolling, sandy, and stony glacial drift. Part of this extensive zone lies in Planning Subarea 5.3, but most of its lies in Planning Subarea 5.2. The northern part of the area lies in the nearly level to undulating St. Lawrence lowland which has mixed glacial drift, lake-laid silts and clays, and extensive bedrock outcrops. The eastern part of the planning subarea lies in the steep Adirondack Highland with extensive crystalline rock outcrops, stony areas, and variable soil conditions. Stream gradients range from a few feet per mile in the lowlands to more than 100 feet per mile in the strongly rolling sandy glacial drift and mountain areas.

The predominant soils are the Worth-Empeyville, Camroden-March, Colton-Adams-Hinckley-Windsor, Grenville-Swanton-Panton, and Gloucester-Essex-Rockland soil associations.

Section 12

SOLUTIONS TO EROSION AND SEDIMENTATION PROBLEMS

12.1 General Nature of Problems

A general discussion of the whole subject of erosion and sedimentation is essential before the merits of various suggested solutions and program approaches are considered. One element of this discussion will be certain common misconceptions about erosion and sedimentation and related problems. Another element will summarize the erosion and sedimentation problems and consider their impact on the resources of the Basin.

It is an important basic fact that land and water resources in the Great Lakes Basin are both extremely valuable and are, for the most part, intensely used. Recognition of this fact is essential in order to comprehend and put into focus the meanings of the many ramifications of sedimentation and erosion phenomena in the Great Lakes Region.

A commonly held concept is that there is a more or less direct relationship between the amounts of erosion and sediment (in terms of volume or weight) and the amount of damage that results. This concept had some merit in years past when sedimentation involved largely "volumetric" problems such as volume loss in reservoirs. We still have such problems as reservoir and harbor sedimentation, but our present concern has become much broader. It now encompasses the entire erosion and sedimentation process as it affects utilization of our water and land resources. In short, because of the intensification of demands on our land and water resources, our concept of erosion and sedimentation problems has become more sophisticated than the older volumetric concept.

It is important to point out this broader concept because important and extensive economic damages would go unnoticed by those who may say the Great Lakes Basin does not have large erosion and sedimentation rates compared to many other regions in the United States. This statement concerning the entire Great Lakes Basin is no doubt true as it relates to specific rates and quantities, but it has no relationship to the impact of erosion and sedimentation rates and quantities on the resources of the Region. Even though rates and quantities of erosion and sedimentation in the Great Lakes may be less than in other regions, the resulting damages are large because of the degrading effects on highly utilized water and land resources and the demands for a high level of water quality.

Soil conservation was conceived to conserve the longtime productivity of the land. Erosion control is one aspect of this conservation function. Soil conservation, which assumes the application of land treatment measures to control erosion where necessary, is important to erosion control. Under practical application, it generally falls short of 100 percent control of erosion. Soil conservation practices frequently do only a partial job in the reduction of erosion rates to desirable levels. For example it has been said for years that good soil conservation on many of our better midwestern cultivated soils would be achieved if soil erosion rates could be reduced to, and maintained at, three or four tons per acre per year, or less. This means that the land in this well-managed environment, along with nature's process of weathering and gradually developing new soil from parent material, would remain at a high level of productivity in the foreseeable future. The soil would rebuild as rapidly as it is eroding. But even with these reduced erosion rates, three or four tons per acre of eroded soil material would be entering the drainage system and ending up as sediment somewhere downstream. Only by additional intensive erosion control measures such as use of ground cover with row crops could these erosion rates be reduced. Soil conservation is vitally needed for reducing erosion and resultant sediment yields. However, the reductions obtainable by soil conservation measures alone will not necessarily reduce sedimentation rates sufficiently to meet the requirements for future standards. Additional and more intensive control systems may be needed to meet these standards.

The sources of solids that affect the water resources in the Great Lakes Basin and the erosion and depositional processes that influence land management are complex. A large amount of the solids, but not all, result from erosion on and transport from the land. These erosion sources include sheet erosion from farmland, erosion from developing urban areas (construction activity), streambank and roadside erosion, and a vast number of miscellaneous sources such as mine wastes and other disturbed land areas.

The damages and effects of erosion and of the solids from all of these sources fall into one of the following categories:

(1) the loss of capacity in water impoundments, channels, sewers, and other installations

(2) the effect on the quality of water for the following desired uses: water supply; public health aspects; recreation; fish and wildlife; aesthetic values

(3) damages to the land and associated facilities: loss of productivity to farmland; costs of repairing gullies, urban and rural; aesthetic values

The diverse sources of solids and their locations result in an extensive array of damages and other effects. The intricate relationships between the variety of sources of solids and the resulting problems associated with the erosion and sedimentation phenomena in the Great Lakes Region make these problems the responsibility and concern of agriculture, industry and business, government at all levels, and the general public. Finally, it should be realized that there is no panacea for the problems associated with sedimentation and erosion. The solution to these problems involves various avenues of approach and the consideration of basic economics. The basic approach is to control the runoff of solids from the land by various programs. These programs will need to be backed up by downstream works to further reduce solids in the water. The degree of treatment will depend upon the standards demanded for quality of water and other protection needed.

12.2 Erosion and Sedimentation—Agricultural Land

A major Basinwide problem is reducing erosion rates from cultivated land and the resultant sedimentation. The extent and effectiveness of conservation erosion control practices were quantified in Section 1, Trends in Erosion Rates. It was shown that to date conservation crop rotations, the major means of controlling erosion on cropland, have been adopted on 30 percent of the cropland in the Basin. Mechanical practices supporting erosion control have also been established on approximately three percent of the cropland in the Basin.

The results of the most recent conservation needs inventory indicate that an additional 16.7 million acres of cropland in the Basin need conservation crop rotations. This is more than twice the acreage that has been established in rotations (8.3 million) to date. The inventory indicates a need for the establishment of supporting mechanical practices (contouring, strip cropping, terraces, etc.) on an additional 3.0 million acres. This is more than three times the amount of land (0.9 million acres) on which supporting mechanical practices have been established to date.

If all needed rotations and other erosion control practices were established, the erosion rates in the Basin would theoretically approach normal natural geologic erosion rates. However, as pointed out in this chapter, soil conservation falls far short of complete erosion control. A completed conservation program for erosion control would be only 65 to 75 percent effective in reducing erosion rates to natural levels. Only under a massive, concentrated program of maximum usage of cover crops and minimum tillage could a reduction to near-natural rates be achieved.

Some severe barriers face us in further reducing present erosion rates in the Great Lakes Basin by the use of crop rotations and conventional supporting mechanical practices. These barriers basically center on economics, but they also involve other factors. For example, to gain acceptance of conservation erosion control practices, we must stimulate public interest and motivation. This aspect has been explored in detail and we will only mention it here.

Economic implications presenting barriers to the reduction of erosion rates must be examined. Extension of crop rotations on cultivated lands as a means to reduce erosion rates is a case in point. Crop rotation will reduce erosion rates on a plot of land if it improves the tilth of the soil, which accelerates infiltration of precipitation, and if it keeps the land surface under good vegetative cover for a longer period of time. For example, erosion rates on a field can be reduced by 60 percent by converting from continuous corn to a rotation of two years corn, one year of small grain (oats or wheat), and one year of standover grass and clover meadow. Much research data is available on the effectiveness of rotations to reduce erosion rates.

To accomplish this shift in cultivation practice, the land operator foregoes two crops of corn and must be able to utilize the small grain and meadow crops. There is a difference between the yields of corn from the two systems, but some of the yield loss of the two corn crops can be made up by using the longer rotation. On land where intensive cultivation is used, modern technology has made it possible to maintain high yields by use of various soil amendments, residue management, and tillage practices.

The basic economic projections indicate that the various planning subareas will need to supply given quantities of crops to fulfill future requirements. The quantities will require given numbers of acres and the required acreage adjusted to discount future technological developments. The projected demand for crops shows a gradual decrease in most of the planning subareas to year 2000. The balance of acres will presumably be retired to cover crops. The resulting erosion rates will decrease because of the retirement of the land. This is reflected in the values on Table 18–4. After 2000 this trend will reverse, and more land will move into cultivated crops with a resulting increase in erosion rates.

A given acreage of land utilized for cropland (with the exception of some reserve) cannot tolerate lengthened rotations and still provide required production. Widespread crop rotation has its economic limitations, and it presents a barrier to increasing the amount and quality of cover on the land to effect further reductions in erosion rates. It is not known to what extent rotations and acreage shifts could be made to accomplish reduced erosion rates. However, there are severe limitations on the frequencies of rotations or other changes in farming patterns.

The erosion and sediment problem in the Maumee area (Planning Subarea 4.2) is particularly acute from the standpoint of sediment volume. Economic projections show a steady increase in demand for row crops from the present to year 2020. Row crop acreage will increase by nearly 25 percent during the next 50 years. Planning Subarea 2.3 shows a similar percentage increase but a different pattern. Much of the increase comes during the 2000 to 2020 interval. These two planning subareas are particularly significant because of their contributions of sediment to the whole Great Lakes system and because of their concentrations of cultivated crops. Problems from sedimentation in these planning subareas will remain intense and will influence all aspects of water utilization including water quality, dredging, and others.

In Planning Subarea 2.2 erosion rates on agricultural land are the highest in the Basin. This area contributes largely to the Mississippi River drainage. Only part of the planning subarea affects the Great Lakes directly. The projected rates of erosion in this planning subarea show a gradual decrease in the future because of the removal of agricultural land from production and the spread of urbanization in the Chicago and Milwaukee areas. Erosion rates in Planning Subarea 2.1 are sufficiently high, and will remain high enough to cause extensive water quality and navigation problems. The rates of erosion in Planning Subareas 3.2 and 4.1 have widespread effects on water quality and navigation. These problems will intensify, particularly in Planning Subarea 4.1, because of the projected population growth in the Detroit region and the continual rise in demands for better water quality standards.

The influence of the rates of erosion from agricultural land will remain strong in Planning Subarea 4.3 during the next 50 years. As in Planning Subarea 4.1, the effects on water quality and on navigation facilities will be of urgent concern. The planning subareas lying to the east, PSAs 4.4, 5.1, and 5.2, will also be subjected to a continuous combination of water quality, navigation, and other sedimentation problems because of erosion on agricultural lands.

The nature of erosion and sedimentation problems in the planning subareas lying in the more northern parts of the Great Lakes Basin are generally more localized because of the limited and spotty location of agriculture in these regions. These damages influence a wide range of land and water uses, including fish and wildlife, water quality, and certain aesthetic aspects. Erosion and sedimentation rates will remain relatively constant during the next 50 years. Projected land use changes and reductions of cropland acres in Planning Subareas 1.1, 1.2, 3.1, and 5.3 are not extensive.

Grade stabilization and other structural measures to control erosion should be implemented. A variety of structural measures is used for this purpose. They include grade stabilization structures to prevent the degradation of waterways and other channels by erosion. They also include diversions to protect susceptible areas from intense erosion, and various bank protection measures. Sometimes farm ponds serve as grade stabilization structures as well as sources of water.

The conservation measures applied to date (1969) in the Great Lakes Basin include approximately 5,000 grade stabilization structures, 350 miles of streambank protection works, and 36,000 farm ponds. The effect of these works on the reduction of erosion rates and sedimentation damages is not known. The locations and purposes of these various works are too complex to evaluate. The needs for structural works for erosion protection in the Basin are not known.

The present and projected rates of erosion might be decreased by:

(1) promoting as widespread a use of crop rotations as possible under the limitations imposed by economic conditions

(2) promoting extensive utilization of ground cover and minimum tillage on cultivated land

(3) promoting widespread programs for supporting mechanical erosion and grade control structures

(4) maximizing land use adjustments in order to concentrate intensive cultivation on the least erosive land

(5) periodically diverting production from normally used cropland to reserve acreage. Reserve acres, normally in sod, can be broken out occasionally for row crops. This provides more cover to normally used cropland. The net effect (because of the soil tilth factor) is less erosion.

(6) promoting agricultural research in those areas of management that involve moisture infiltration, permeability, and resistance to erosion

Items (2) and (3) offer the greatest potential in the long run for reducing gross erosion rates throughout the Basin. Both of these approaches are physically feasible on widespread acreages, and both incur a minimum of economic restraints in their adoption.

12.3 Erosion and Sedimentation—Forest Land

Forest land in the various planning subareas was included in the cover factors used to compute the sheet erosion rates in Section 4. Forest land is considered separately here because of its different management and erosion control problems. Forest cover varies greatly because of soil, topography, climate, and the past activities of man. Forest land is generally characterized by a vegetative canopy above the ground surface, a layer of decayed and undecayed plant remains on the surface, and a system of living and dead roots within the soil body. These conditions insulate the soil against the impact of rain, obstruct overland flow, and retard movement of soil by wind and water action. These conditions reduce erosion and sediment production to a minimum rate.

Despite forest characteristics that reduce erosion and sedimentation, accelerated erosion is occurring on approximately 139,000 acres of State, county, and private forest land. Major causes of erosion on forest land include: damage to cover from cutting and logging activity; damage to cover because of fires, grazing, and recreation; and damage to land reverting to forest cover from other land use on which adequate cover conditions have not developed.

Erosion control measures are needed to protect logging roads and log skid trails. Programs for fire and grazing control, improved harvesting methods, and reforestation and forest stand improvement are needed to enhance cover conditions and to minimize erosion rates in forested areas.

12.4 Erosion and Sedimentation—Urban Erosion

The problems associated with erosion and sedimentation that occur during construction activity in the expanding urban complexes in the Great Lakes Basin assume major proportions in some of the planning subareas. Computed estimates indicate that erosion from this source accounts for approximately 10 percent of the gross erosion in Planning Subarea 2.2, which includes the Chicago and Milwaukee metropolitan areas. Projections indicate that this rate will increase 30 percent by the year 2020. This increase is due to both an accelerated rate of building and a continuously larger proportion of urbanization in the planning subarea.

Urban-related erosion accounts for 13 percent of the gross erosion in Planning Subarea 4.1 and approximately 17 percent in Planning Subarea 4.3 because of the Detroit and Cleveland metropolitan areas. By 2020 these rates will increase to approximately 35 percent in Planning Subarea 4.1 and to nearly 40 percent in Planning Subarea 4.3. Urban erosion sources in Planning Subarea 2.3, where there are several smaller metropolitan areas, account for two percent of the gross erosion, and it will increase to three percent by the year

2020. The other planning subareas that have a substantial amount of urban construction activity, Planning Subareas 2.1, 3.2, 4.2, 4.4, 5.1, and 5.2, have erosion rates from these sources that range from less than one percent to five percent of the gross erosion.

The solutions to erosion problems and resultant sedimentation from urban erosion are similar to those associated with agricultural land. The need exists for control practices to minimize erosion on construction sites. A recent publication by the National Association of Counties Research Foundation[9] outlines guidelines by which community action programs for erosion and sedimentation control can be established. This type of program and the many technical standards and specifications for soil conservation control measures available may offer the best approach to urban erosion problems.

12.5 Erosion and Sedimentation—Other Sources

There is ample evidence that the inflow of solids, which can be generally described as urban waste debris, affects the water resources in the many urban areas of the Great Lakes Basin. The quantity of solids in the water resources from this source needs to be studied. Urban debris includes settled dust from the burning of immense volumes of fuels, discharge of wastes from industrial process and sewage treatment, and a multitude of other sources such as garden plots, driveways, littering, and wind-scattered trash.

Organic solids also accumulate in the Basin water bodies. This material is influenced by the nature of the runoff water and its sediment load from adjacent lands. The plankton growth in the water bodies produces these organic solids, but the inflow of organic debris, such as leaves and branches, also contributes to their accumulation.

12.6 Needed Legislation

All of the States in the Great Lakes Basin have laws that provide for the creation of soil conservation districts. These districts, which are governed by local boards of directors, provide local leadership to deal with soil erosion and other soil conservation problems. The Michigan Soil Conservation Districts Law, Act 297 of the Public Acts of 1937,[7] originally contained sections that provided for adoption and enforcement of land use and treatment regulations. These sections were repealed in 1945 because districts preferred to provide voluntary technical assistance on erosion control to those requesting help. A spirit of voluntary participation in sound land use and management prevails in all the soil conservation districts within the Great Lakes States. In recent years the soil conservation districts have been revising their operations to broaden their assistance into nonagricultural areas.

Detrimental effects to water quality from erosion and sedimentation have generally been handled by water quality control acts. These acts, which generally establish water quality standards, handle the problem of sediment in terms of allowable concentrations of suspended colloidal and settleable materials. In these acts, sediment is considered a pollutant when it enters a stream. Therefore, it should be abated. However, the laws are geared to handling a much smaller number of cases than a sediment policing program would entail. Staffs on all levels of government are too small to efficiently administer the sediment control programs proposed in these acts.

The Michigan Real Estate Plat Act and its recent amendments may aid the solution of sediment and erosion problems in the Great Lakes Region. This act, and its recent amendment, Act 288 of the Public Acts of 1967, State of Michigan, is primarily a planning and zoning act passed to encourage orderly growth. However, this act could provide authorization for local authorities to influence design and construction procedures in order to minimize erosion during the construction phase.

In the Great Lakes States legislation that would give local governmental entities the authority to establish broad regulatory ordinances is needed. This authority should be given to existing agencies or to new community action agencies. The implementation of these local programs should probably utilize cutoff date procedures. By this method local governments would be given ample time to establish their own codes of ordinances, which would fit their particular situations. If the local governments did not establish such regulations by cutoff dates, State-established regulations would prevail. Guidelines for these local ordinances should follow the commonly accepted standards and specifications for erosion control measures and State standards for water quality.

Sediment control ordinances have emerged to date in the rapidly developing urban areas as a means of giving some measure of protection to local water quality from problems associated with sedimentation. The following is a sample ordinance taken from the Community Action Guidebook for Soil Erosion and Sediment Control.[9] This ordinance, for Montgomery County, Maryland, is one of the earliest regulatory measures of its type in the United States.

Sedimentation Control Ordinance
Montgomery County, Maryland

In the Spring, 1965, a sediment control task force, formerly appointed by the Montgomery County Council, completed development of a proposed sedimentation control program for the county. The Council subsequently made the program stated county policy and solicited the voluntary cooperation of the building industry. Two years later (6/27/67), the council made sedimentation control mandatory through adoption of an amendment to the county's subdivision regulations, Chapter 104, as codified in the Montgomery County Code. This amendment, which represents the county's sedimentation control ordinance, follows:

Amend Sec. 104.24 Preliminary Subdivision Plan—Approval Procedure by adding new subsection (i) as follows:

(i) Sediment Control. The approval of all preliminary plans and extensions of previously approved plans shall include provisions for erosion and sediment control, in accordance with the Montgomery County Sediment Program, adopted by the County Council June 29, 1965.

(1) The Board, in its consideration of each preliminary plan or extension of previously approved plan shall condition its approval upon the execution by the subdivider of erosion and sediment control measures to be specified by the Board after receiving recommendations from the Montgomery County Soil Conservation District.

(2) One copy of each approved preliminary plan or extension of previously approved plan shall be referred to the Montgomery Soil Conservation District for review and recommendation as to adequate erosion and sediment control measures to prevent damage to other properties.

(3) The installation and maintenance of the specified erosion and sediment control measures shall be accomplished in accordance with standards and specifications on file with the Montgomery Soil Conservation District.

(4) Permits for clearing and grading prior to the recordation of plats shall be obtained from the Department of Public Works subject to the granting of temporary easements and other conditions deemed necessary by the Department in order to inspect and enforce the performance of the specified erosion and sediment control measures provided for in subsection (1) above.

(5) In the event the subdivider proceeds to clear and grade prior to recording of plats without satisfying the conditions specified under Sec. 4, the Board may revoke the approval of the preliminary plan or extension of previously approved plan.

Amend Article 1, Section 23–2 General Requirements (or subdivision plans) by the addition of a new paragraph to be known as 23–2 (1) to read as follows:

(1) Erosion and Sediment Control Measures. Adequate control of erosion and sedimentation of both a temporary and permanent nature shall be provided during all phases of clearing, grading and construction as approved by the Director.

Amend Section 23–8, Preliminary Plats—Preparation by the Addition new paragraph to be known as 23–8(g) to read as follows: (Preliminary plats shall include a)

(g) Statement that Erosion and Sediment control methods shall be provided prior to any clearing, grading or construction.

Amend Article 2 of Chapter 23 by the addition of a new paragraph to Section 23-12. Final Plats—Approval to be known as 23–12(c) to read as follows: (Plats shall be approved only if)

(c) Plans and specifications for the control of erosion and sedimentation, if such controls are deemed necessary, have been submitted and approved by the Director of Public Works or his agent. The approval shall be concurrent with the approval of the aforesaid plans and specifications, and become a part thereof.

12.7 Position Statement on Regulation

The Work Group on Erosion and Sedimentation takes the position that regulatory measures for the control of erosion and sedimentation should be adopted. The spirit of the regulation should not only be to eliminate nuisance erosion situations, but it should also be directed toward protection, preservation, and enhancement of water and related resources.

Voluntary action to minimize detrimental effects from the inflow of sediment and other solids should be strongly encouraged. The community action guidebook[9] recognizes that sedimentation control programs that appear to work best are those that initially evolve from voluntary action. The voluntary approach, as far as it can be effectively exploited to achieve real results, should be utilized.

The work group recommends a second avenue of approach that is similar to the purely voluntary. This is utilization of a system of incentives. Agriculture has had a program for years in the form of the Agricultural Conservation Program (ACP). This program has reimbursed farmers for installing agricultural conservation practices—many of them for erosion control. This program, recently renamed Rural Environmental Assistance Program (REAP), has provided farm operators incentive to apply erosion control measures. The possibility of extending this type of incentive program into the urban sector as it relates to runoff of sediment and other solids should be investigated. The incentive should be in the form of cost-sharing on measures used to directly control these solids. The possibility of utilization of a special tax write-off justified on environmental enhancement should be explored.

The work group recognizes the fact that control ordinances are essential in order to achieve the results desired by society in many situations. Ordinances designed to control the inflow of sediment from erosion and other sources may be essential in order to approach the levels essential for water quality.

Regulation to control sedimentation and suspended solids must be uniformly applied to all sources if water quality is to benefit. If an ordinance is established to regulate the subdivision developer because of pollution resulting from erosion and sedimentation, why shouldn't the farm operator be regulated in the same way? Under lax management both types of operations can produce sediment that becomes a nuisance and affects local water resources. But it does not stop here. There is ample evidence that wastes from established urban areas contribute large quantities of solids to adjacent watercourses and lakes. These solids constitute the same debasement of water quality as do solids from erosion of land. When we point the finger at a sediment polluter, we end up with a circular arrangement. The urban people point to the subdivision developer, the developers point to the farmer, and the farmers point back to the urban areas.

A complex legal involvement could stem from a regulatory effort, but this is no reason to sidestep the problem. Perhaps this is one of the prices to be paid for ultimately reaching the clean water goal. The Erosion and Sedimentation Work Group endorses a system of regulatory ordinances, while it strongly urges the exploitation of voluntary and incentive systems to fulfill as many aspects of the goal as possible.

12.8 Other Needs

Other needs include the expansion of ongoing long-term programs and improvement of their effectiveness in the control and reduction of erosion. New long-term programs are needed to attack problems of erosion and sedimentation that have not previously been solved. Two major problem areas are organic sediments and control of waste debris from urbanized areas. Numerous short-term programs are needed in order to correct undesirable erosion and sedimentation on roadsides, difficult areas in the red-clay areas in Wisconsin and Minnesota, and critical shore erosion problems along the Lakes.

There is a vital need for an aggressive educational program to stimulate public awareness of the factors involved in developing and conducting successful programs to reduce erosion and sedimentation problems. This program will very likely be associated with overall conservation and environmental educational programs. The program should include concentration on classroom curriculum, informational promotions, and public relations aspects.

Two broad categories of alternatives to reduce erosion and sedimentation rates and damages have already been covered: intensification of land treatment applications and the installation of erosion control ordinances. Another broad category of alternatives includes mitigating measures to control the damages that result from erosion and runoff of other solids. These measures are, in a sense, backup or secondary defense measures.

A massive program of land treatment for erosion control will help provide the protection needed to reduce sedimentation to levels necessary for future requirements. However, land treatment alone cannot be expected to do the job. The data presented in Section 1, Trends in Erosion Rates, comments made in this section, and information presented in various other sections point to the validity of this conclusion. Various techniques must be employed to backup the task of reducing solids to levels that will satisfy future requirements.

The techniques used will logically center on methods of removing solids either by gravity, chemical treatment, or advanced procedures using other principles. Present technology provides two ways by which solids may be removed in relatively massive quantities in an economical manner. The first is desilting basins. This method has been employed for many years by building basins exclusively for this purpose and by including provisions for desilting in multi-purpose reservoirs. The process involves keeping the water still and eliminating turbulence for periods long enough to settle the solids. The remaining clean water is then decanted from the basin.

One major feature of gravity desilting that places severe limitations upon effective removal of solids is its dependence upon the fall velocities of sediment particles. Fall velocity is the rate at which a solid particle in suspension will settle. Coarse, heavy particles settle rapidly whereas very small, colloidal fractions of solids settle very slowly. The problem then is detention time in a basin. The effectiveness of a desilting basin is a function of the capacity-inflow ratio and the particle size of the solid materials to be settled. To settle fine particles by gravity usually requires large reservoirs in order to achieve high sediment trap efficiency.

The second available method of removing suspended solids is by means of chemical flocculants. This method involves the treatment of water by polymers that collect suspended particles into aggregates, which settle out rapidly. The advantage of this system is that it is particularly effective with the finer-sized sediment particles. Its disadvantage is the necessity of special installations to treat the sediment-laden water systematically. Because larger quantities of solids can be removed by the flocculating technique by using very small concentrations of polymer chemicals, the method is economically justifiable where the demand for good quality water is reasonably strong.

The facts indicate that future land and water resource planning will need to make provisions for trapping and disposing of solids from runoff water if clean water is an objective. There is a need for the development of more precise methods of predicting sediment yields under the variable watershed conditions. More efficient methods, in terms of time and cost, for the removal of solids from water must be developed, and ways of retrieving and utilizing bulk solids from the water must be found. Economic costs for storage space of unutilized waste solids may become a prohibitive factor in many areas of the Great Lakes Basin.

Erosion and sedimentation problems are complex and will become more complex as the desire for a better quality environment grows and as the economic pinch demands greater efficiency.

SUMMARY

Economic damage from erosion and sedimentation in the Great Lakes Basin is extensive because of the intensively used water and land resources and the demand for a high level of water quality. Economic barriers exist that may prevent the reduction of erosion rates on agricultural cropland by the extension of crop rotations and supporting erosion control practices. Economic factors dealing with the projected demands for row crops limit the amount of land that can be placed in rotations. These factors include more stand-over years of cover crops. Rotations must be used in conjunction with erosion control practices. Massive programs using ground cover crops in conjunction with row crops and minimum tillage must be promoted.

A land treatment program for erosion control cannot be expected to do the whole job. Extensive backup systems to control the inflow of sediment and other solids are needed. These systems include desilting basins or provision for deposition of solids in multiple-purpose reservoirs. Systems for flocculating solids chemically or by other processes will be needed. The complexity of these systems will depend upon the levels of suspended solids that can be tolerated in local water resources.

Present erosion rates in the Basin are 75 to 80 percent of those that would exist if no conservation erosion control program existed in the Basin. This program includes crop rotations on 30 percent of the cropland and supporting mechanical erosion control practices on three percent of the cropland. A completed conservation program using conventional rotations and supporting practices would reduce erosion rates to approximately 25 percent of those that would exist if there were no erosion control program in the Basin. Only the application of intensive ground cover crop and minimum tillage systems would reduce erosion rates to a level that would approach natural rates. The annual cost to install and maintain a conservation erosion control program to maintain longtime sustained productivity is nearly $25 million. A massive program of cover crops to minimize erosion rates would cost considerably more.

The current average annual gross erosion rate for the entire Great Lakes Basin is approximately 2 tons per acre per year. This rate varies from 0.1 ton per acre in the northern forested counties to 8.0 tons per acre per year for counties in the intensely cultivated southern part of the Basin. Economic projections for row crops and other cover conditions indicate that gross erosion rates will gradually drop until the year 2000 (with the exception of the intensely cultivated northwestern Ohio area). These rates will show sharp upturns after year 2000 in many of the planning subareas.

The longtime average annual sediment yields from the larger river systems range from a few tons per square mile to more than 200 tons per square mile. The St. Louis River at Duluth, Minnesota, yields an estimated three tons per square mile, and the Maumee River at Waterville, Ohio, has a measured longtime average annual yield of 173 tons per square mile. The Cuyahoga River at Independence, Ohio, has a longtime average annual measured yield of 254 tons per square mile. This last yield illustrates the influence large metropolitan areas have on the yield of solids, which include large quantities of urban waste as well as soil from erosion. The projected sediment production rates in the Great Lakes Basin are similar to those for gross erosion rates.

Erosion from urban construction activity currently produces five percent of the gross erosion in the Basin. Projected population and economic growth indicate that this rate will increase to 10 percent of the gross erosion in the Basin by the year 2020. An urban erosion index was developed for each of the 18 metropolitan complexes in the Great Lakes Basin. These are indicators of the longtime average annual potential erosion from construction sites. The indexes vary, because of relief, soil, and climatic differences, from 85 tons per year in the Buffalo, New York, area, to 200 tons per acre of disturbed land in the South Bend-Elkhart, Indiana, area. These rates assume that there are no on-site erosion control measures.

Streambank erosion is a frequent problem throughout the Basin. Moderate to severe damage occurs on nearly 11,000 bank miles along the watercourses of the Basin. This erosion is estimated to cause 1.4 million dollars annual damage. The damage consists of 0.6 million dollars from sedimentation, 0.6 million dollars from direct land loss, and 0.2 million dollars from other damage.

Dredging of sediment removes approximately 10.8 million cubic yards from Great Lakes harbors and navigation channels each year. This dredging is done periodically in 115 harbors. Lake Erie harbors receive the most dredging, primarily at Cleveland and Toledo. Direct relationships between measured sedimentation rates and dredging are very difficult to find because of the complex nature of the distribution of sediment, the different methods of dredging used, and the irregularity of dredging activities. The benefits of using diked areas for the disposal of dredge materials to protect the quality of lake water are not clearly defined.

A limited number of locations along the streams in the Basin are periodically sampled for suspended sediment. The Cuyahoga River at Independence, Ohio, the Maumee River at Waterville, Ohio, and the St. Marys River at Ft. Wayne, Indiana, have good longtime continuous sampling records. Reservoir sedimentation surveys have been made and the results have been reported for 49 reservoirs in the Great Lakes Basin. The total original capacity of these reservoirs is 262,000 acre-feet. The surveys indicate that 37,500 acre-feet of this total capacity have been lost by sedimentation. Sedimentation rates in these reservoirs vary from a fraction of one percent to several percent in loss of capacity each year. Organic sediment is an important aspect of reservoir sedimentation in the Great Lakes Region.

Gully and other channel erosion occurs most frequently in parts of the Lake Ontario basin and in parts of the Lake Superior basin (red clay area). Wind erosion is the most severe in the counties in the Lake Michigan and Lake Huron basins. Damage from infertile overwash on productive flood plain soils is not an extensive problem in the Basin. Only in one percent of the counties is it recognized as a severe problem. Sedimentation in drainage and other channels is the most severe in the Lake Erie and Lake Ontario basins. Erosion along roadsides is a frequent problem that occurs throughout the Basin. Table 18–47 rates the intensity of erosion and sedimentation problems and the need for controls in the individual planning subareas.

The basic erodibility characteristics of the soils in the Basin vary by as much as 100 percent between the sandy soils and the clay soils. Slope steepness and slope length are quite variable, and much of the land surface in the Basin is irregular and hummocky with poor to imperfectly developed drainage patterns. The intensity of the rainfall, as it relates to quantitative analysis of erosion, varies by as much as 100 percent between the northern and eastern parts of the Basin and southern and western parts.

The Great Lakes Basin is part of the Central Lowlands Province with extensions into the Superior and Adirondack highlands of the Laurentian Upland and into the Allegheny section of the Appalachian Plateau. The surface of the Basin ranges in elevation from 250 to nearly 3,000 feet. The age of the bedrock extends from Precambrian in the Laurentian Upland to Devonian in the Allegheny Plateau section.

The Basin is covered by a thick blanket of glacial drift over most of its surface. This glacial drift surface was molded by the Tazwell, Cary, and Port Huron substages of the Wisconsin glacial stage and by the various glacial lake stages associated with the advance and retreat of the ice sheets. The soils in the Basin are developed in a wide variety of material. These materials include stratified glacial drift; undifferentiated glacial till; outwash silt, sand, and gravel; and lacustrine clay, silt, and sand. The soils have various origins, and they range from the prairie types (Mollisols) to the gray-brown podzolics (Udalfs) to the podzols (Orthods).

TABLE 18–47 Ratings of the Intensity of Erosion and Sedimentation Problems (on a scale of intensity increasing from 1 to 5)

Problem or Needed Control	Planning Subareas														
	1.1	1.2	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	4.3	4.4	5.1	5.2	5.3
Application of Erosion Control Practices on Agricultural Cropland and Pasture Land	1	1	5	5	5	4	2	5	4	5	3	3	4	4	2
Land Use Adjustments for Erosion Control	1	1	5	5	5	4	1	3	2	4	2	3	2	5	4
Measures to Control Erosion from Urban Construction	3	1	3	5	4	2	1	4	5	4	5	4	3.5	4	1
Control of Gully and Roadside Erosion	5	3	4	3	4	3	2	3	3	4	3	4	4	4	3
Control of Streambank Erosion	3	5	4	3	4	5	4	4	4	4	3	1	1	2	1
Control of Wind Erosion	2	2	4	4	5	5	3	4	4	4	3	4	4	4	2
Control of Sediment in Drainage Ditches	2	1	4	4	4	3	3	5	4	5	3	5	4	4	2
Control of Infertile Overwash on Bottomland Soil	2	1	3	4	3	3	2	2	3	4	3	3	2	2	1
Control of Sedimentation in Navigation facilities	4	3	4	4	4	3.5	2	4	5	5	5	4	3	2	1
Control of Sedimentation for Water Quality	3	2	4	5	5	3	2	4	5	5	5	4	4	4	3
Need for Mitigating Measures (Desilting Basins and Flocculating Systems)	3	2	4	5	5	3	2	4	4	5	4	4	4	4	3

GLOSSARY

abrasion—wearing away by friction, used in connection with streambank erosion.

acre-foot—a volume that would cover an area of one acre to a depth of one foot.

acres of associated facilities—in urban development, areas of land used for roads, shopping centers, industrial parks, schools, etc., in association with the acres of land used for residential building.

bank mile—there are two bank miles in each mile of a stream channel.

bottomland scour—erosion of the surface of lowland alluvial soil by water.

c value—a factor based on a maximum value of 1.0 that reflects the effectiveness of vegetative land cover in controlling erosion. The factor is used in the universal soil loss equation.

capacity inflow ratio—the capacity of a reservoir in watershed inches divided by the average annual inflow in watershed inches.

channel sedimentation—disposition of sediment in a channel where the transporting capacity and the duration of channel flow have been insufficient to remove sediment as rapidly as it has been delivered.

cohesive properties—soil terminology expressing the degree of force holding like particles together, or the intensity of molecular attraction.

conservation needs inventory—an inventory, based upon sampling from soil surveys, of soil, slope, erosion, land use, and other factors. Needed conservation practices are also recorded. A given percent of an area, generally a county, is sampled. The data are expanded to the entire area.

delivery ratio—the percent of total solid input to a stream system that reaches a given downstream point in the watershed.

density of dredged material—the unit dry weight, usually in pounds per cubic foot, of dredged material.

deposition—the accumulation of material (sediment) dropped because of slackening movement of the transporting agent—usually water, sometimes wind, or ice.

drainage density—ratio of the total length of all drainage channels in a drainage basin to the area of that basin.

drift plain—rock debris transported by glaciers and deposited directly by ice or meltwater and left on undulating to steeply sloping plains.

eroded material—the material that has been removed from a location by the erosive force of wind, water, or ice.

erosion—the group of processes whereby earth or rock material is loosened or dissolved and removed from any part of the earth's surface.

erosion, accelerated—an increase in the rate of erosion over the normal, natural rate.

erosion, channel—erosion of the sides and/or bottom of a channel.

erosion damage—the direct damage done, generally to land, by the erosion processes. Included are loss of topsoil or other soil mass by sheet, wind, or voiding in gullies or trenches. Damages are expressed in terms of dollar loss of productivity or in costs of repair.

erosion, geological—normal erosion that takes place in nature without the influence of man.

erosion, gross rate of—total erosion from all sources in a given area expressed in tons per acre per year. These sources include sheet, gully, wind, streambank, roadside, etc.

erosion, rate of—the average quantity of material that is eroded from an area in a certain period of time. Usually expressed in tons per acre per year from some single form of erosion.

erosion, rill—removal of soil by running water, with formation of a small furrow that can be smoothed out by normal plowing.

erosion, roadside—erosion of a road berm and/or the banks and bottom of a roadside ditch.

erosion, sheet—the removal of a fairly uniform layer of soil from the land surface by runoff water.

erosion, shore—the recession of a lakeshore by the various hydraulic erosion processes.

erosion, streambank—removal of soil from the bank of a stream by the erosive force of the stream and/or by the force of rain falling on the banks.

erosion, urban—the erosion on land exposed during the development of urban type improvements such as residential subdivisions, business and industrial areas, and associated improvements.

erosion, wind—the removal of soil particles by the erosive force of wind.

fall velocity—a term used in soil mechanics engineering referring to the distance fine solid particles (of various size, density and shape) fall by gravity through a liquid medium such as water, in a given period of time.

flocculate—the process of aggregation of fine suspended soil particles into larger, settleable sediment particles.

gaged cross section—the cross-sectional area of a stream channel that has been rated so that the rate of flow in the stream can be determined by measuring the water surface elevation.

gully—a channel cut by concentrated runoff through which water flows only during or immediately after heavy rainfall. A gully is sufficiently deep that it is not obliterated by normal cultivation practice and is too deep to be crossed by wheeled vehicles.

ground cover—a general reference to vegetative growth with sufficient foliage to largely cover an erodible soil surface.

infertile overwash—the deposition of sterile soil debris, such as sand, gravel, stones, or silt and clay on productive flood plain land.

internal drainage—the downward movement of water through a soil profile. Texture, structure, and other characteristics determine the rate. Internal drainage is expressed generally as poor, imperfect, moderately good, good, or excessively good.

interfluves—the district between adjacent streams flowing in the same general direction.

isogreros lines—lines of an isogram that connect points of equal rates of gross erosion.

isosetay lines—lines on an isogram that connect points of equal rates of sheet erosion.

k value—a factor used in the universal soil loss equation to reflect relative basic erodibility differences of soils.

land management—a broad term that covers a wide range in both type and levels of land utilization.

land reshaping—massive movement of earth materials to achieve a desired combination of slope steepness and contour.

land voiding—massive removal of soil material by the erosive force of water. Similar to gully development.

land use shift—a change in the trend of land use over a period of time.

littoral drift—the lateral movement of sand and other materials in the shallow water of shore and coast areas.

maintenance dredging—the periodic dredging of sediment from rivers and harbors to maintain navigation facilities.

minimum tillage—cultivation practice that minimizes amount of ground cover and its duration in protecting cropland from erosion.

net drainage area—that part of a watershed that is "uncontrolled" and contributes sediment and runoff directly to the downstream reach through the natural hydraulics of the system.

organic sediment—a low density, high organic accumulation on the bottom of reservoirs, lakes, channels, and other water-inundated areas.

parent material—the unconsolidated, chemically weathered mineral or organic material in which a soil solum (A & B horizons) is developed.

rainfall factor, R—a numerical expression of rainfall used in the universal soil loss equation. It is expressed as a rainfall erosion index that is a summation at a particular location of the longtime-average yearly total of EI values. An EI value is the product of total kinetic energy of a storm times its maximum 30 minute intensity.

sediment—solid material, both mineral and organic, that has been deposited within a water impoundment or in a channel.

sediment concentration—the amount of suspended sediment in water expressed as parts per million by weight or as a percent by weight.

sediment discharge (load)—the quantity of sediment, expressed either by weight or by volume, that is transported through a stream cross section in a given time. It includes both suspended load and bed load.

sediment production—a general term that expresses the total sediment quantity, in tons or acre feet, that reaches a given point or area in a stream system during a given time interval.

sediment, suspended—solid material being carried in transport by moving water or solid material in more or less still water that is suspended in a turbid or colloidal condition.

sediment transport—the process of moving sediment from its place of origin to a downstream point.

sediment yield—the product of input of solids by erosion or other sources to a stream system and the delivery ratio of the stream at a given downstream point. Sediment yields continually change along a given stream system.

sedimentation—a broad term used to describe the entire process of solid accumulation due to settlement of solids from runoff water.

sedimentation damage—damage to water and related land resources due to the presence of suspended or deposited sediment.

soil resource group—a combination of soil units in which the broad productivity, management requirements, and site characteristics are similar.

soil texture—the relative proportions of the broad particle size classifications: sand, silt, and clay, in a soil mass.

strand lines—a term synonymous with beach. Often used in connection with old or abandoned beach lines associated with former lake levels.

thalweg—the line joining the points along the deepest part of a submerged stream channel.

till—unstratified glacial drift deposited directly by ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion.

trap efficiency—the percentage of the total sediment transported by tributary streams to an impoundment that settles out of the runoff water passing through the impoundment. This trap efficiency is generally related to the capacity of the impoundment, the amount of inflow, and other factors.

urban erosion index—a numerical value that rates an entire area into which urbanization is extending as to its weighted average susceptibility to erosion of land that will be denuded of cover in the urban construction process. This index weighs the following factors: basic soil erodibility based upon soil types; slope and other relief characteristics; and rainfall intensity.

urban waste debris—solids entering the streams and other watercourses in urban areas that are derived from a wide variety of sources other than soil erosion.

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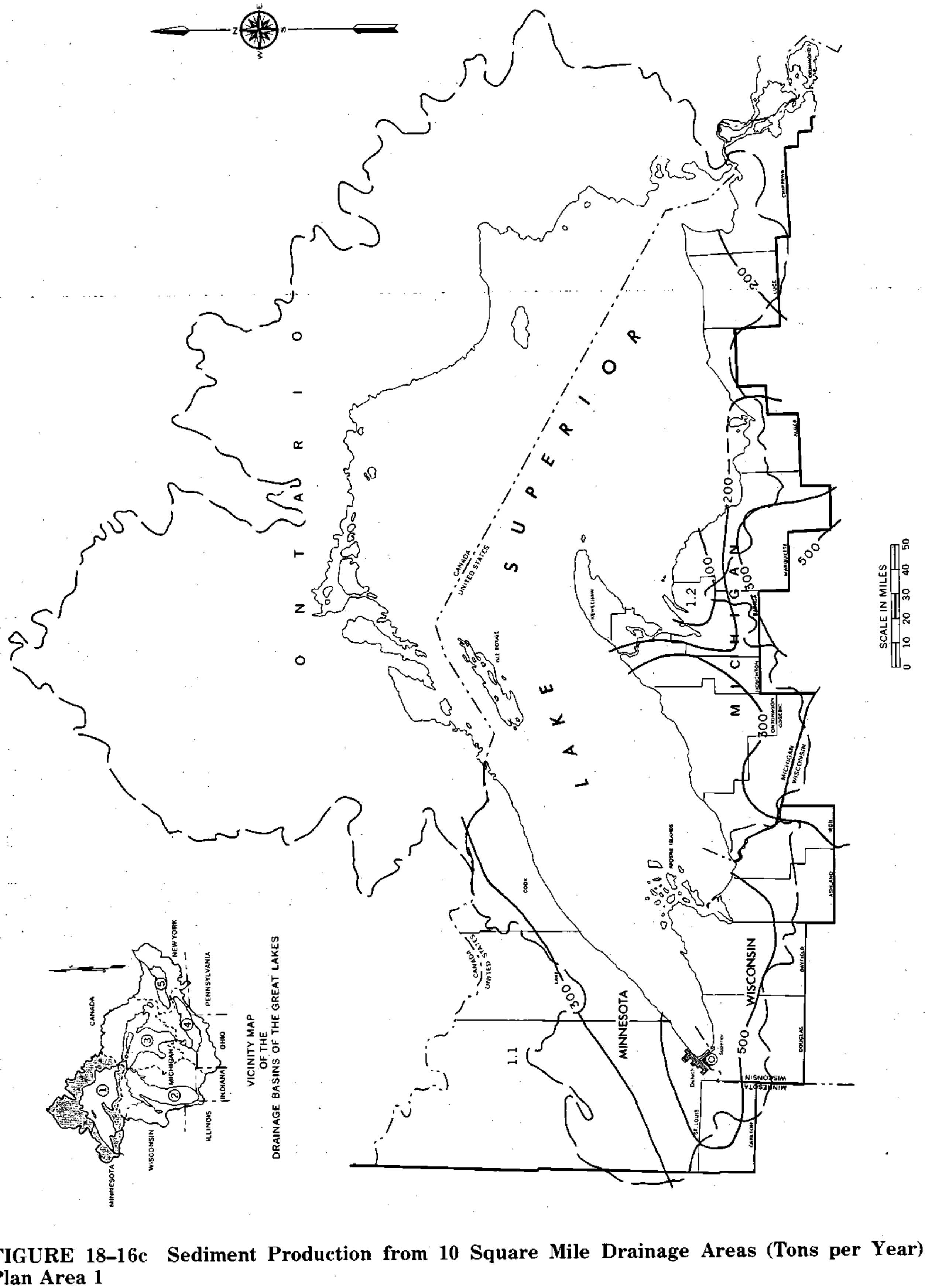


FIGURE 18–16c Sediment Production from 10 Square Mile Drainage Areas (Tons per Year), Plan Area 1

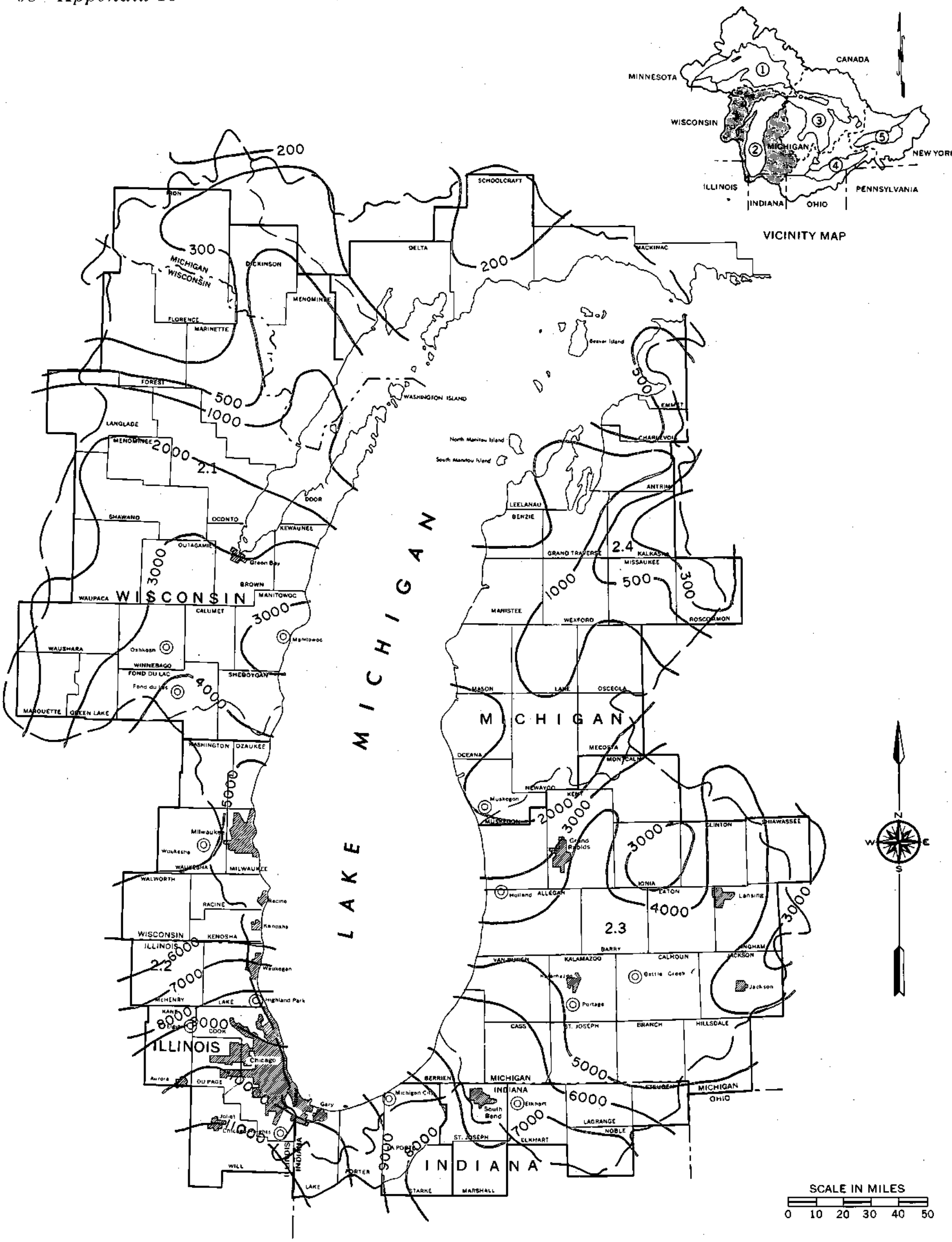


FIGURE 18–17c Sediment Production from 10 Square Mile Drainage Areas (Tons per Year), Plan Area 2

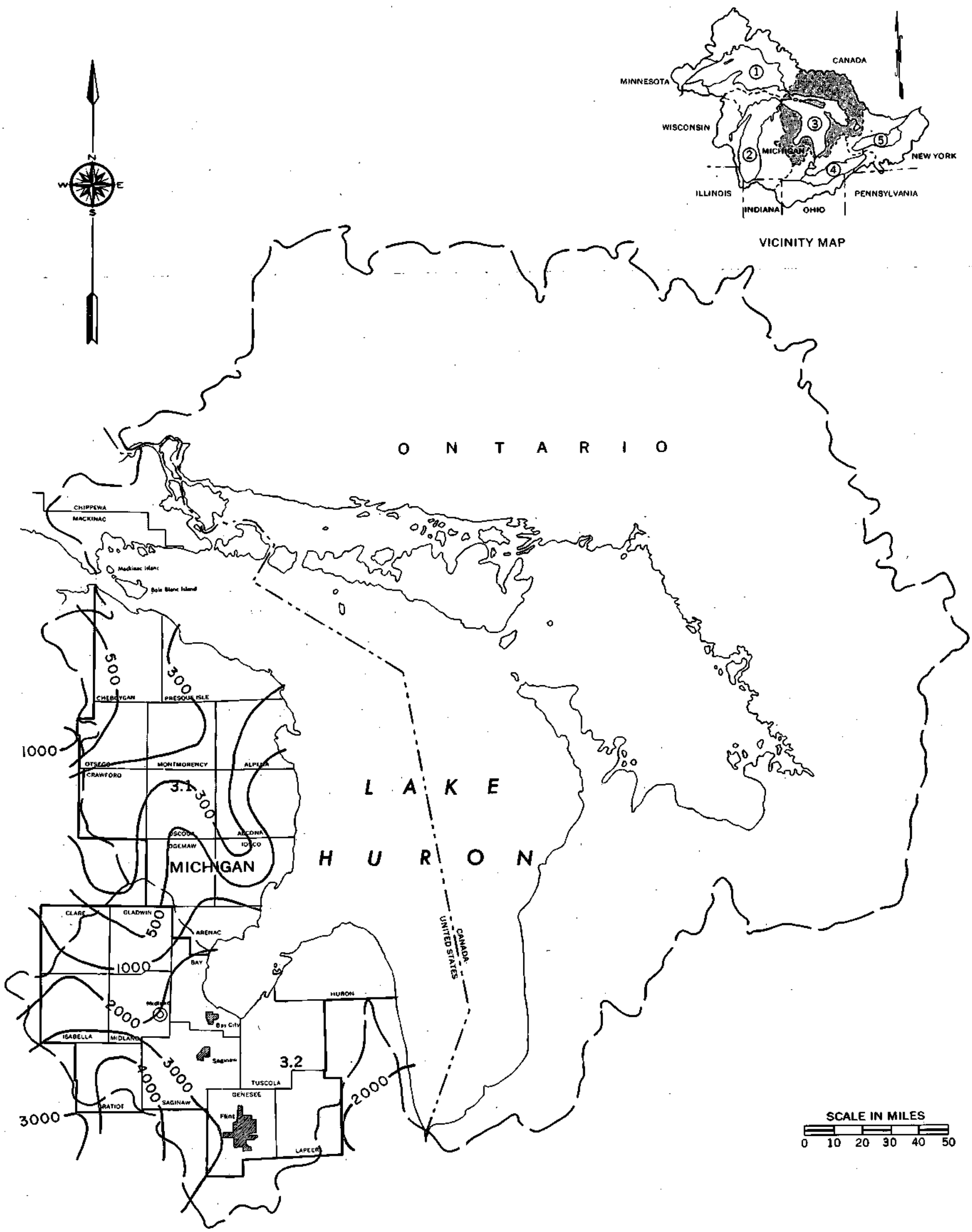


FIGURE 18–18c Sediment Production from 10 Square Mile Drainage Areas (Tons per Year), Plan Area 3

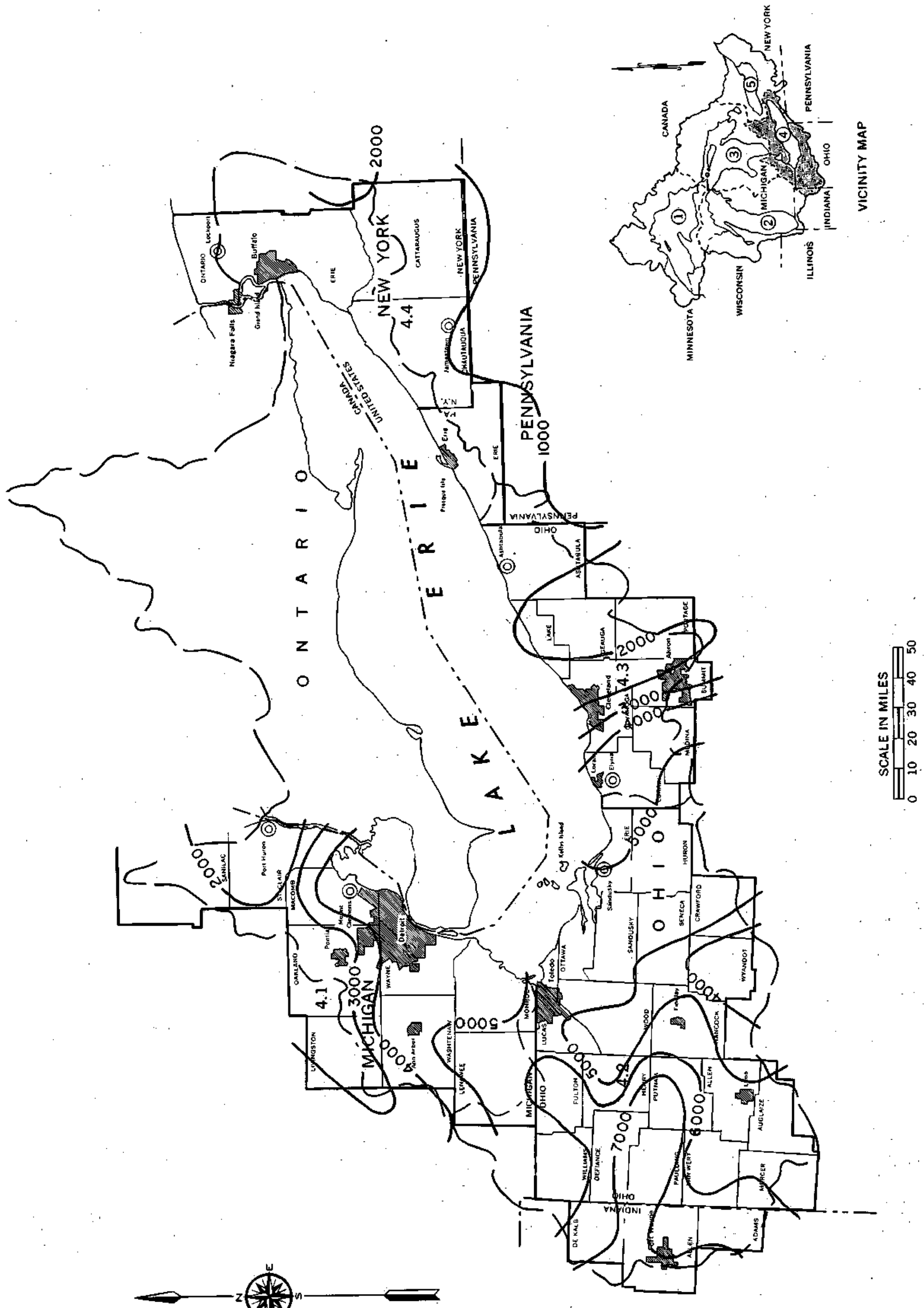


FIGURE 18–19c Sediment Production from 10 Square Mile Drainage Areas (Tons per Year), Plan Area 4

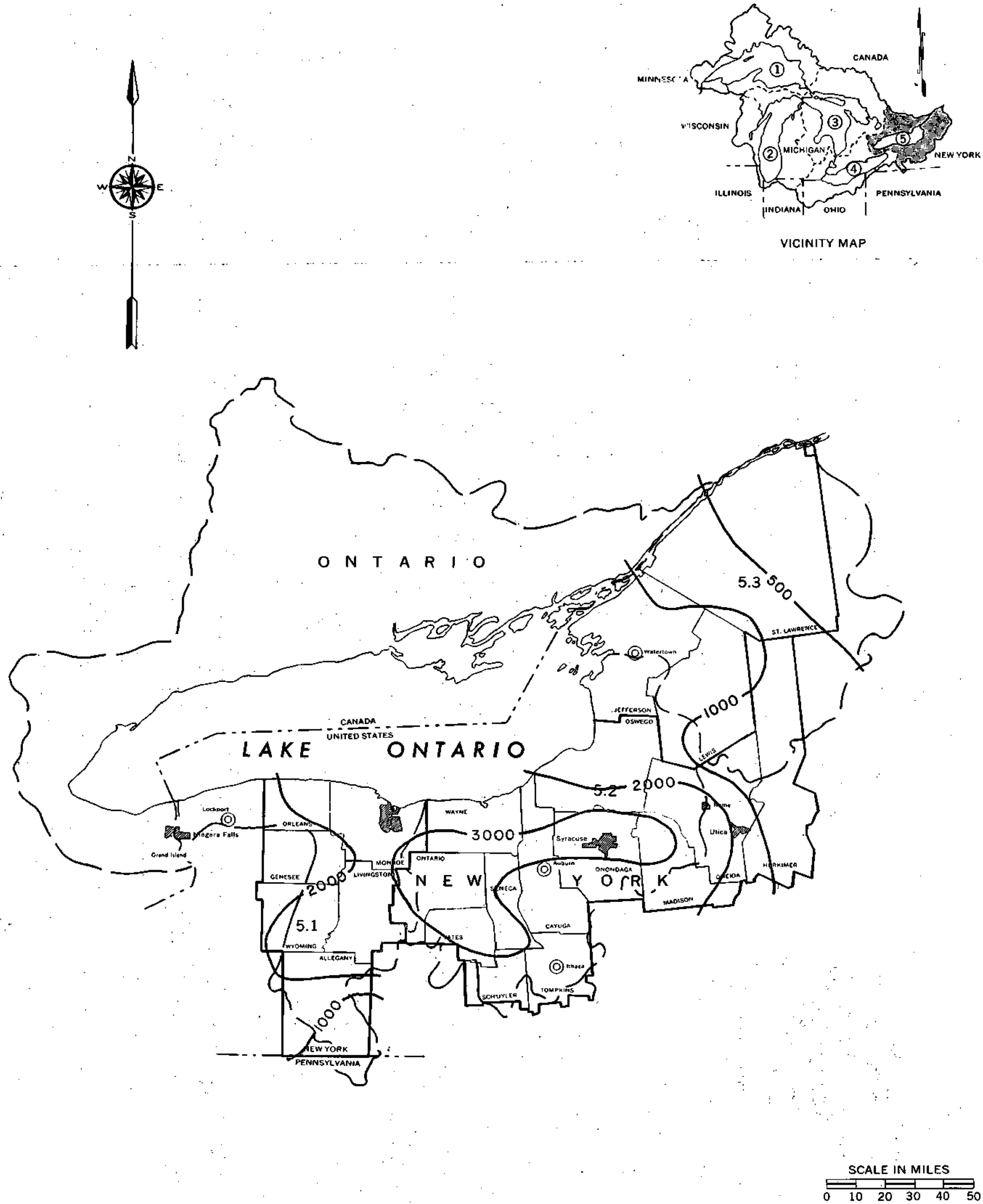


FIGURE 18–20c Sediment Production from 10 Square Mile Drainage Areas (Tons per Year), Plan Area 5

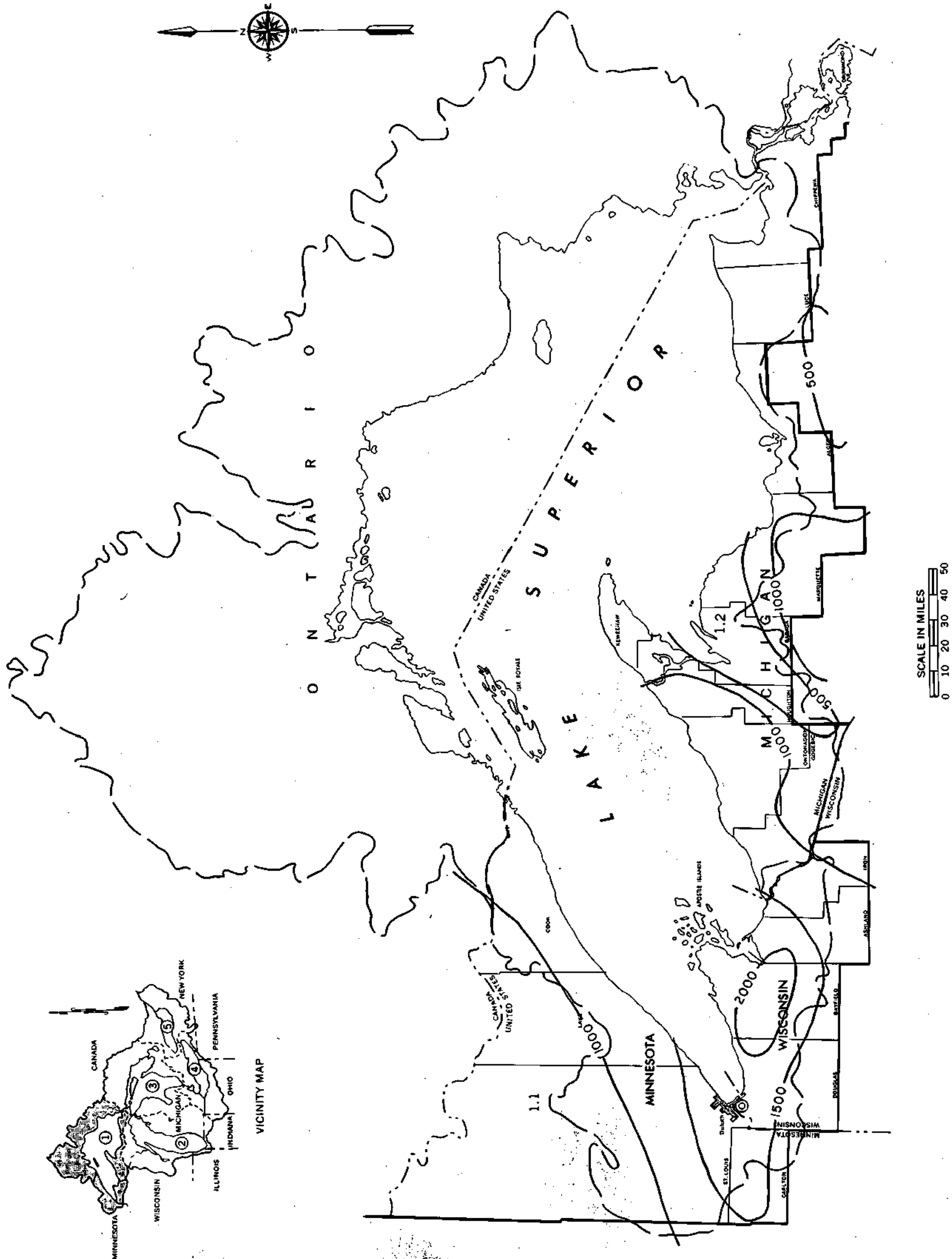


FIGURE 18–21c Sediment Production from 50 Square Mile Drainage Areas (Tons per Year), Plan Area 1

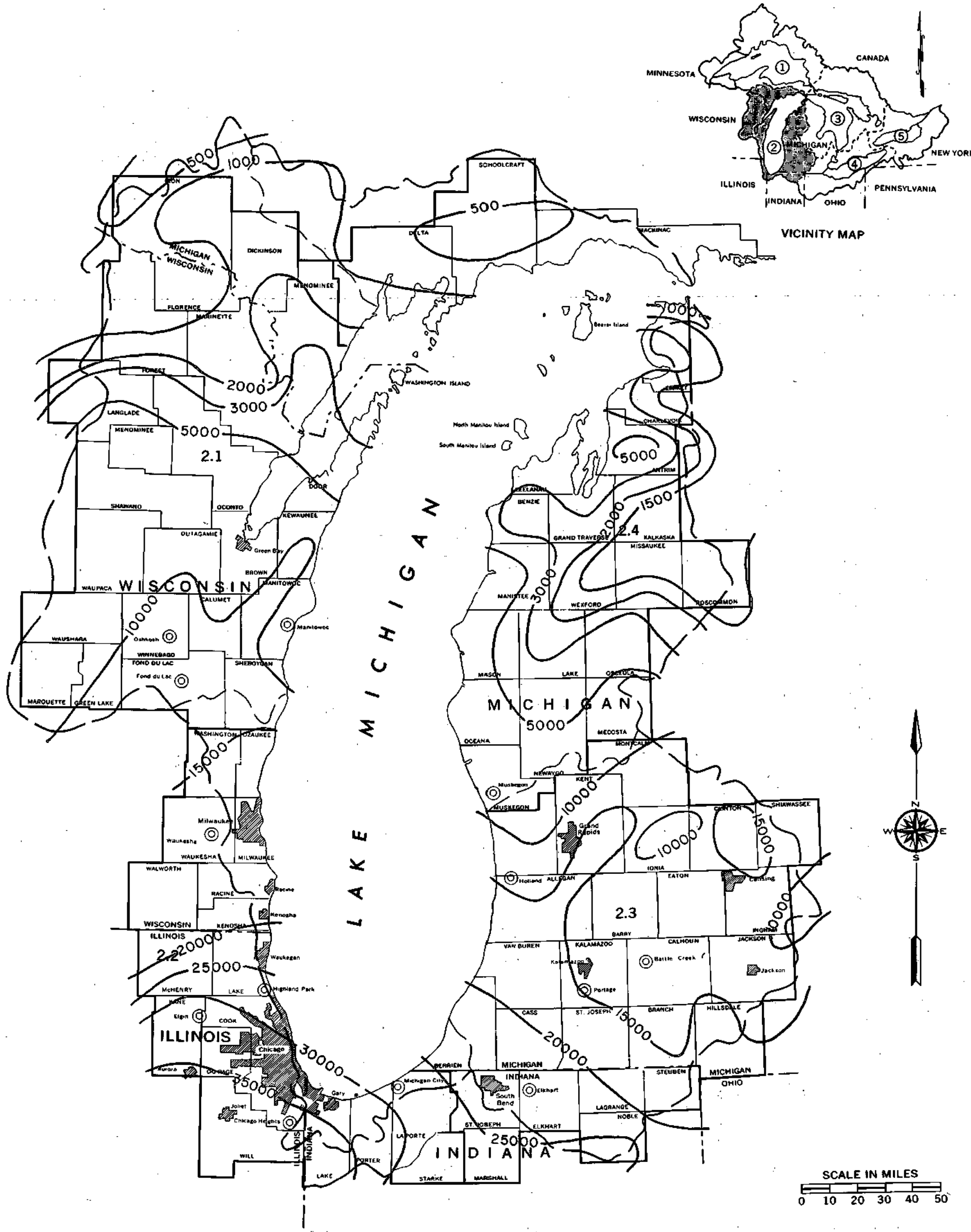


FIGURE 18–22c Sediment Production from 50 Square Mile Drainage Areas (Tons per Year), Plan Area 2

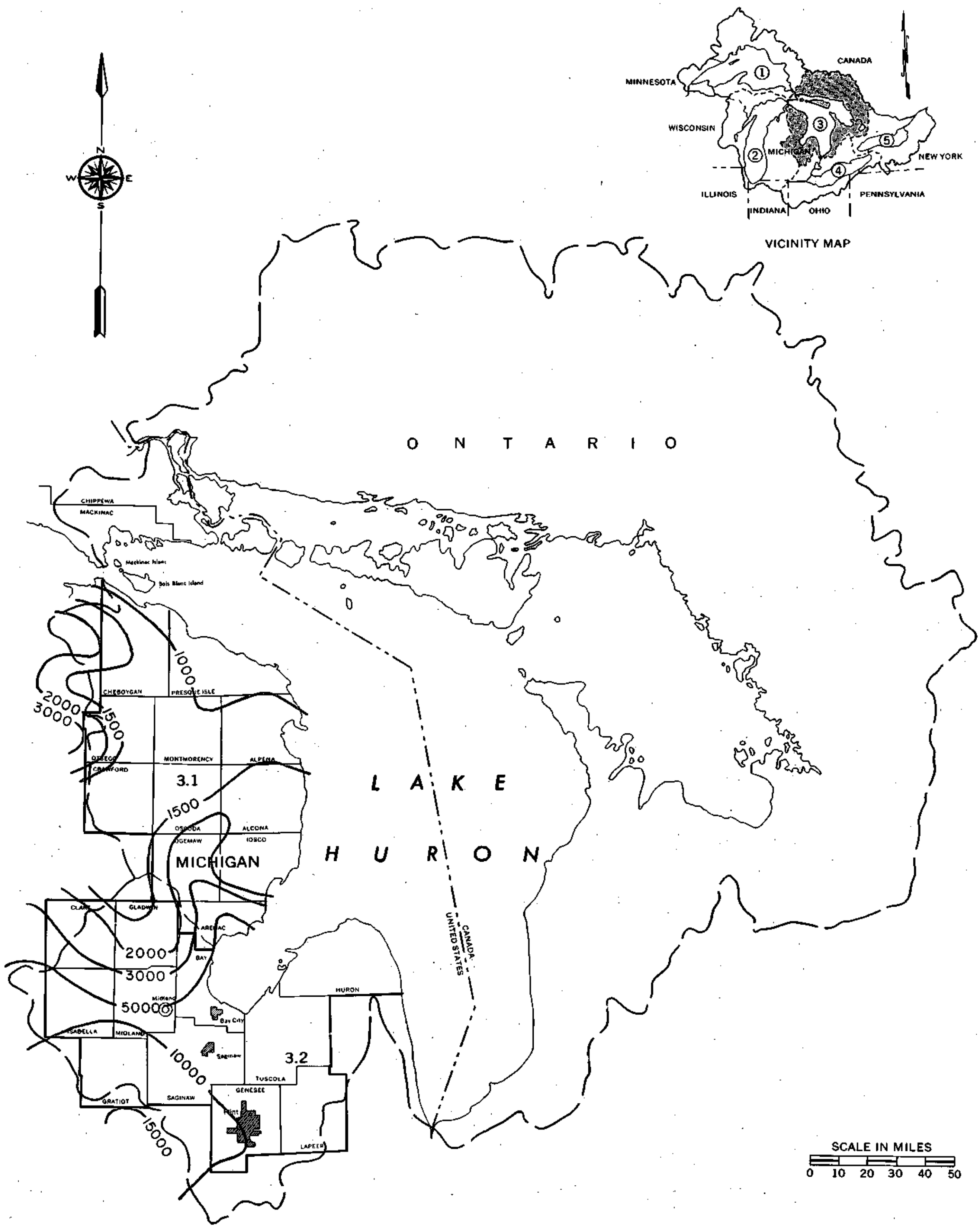


FIGURE 18–23c Sediment Production from 50 Square Mile Drainage Areas (Tons per Year), Plan Area 3

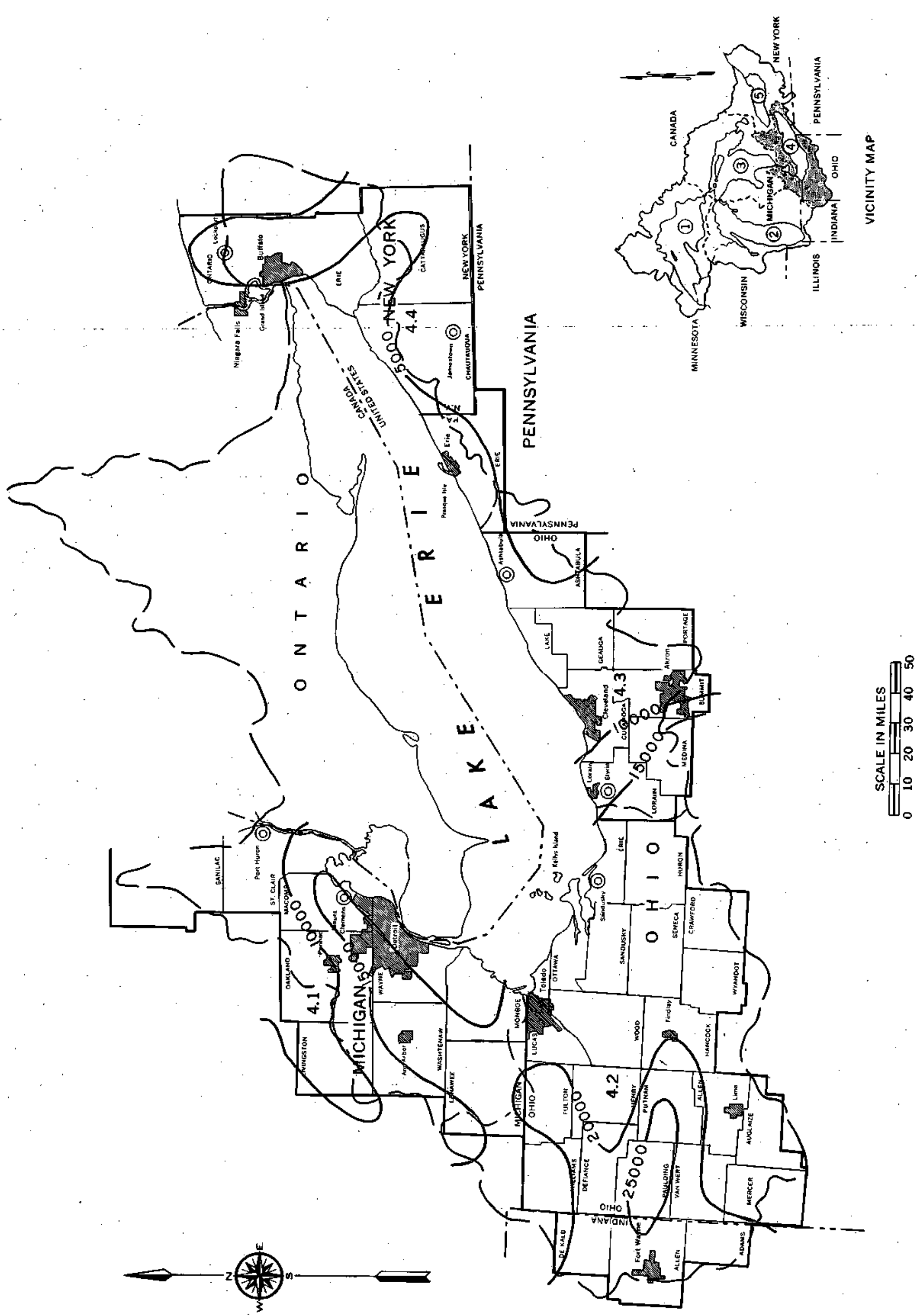


FIGURE 18–24c Sediment Production from 50 Square Mile Drainage Areas (Tons per Year), Plan Area 4

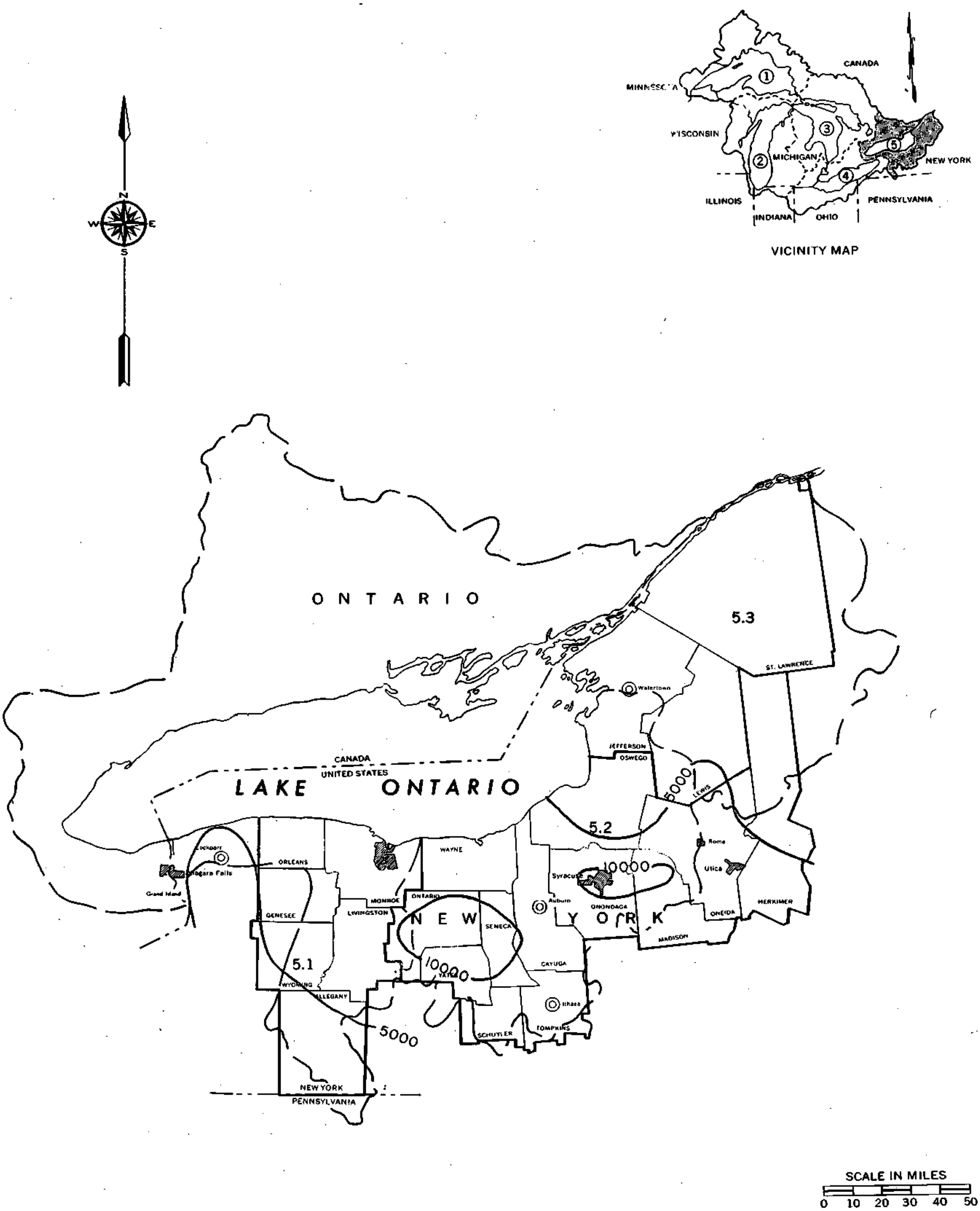


FIGURE 18–25c Sediment Production from 50 Square Mile Drainage Areas (Tons per Year), Plan Area 5

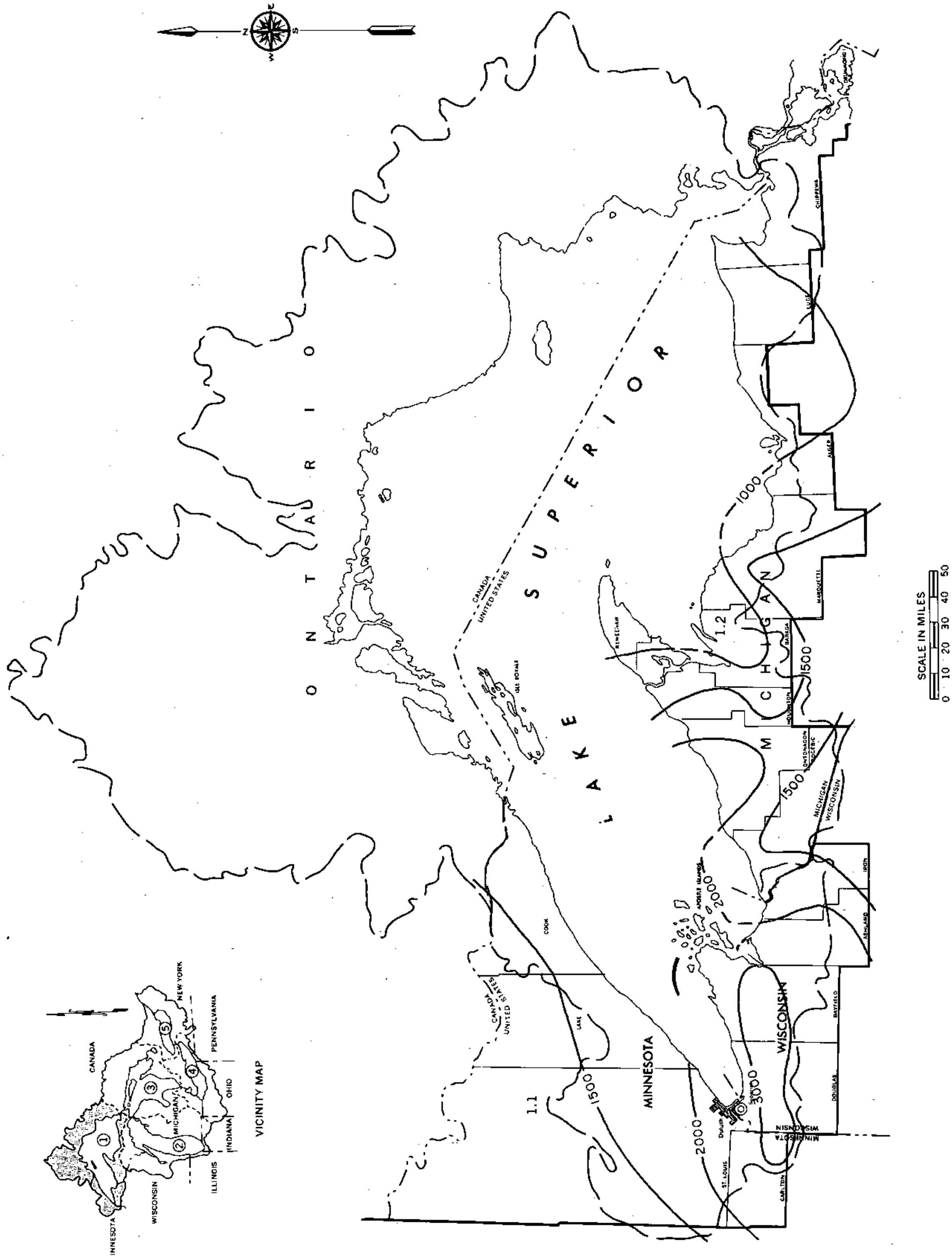


FIGURE 18–26c Sediment Production from 100 Square Mile Drainage Areas (Tons per Year, Plan Area 1

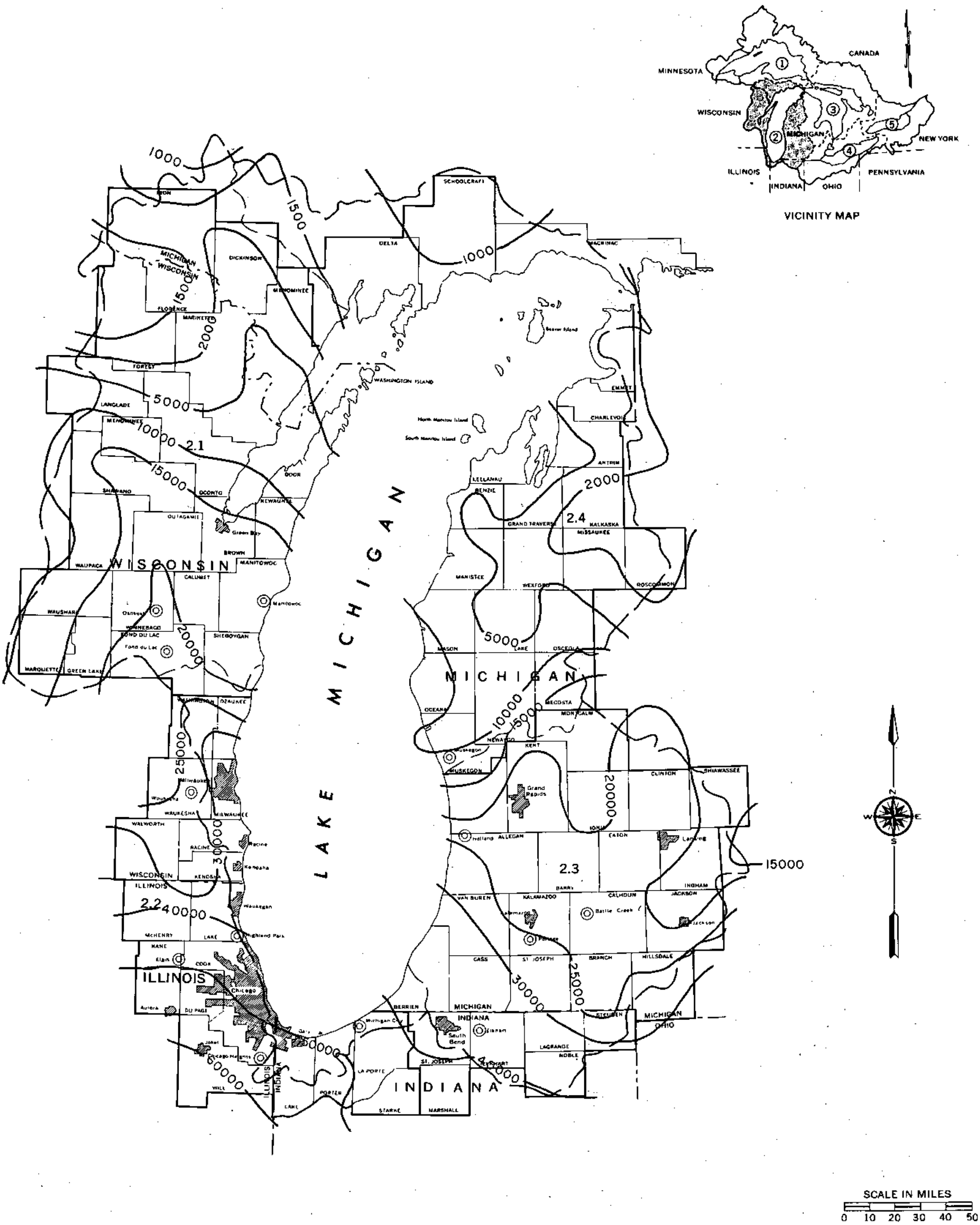


FIGURE 18–27c Sediment Production from 100 Square Mile Drainage Areas (Tons per Year), Plan Area 2

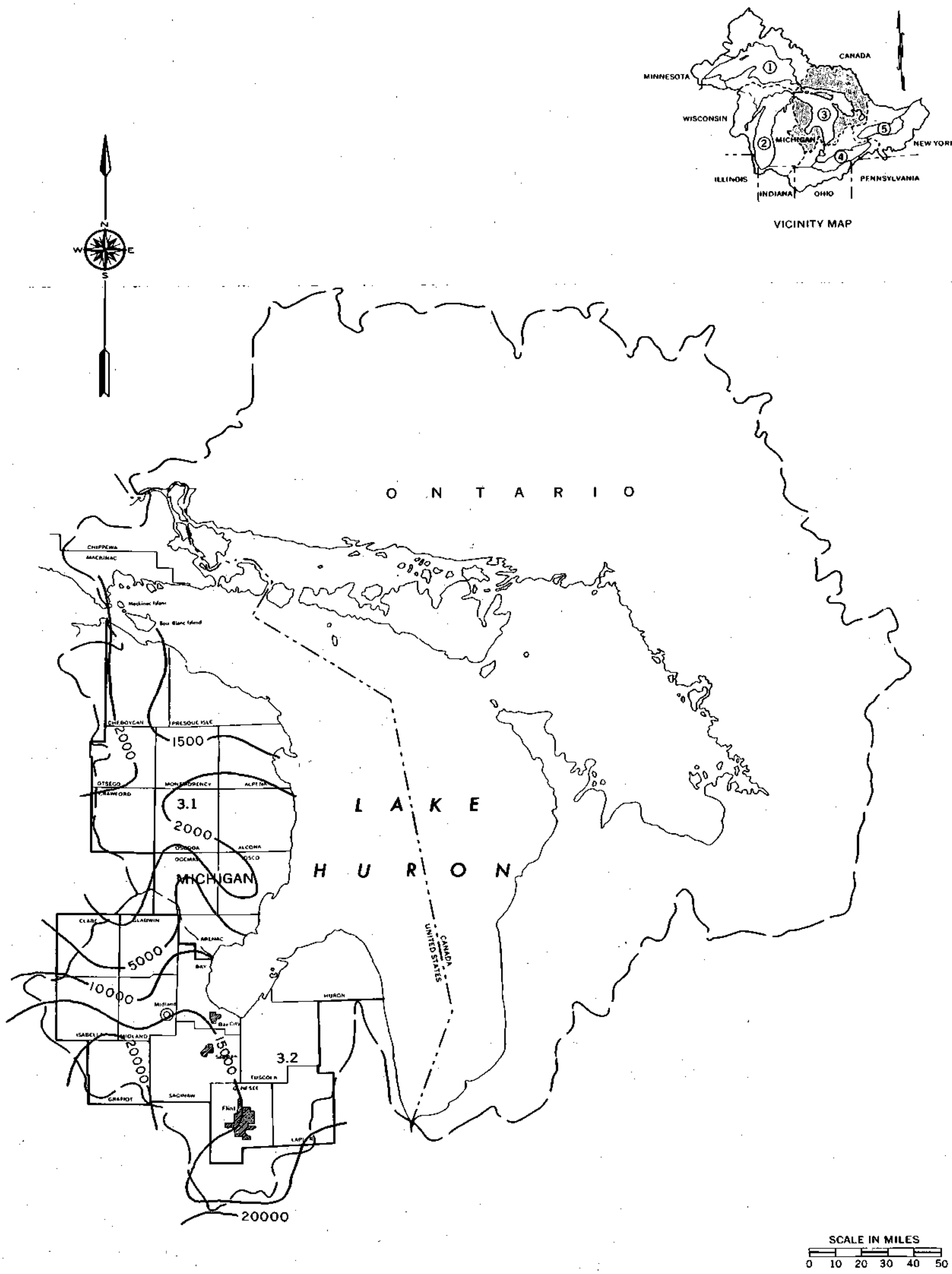


FIGURE 18–28c Sediment Production from 100 Square Mile Drainage Areas (Tons per Year), Plan Area 3

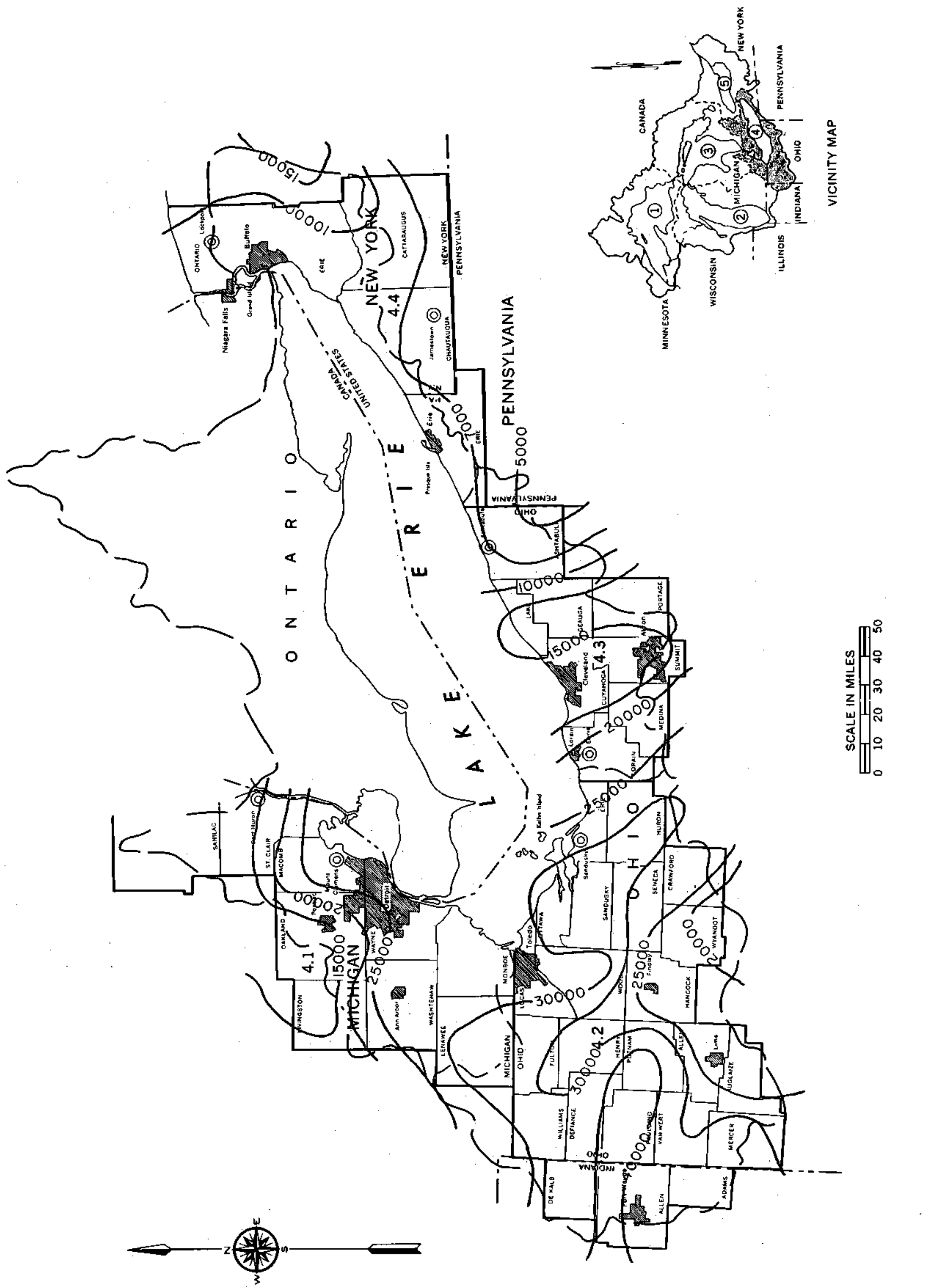


FIGURE 18–29c Sediment Production from 100 Square Mile Drainage Areas (Tons per Year), Plan Area 4

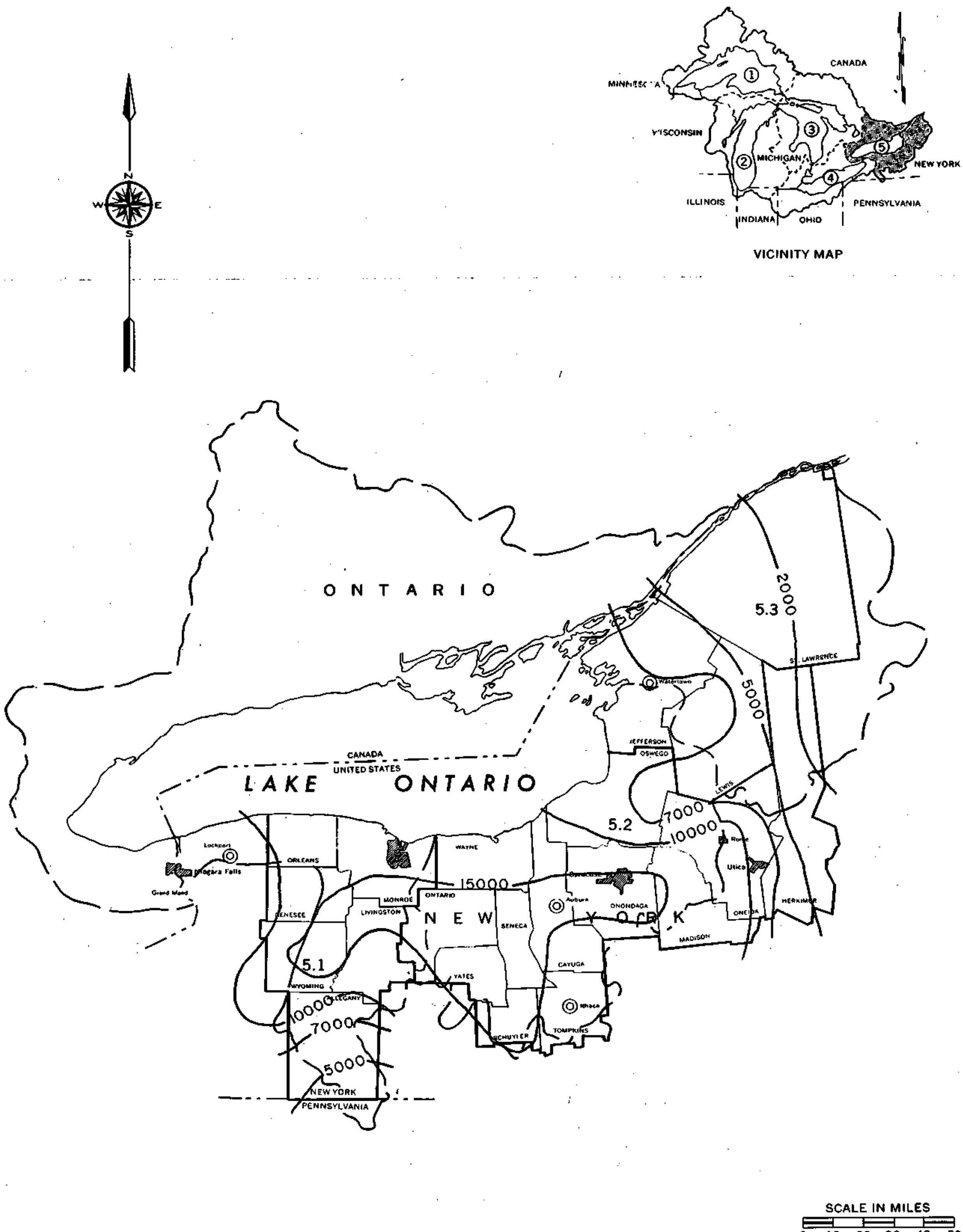


FIGURE 18-30c Sediment Production from 100 Square Mile Drainage Areas (Tons per Year), Plan Area 5

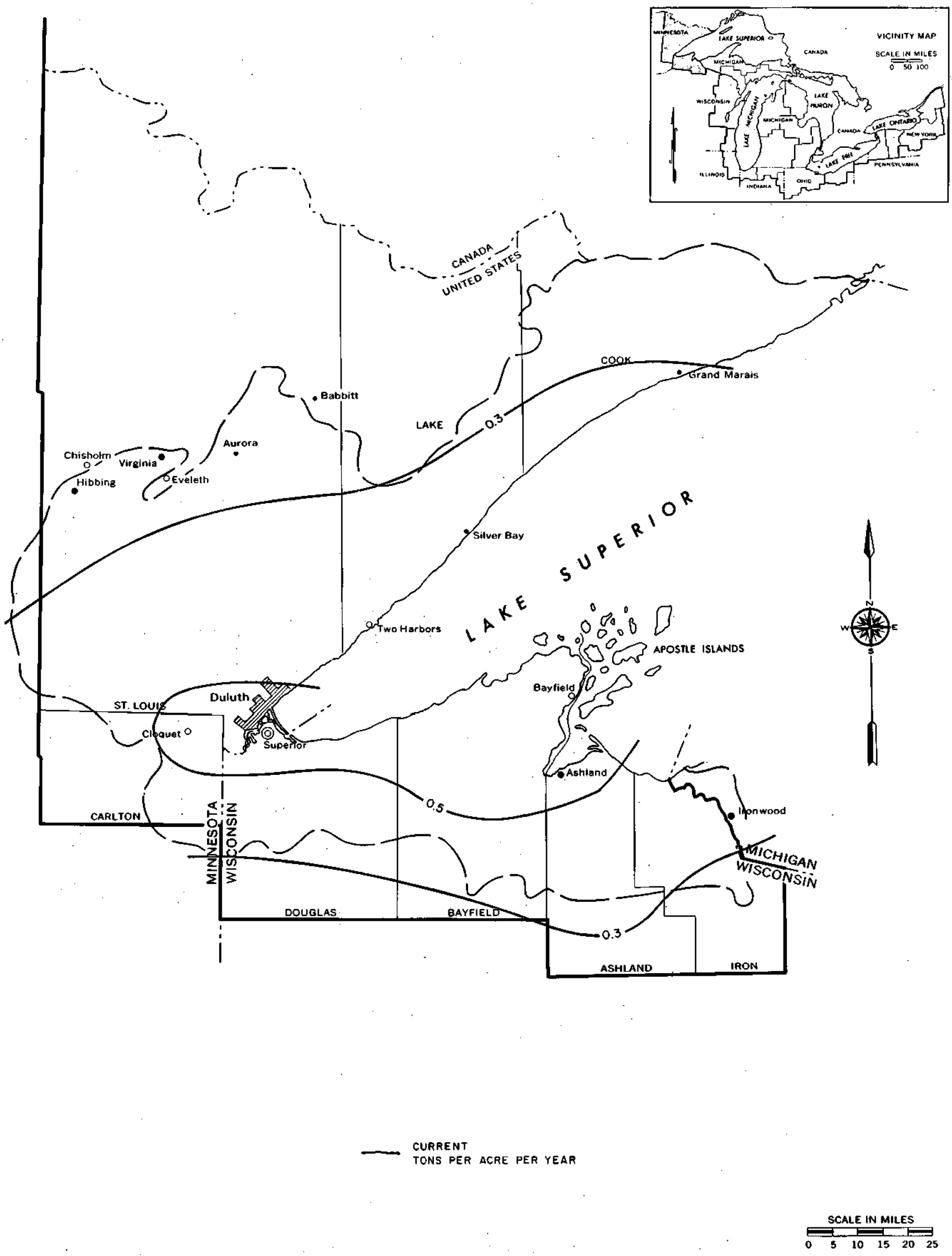


FIGURE 18-31c Gross Erosion Rates, Planning Subarea 1.1

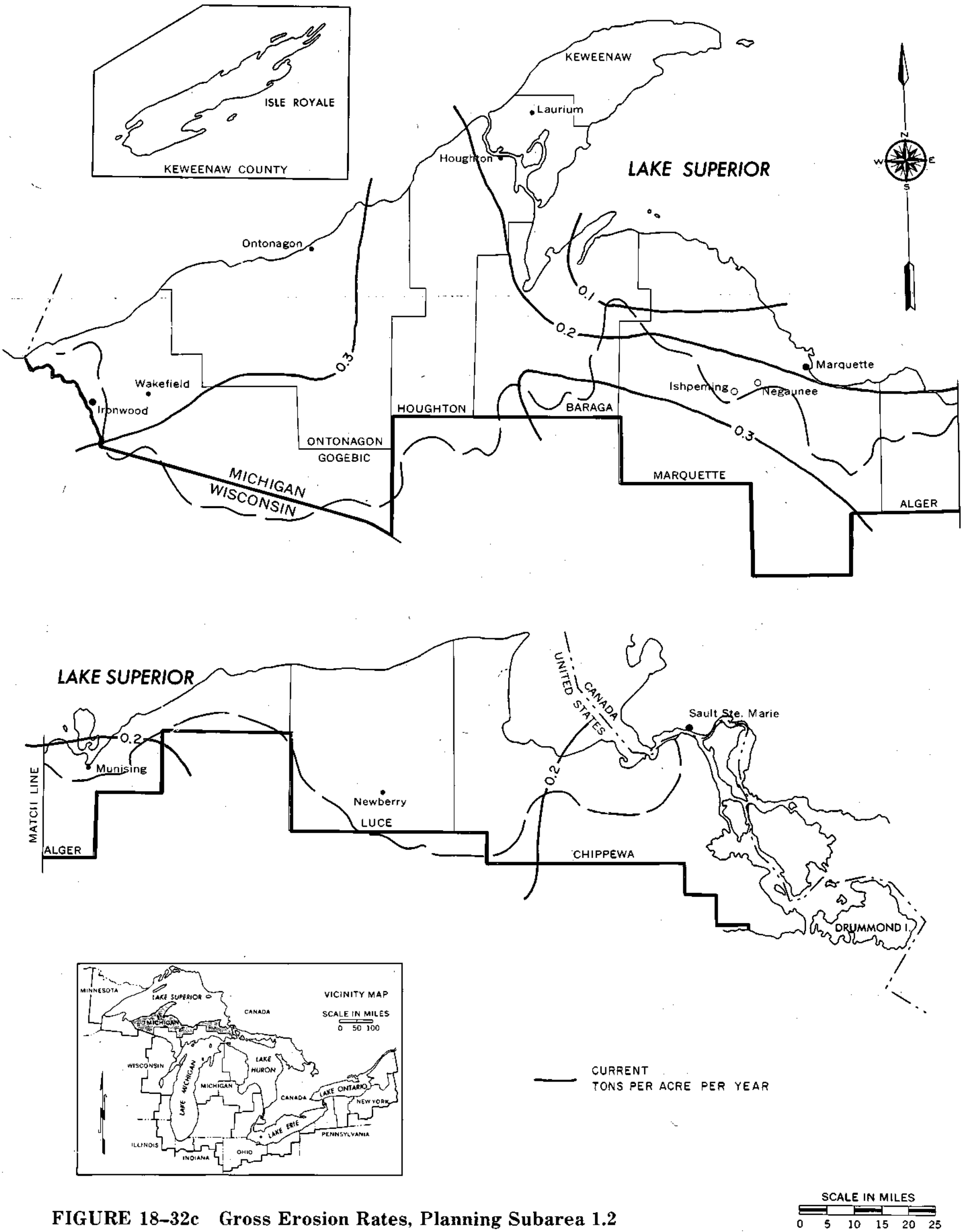


FIGURE 18-32c Gross Erosion Rates, Planning Subarea 1.2

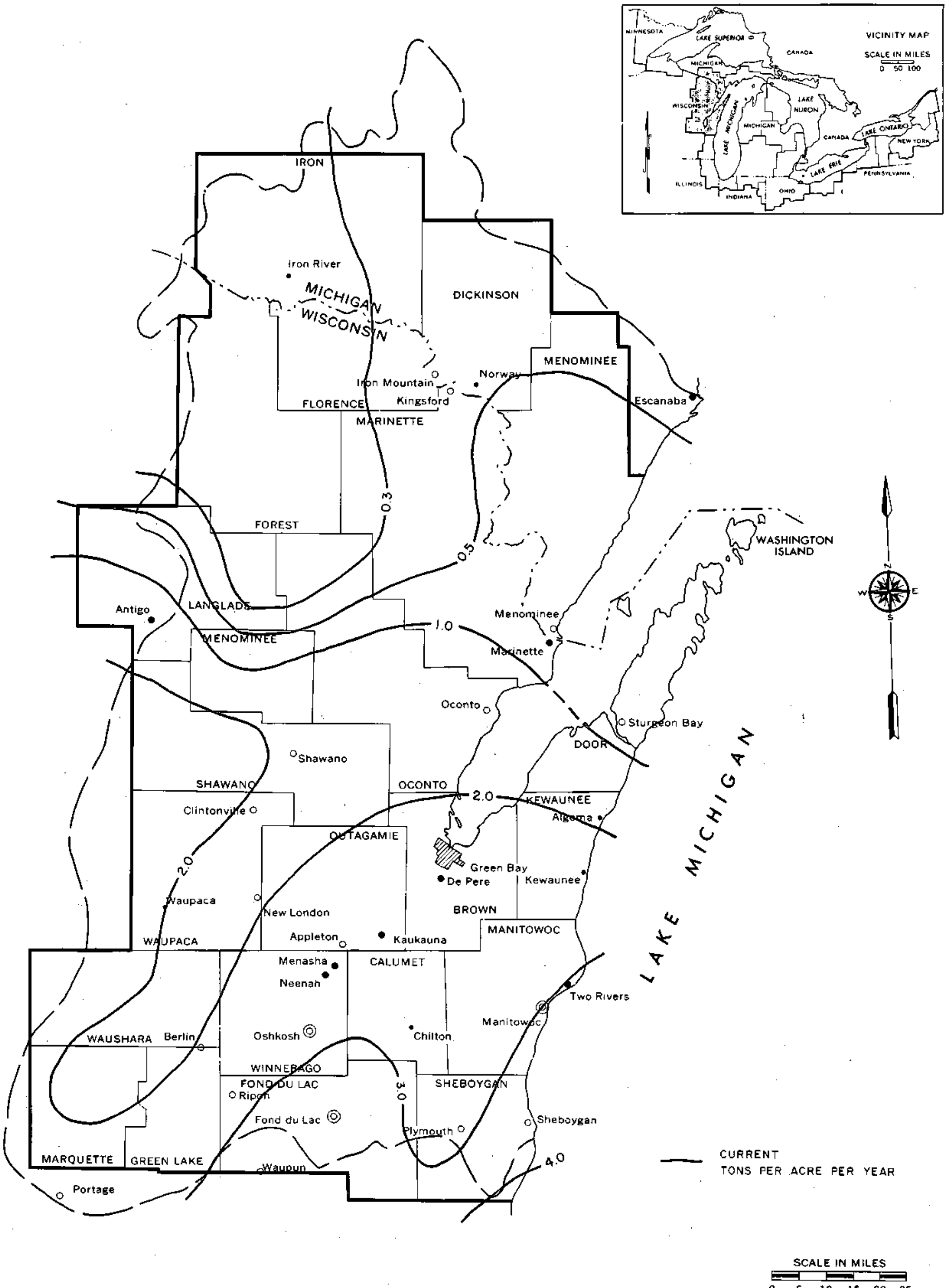


FIGURE 18–33c Gross Erosion Rates, Planning Subarea 2.1

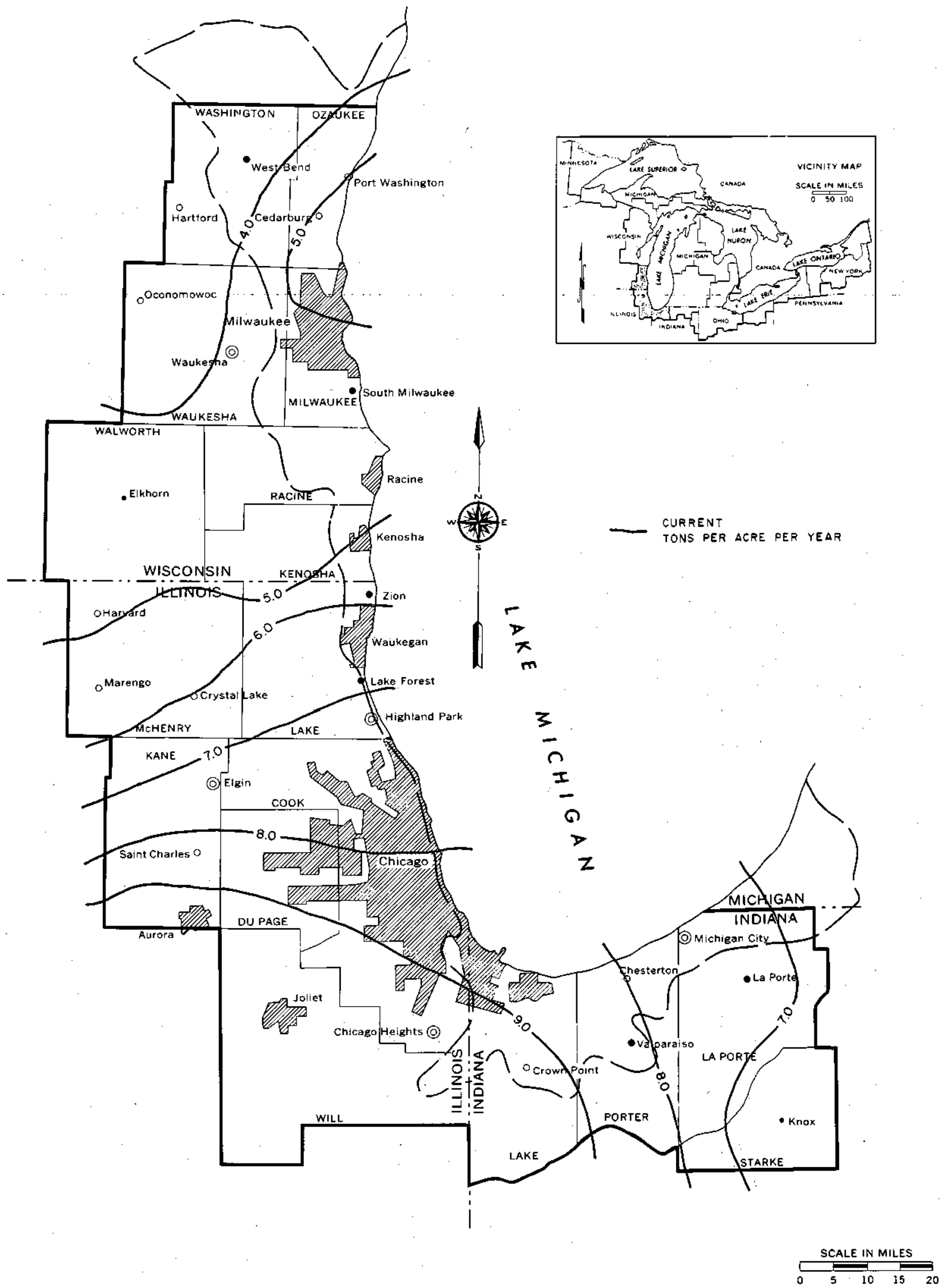


FIGURE 18-34c Gross Erosion Rates, Planning Subarea 2.2

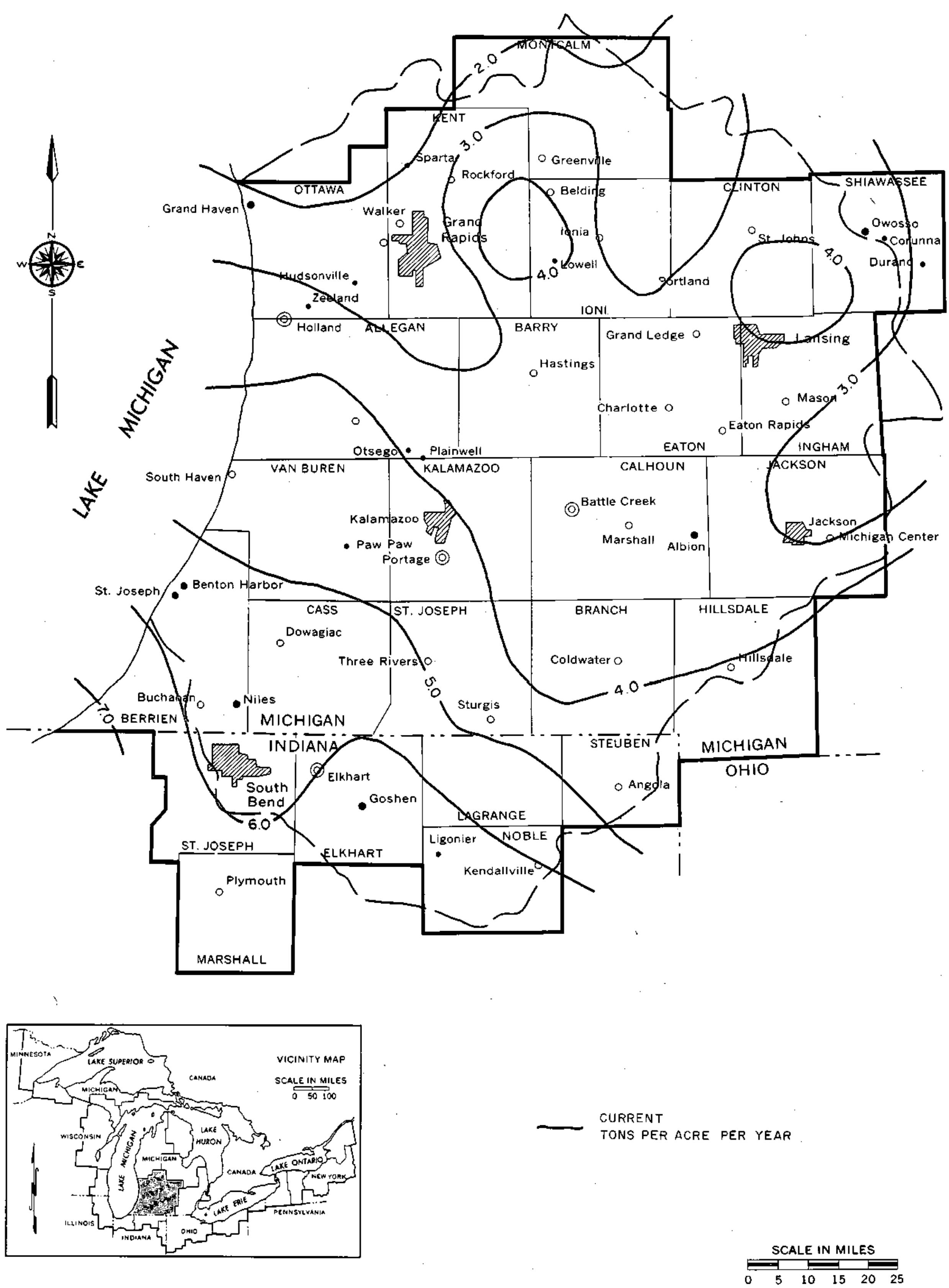


FIGURE 18–35c Gross Erosion Rates, Planning Subarea 2.3

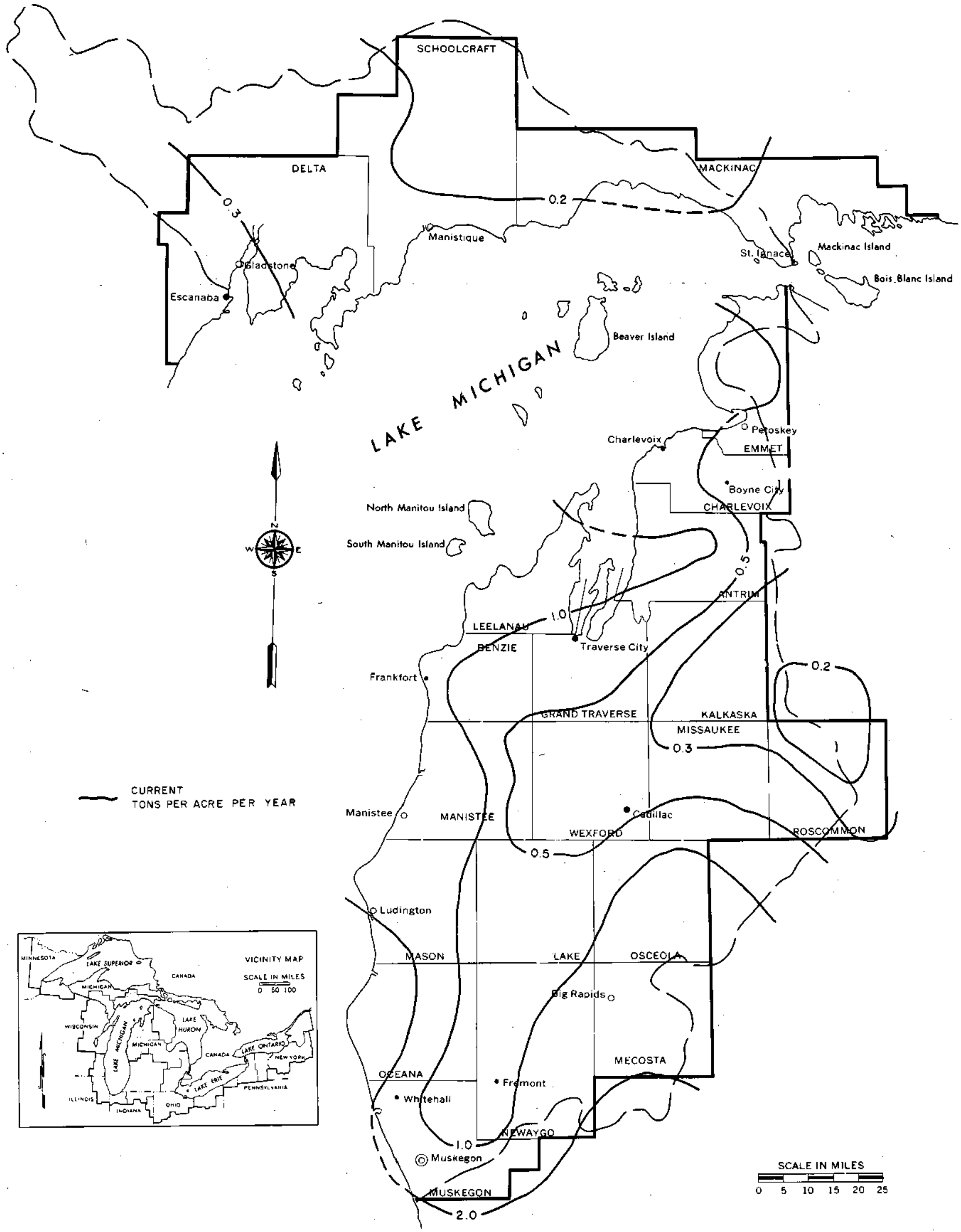


FIGURE 18–36c Gross Erosion Rates, Planning Subarea 2.4

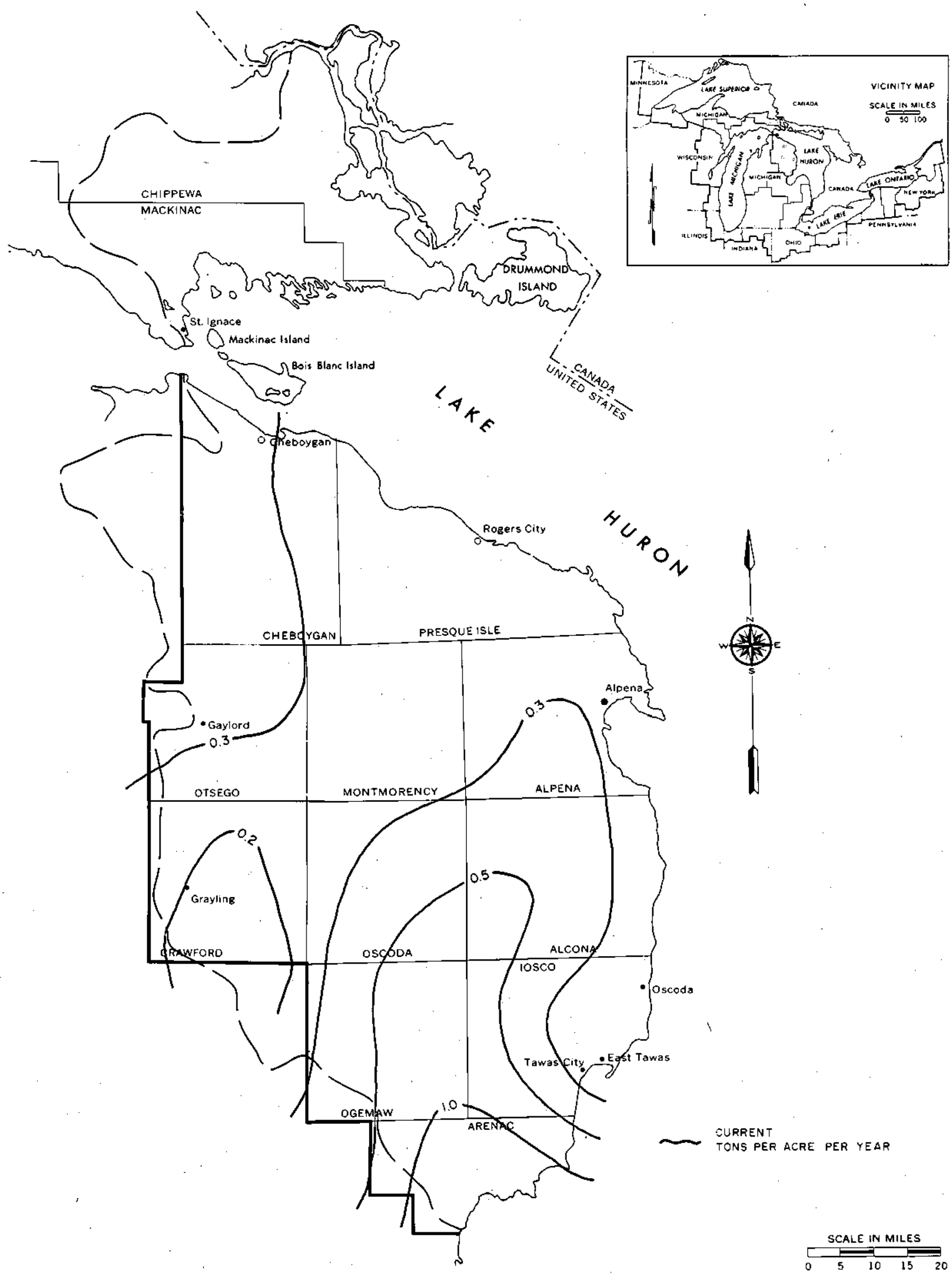


FIGURE 18–37c Gross Erosion Rates, Planning Subarea 3.1

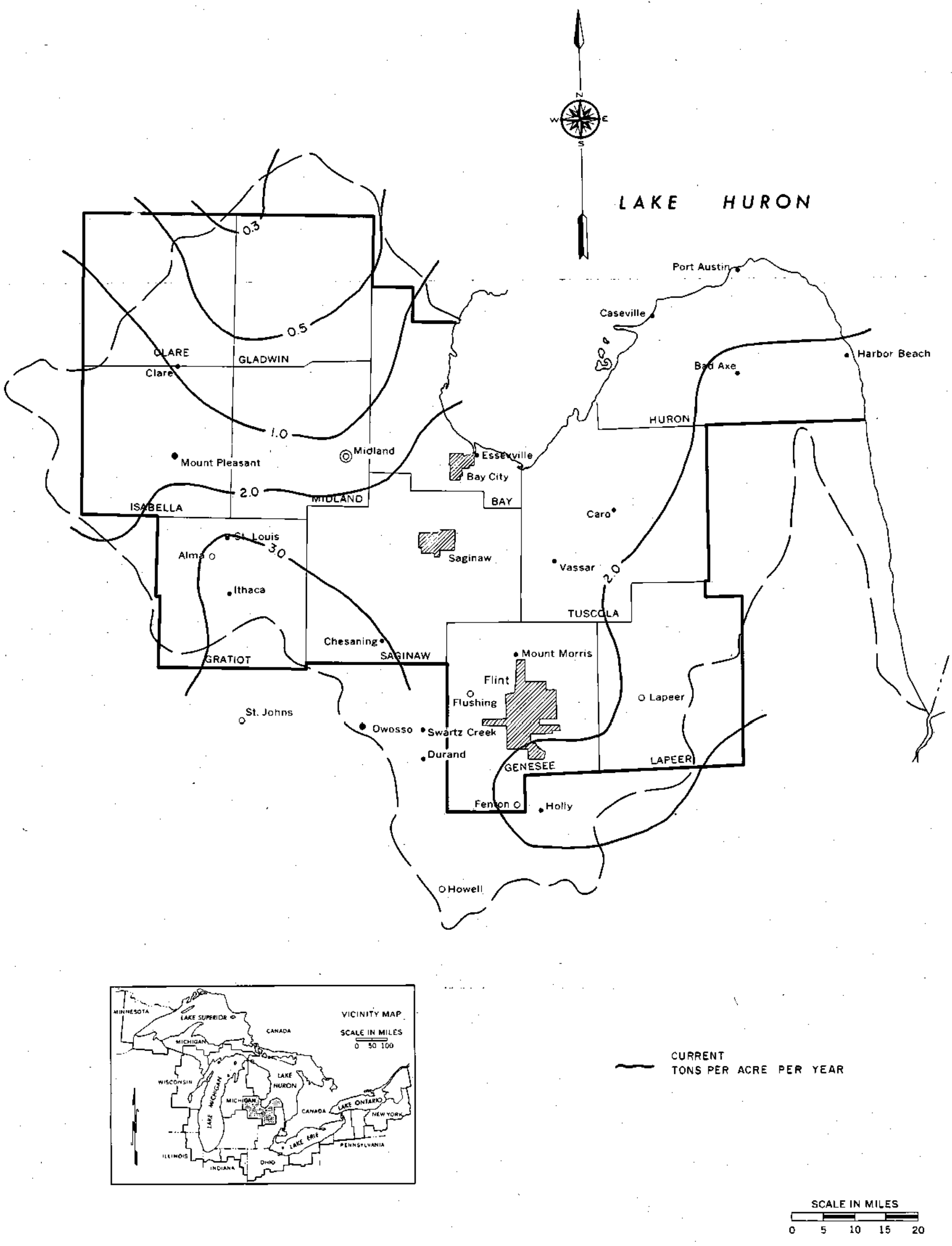


FIGURE 18–38c Gross Erosion Rates, Planning Subarea 3.2

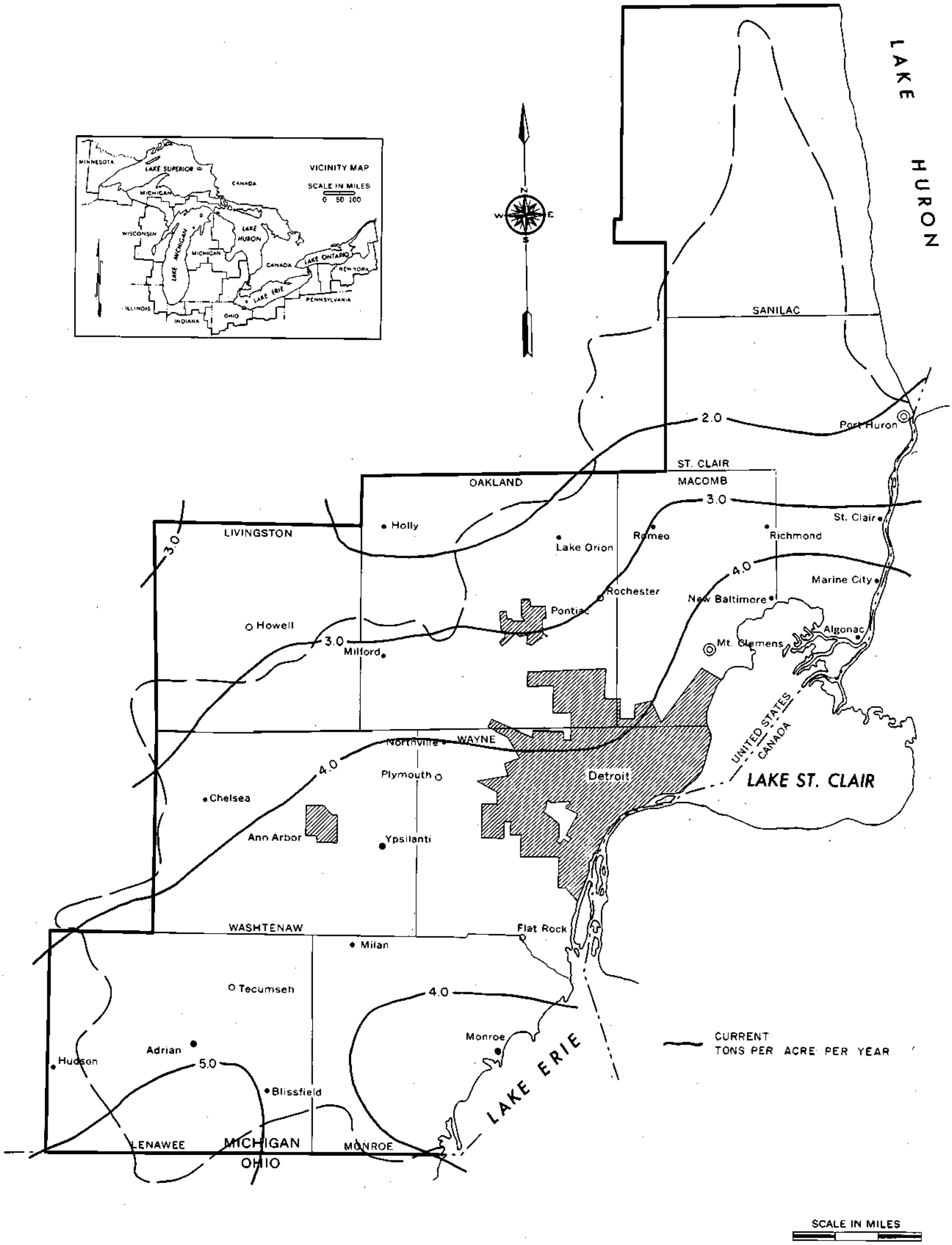


FIGURE 18–39c Gross Erosion Rates, Planning Subarea 4.1

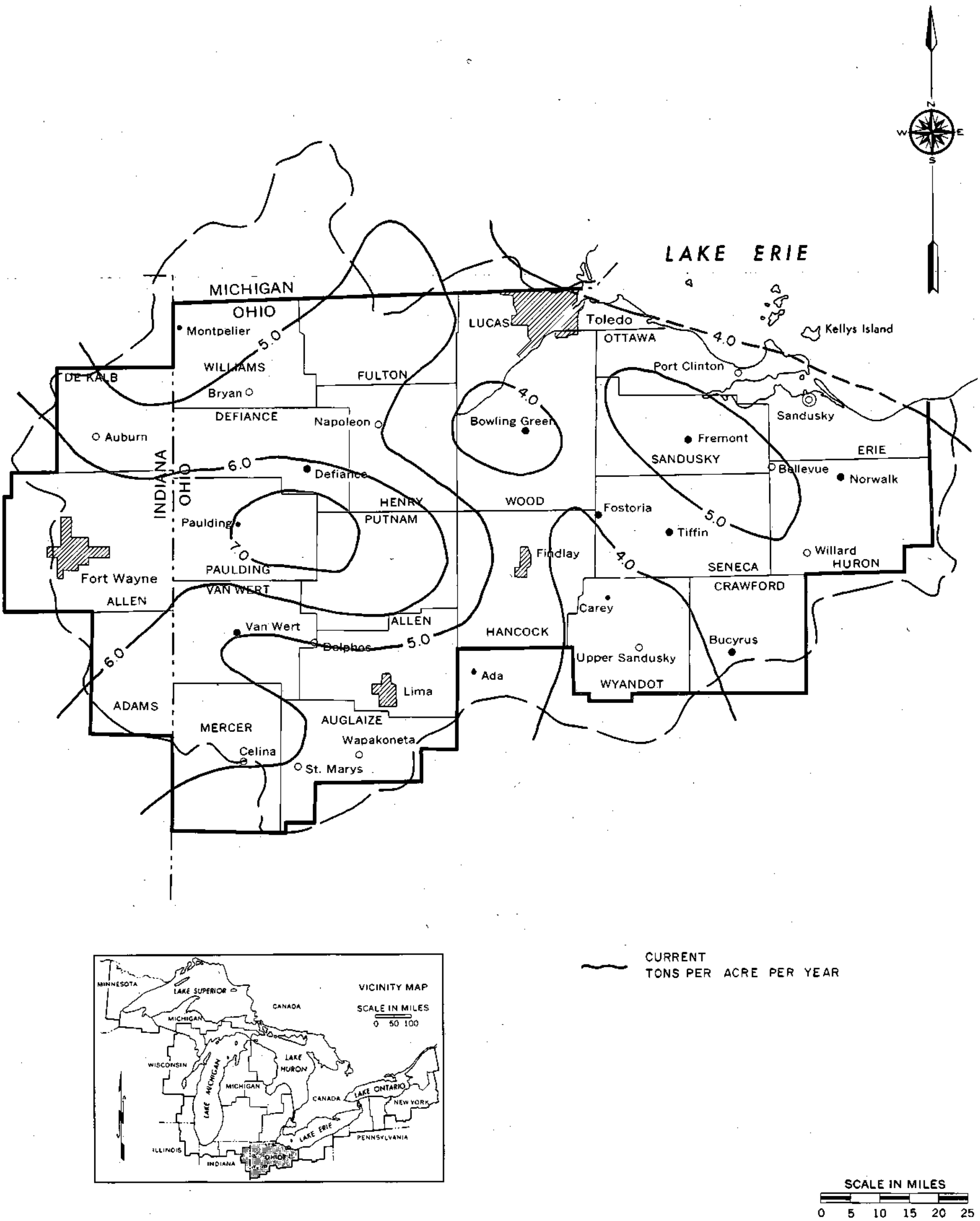


FIGURE 18–40c Gross Erosion Rates, Planning Subarea 4.2

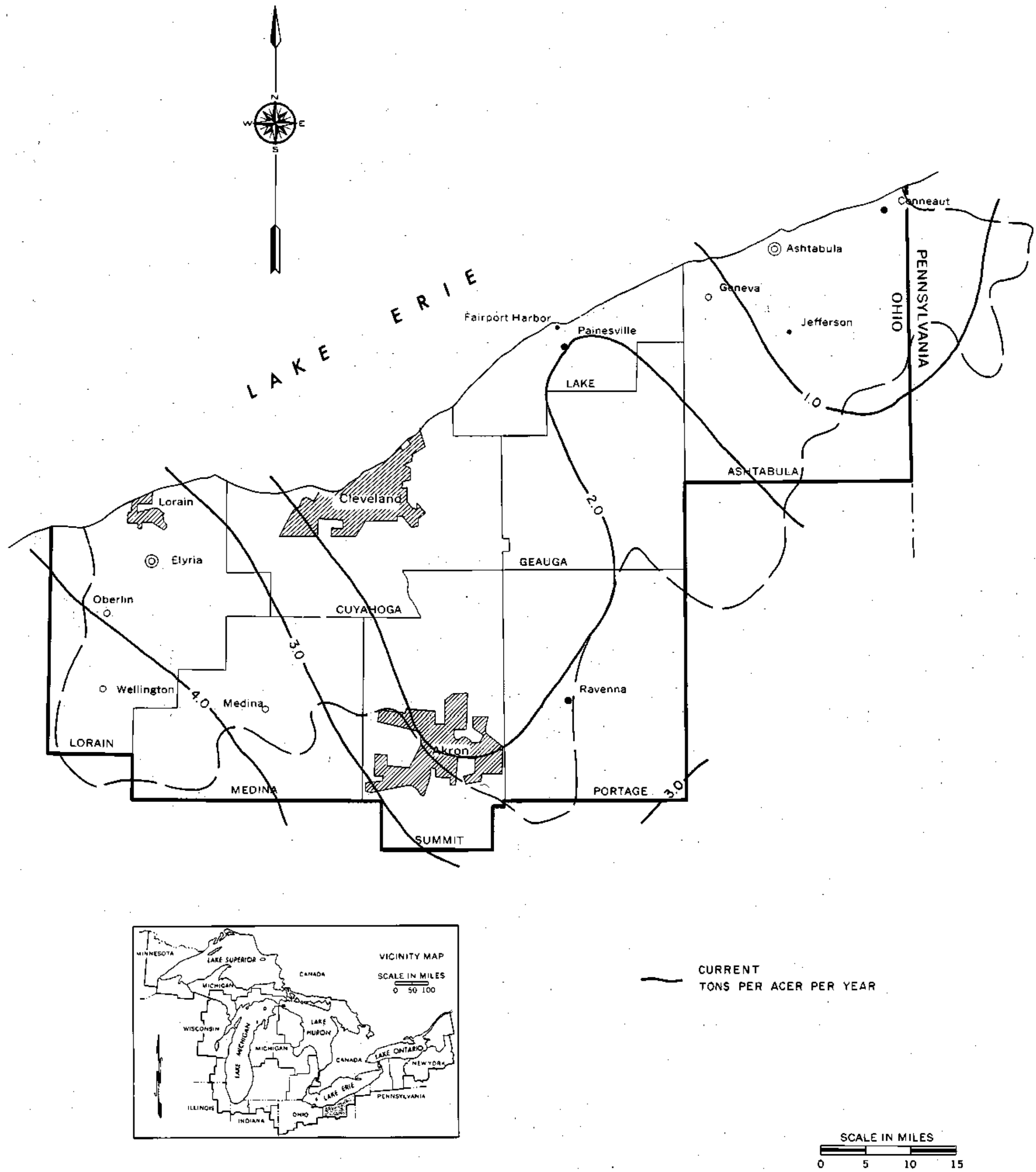
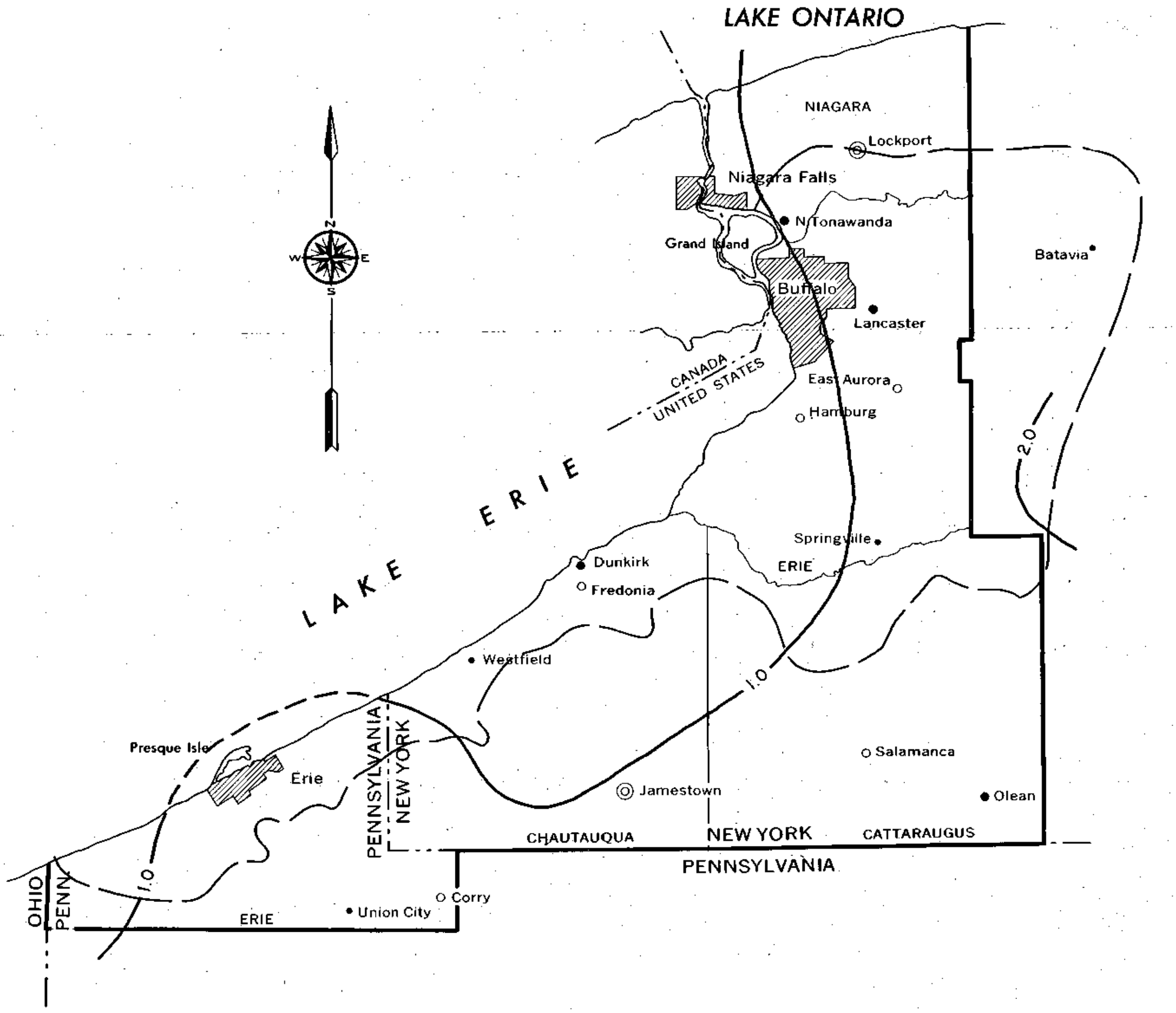


FIGURE 18-41c Gross Erosion Rates, Planning Subarea 4.3



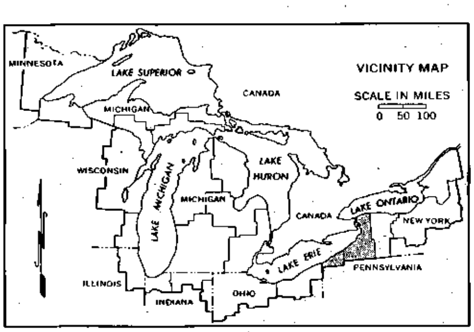


FIGURE 18–42c Gross Erosion Rates, Planning Subarea 4.4

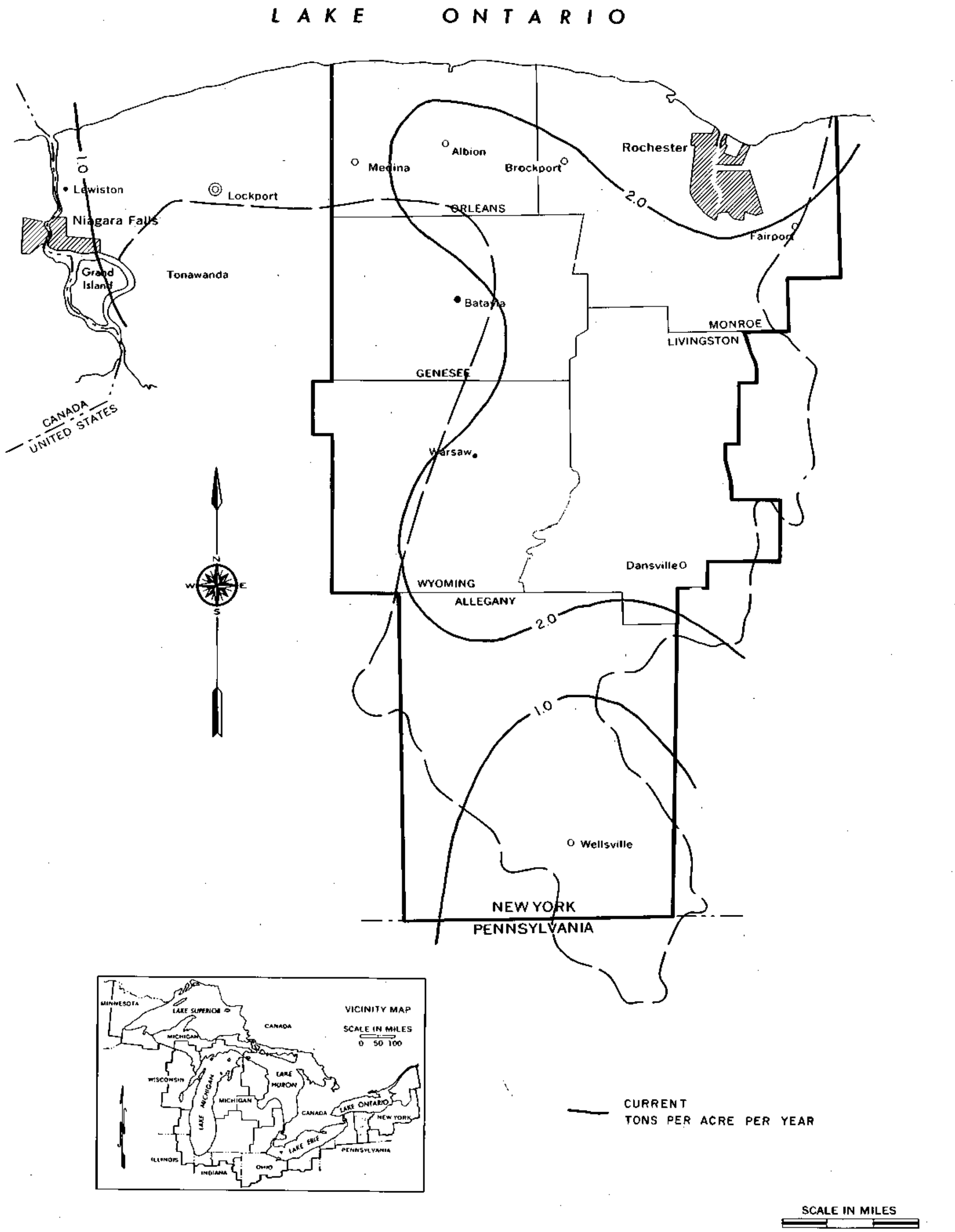


FIGURE 18-43c Gross Erosion Rates, Planning Subarea 5.1

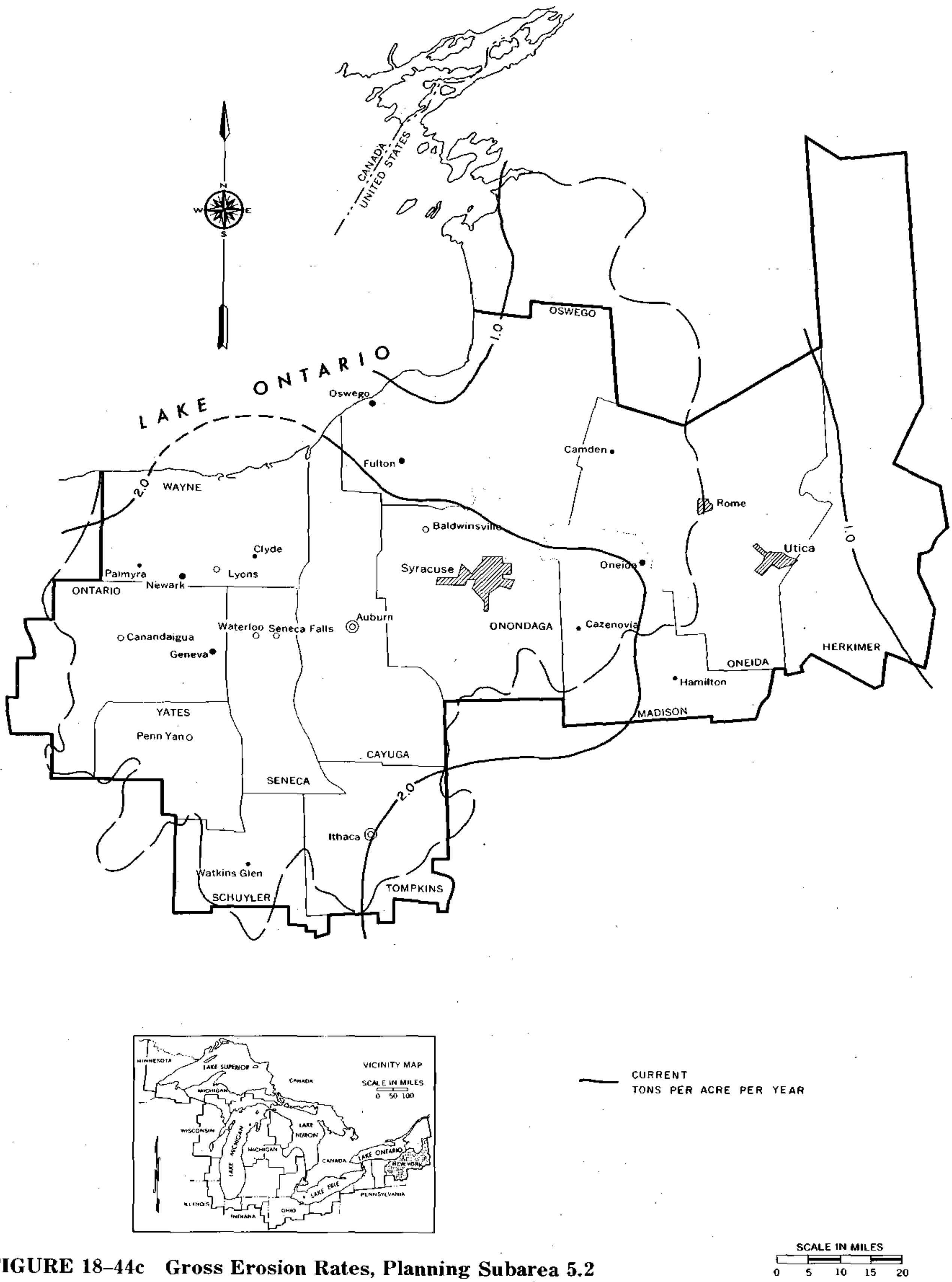
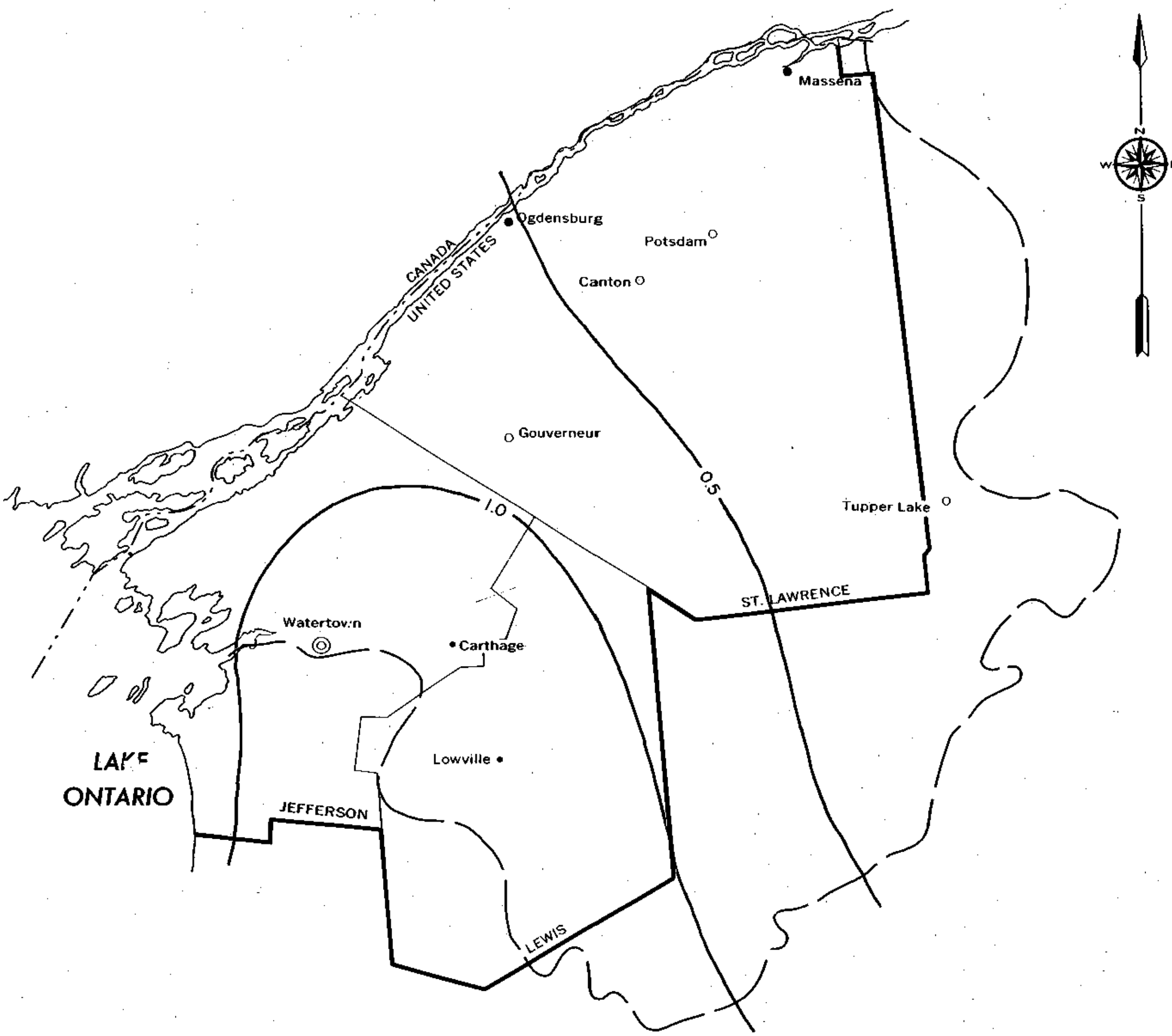


FIGURE 18–44c Gross Erosion Rates, Planning Subarea 5.2



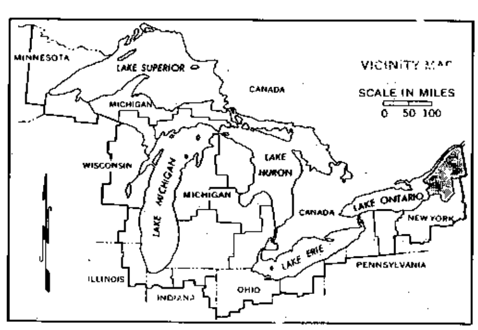


FIGURE 18–45c Gross Erosion Rates, Planning Subarea 5.3

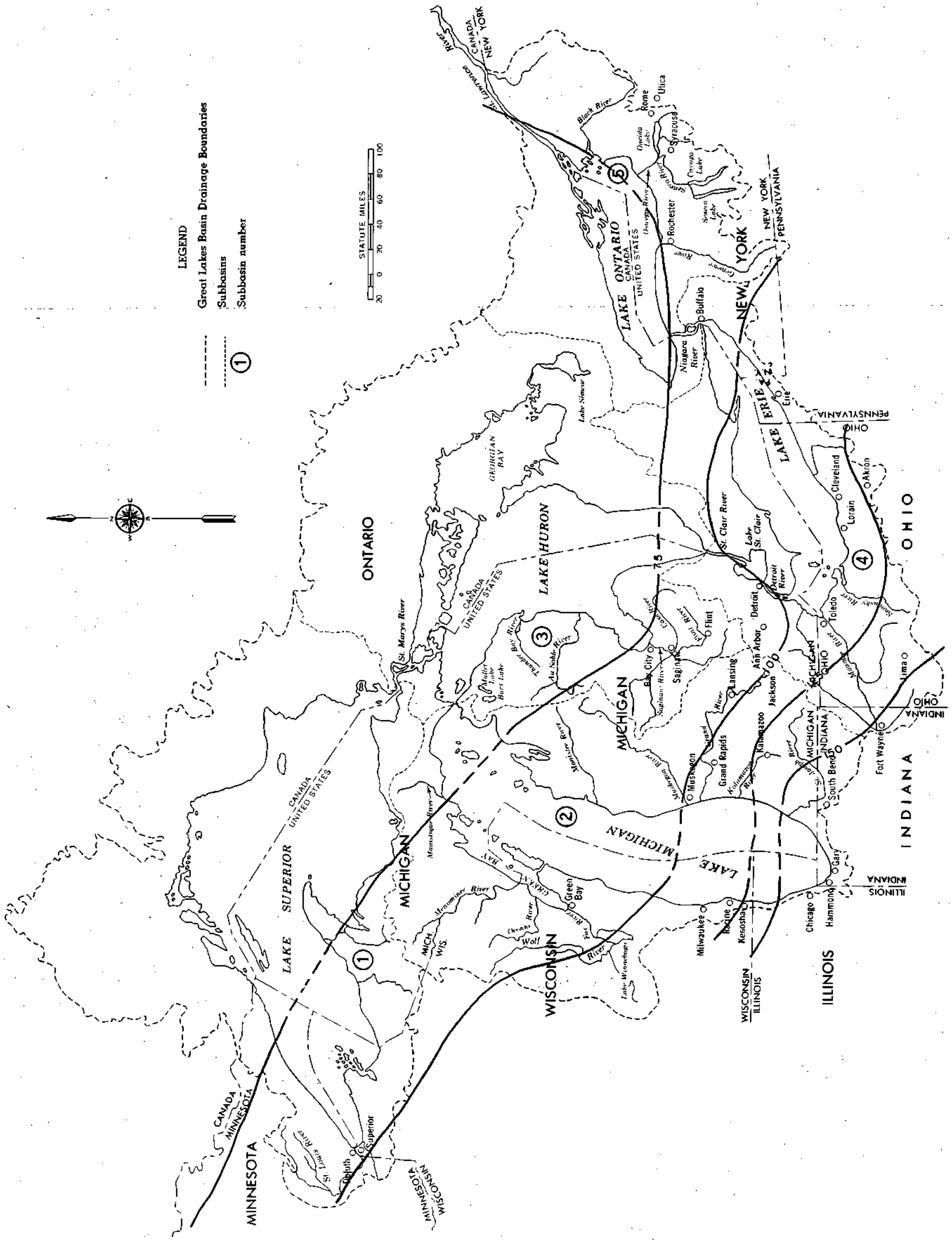


FIGURE 18–46c Average Annual Value for the Rainfall Factor "R"

AUTHOR

TITLE GREAT LAKES BASIN FRAMEWORK STUDY - APPENDIX 18

DATE DUE	BORROWER'S NAME

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Frederick O. Rouse, Chairman

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