United States
Environmental Protection
Agency

Great Lakes National
Program Office
536 South Clark Street
Chicago, Illinois 60605

905479029A

Volume 1

EPA

Menomonee River Pilot Watershed Study

Summary And Recommendations

The United States Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment.

The Great Lakes National Program Office (GLNPO) of the U.S. EPA, was established in Region V. Chicago to provide a specific focus on the water quality concerns of the Great Lakes. GLNPO provides funding and personnel support to the International Joint Commission activities under the US - Canada Great Lakes Water Quality Agreement.

Several land use water quality studies have been funded to support the Pollution from Land Use Activities Reference Group (PLUARG) under the Agreement to address specific objectives related to land use pollution to the Great Lakes. This report describes some of the work supported by this Office to carry out PLUARG study objectives.

We hope that the information and data contained herein will help planners and managers of pollution control agencies make better decisions for carrying forward their pollution control responsibilities.

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EPA-905/4-79-020-A

MENOMONEE RIVER PILOT WATERSHED STUDY
Volume I
Summary and Recommendations

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U.S. Environmental Protection Agency
Chicago, Illinois
EPA Grant No. R005142

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This study, funded by a Great Lakes Program grant from the U.S. EPA, was conducted as part of the Task C-Pilot Watershed Program for the International Joint Commission's Reference Group on Pollution from Land Use Activities.

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ACKNOWLEDGMENTS TO SPONSORING AGENCIES

The personnel of the Menomonee River Pilot Watershed Study wish to express sincere thanks to the U.S.-Canada International Joint Commission, its Windsor Office Personnel and the Pollution from Land Use Reference Group for the high quality of organization of the Program devoted to an examination of the implications of land use and land use practices on the Great Lakes. A special debt of gratitude is owed to the U.S. Environmental Protection Agency for financial support and to its officials in the Chicago Region V Office. These individuals provided the freedom for thought and experimentation essential for the success of an international cooperative program of this magnitude.

ACKNOWLEDGMENT TO PROJECT PERSONNEL

The principal investigators of the Menomonee River Pilot Watershed Study are indebted to the following personnel. These individuals maintained the essential flexibility of thought needed to accomplish the objectives of a program under continuous scrutiny and hence subject to improvement through changes initiated by Study personnel, the International Reference Group members and the personnel in all facets of the PLUARG program:

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1. INTRODUCTION

Concern for the effects of various land use activities on Great Lakes water quality prompted the governments of the United States and Canada, under the Great Lakes Water Quality Agreement of April 15, 1972, to direct the International Joint Commission to conduct studies of the impact of land use activities on the water quality of the Great Lakes Basin and to recommend remedial measures for maintaining or improving Great Lakes water quality.

To effect this undertaking, the International Joint Commission, through the Great Lakes Water Quality Board, established the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG). The Reference Group developed a study program which consisted of four major tasks. Task A is devoted to the collection and assessment of management and research information and in its later stages, to the critical analysis of implications of potential recommendations. Task B required the preparation of a land use inventory, largely from existing data, and secondly, the analysis of trends in land use patterns and practices. Task C is the detailed survey of selected watersheds to determine the sources of pollutants, their relative significance and the assessment of the degree of transmission of pollutants to boundary waters. Task D is devoted to obtaining supplementary information on the impacts of materials to the boundary waters, their effect on water quality and their significance in these waters in the future and under alternative management schemes.

The Task C portion of the Detailed Study Plan includes intense investigations of watersheds in Canada and the United States which are representative of the full range of urban and rural land uses found in the Great Lakes Basin. A Task C Technical Committee and a Synthesis and Extrapolation Work Group were established by PLUARG and assigned primary responsibility for developing and conducting the pilot watershed studies. The Menomonee River watershed was selected for the study of the effects of urban-residential land uses undergoing rapid change.

The Wisconsin Department of Natural Resources (WDNR), the University of Wisconsin System through the Water Resources Center (UW-WRC) and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) serve as the lead agencies or organizations responsible for conducting the intensive study of water quality/land use relations in the Menomonee River Watershed.

The principal functions of these agencies are:

a. Wisconsin Department of Natural Resources: The WDNR is the lead agency and as such, administers the total study including coordination of activities associated with the Menomonee River Study and submission of reports to the U.S. Environmental Protection Agency and PLUARG. WDNR also provided laboratory support for the monitoring program conducted in the Menomonee River basin.

b. University of Wisconsin System: The Water Resources Center (UW-WRC) has conducted special studies of selected land use activities and provided interpretation and assessment of monitoring data through development of land use/water quality models.

c. Southeastern Wisconsin Regional Planning Commission: The SEWRPC has provided background inventories on land use activities and projected land use patterns from its current Menomonee River planning program and developed a computer file of all data and information applicable to the study.

The 35,200 ha Menomonee River Watershed is located in the southeastern corner of Wisconsin and discharges to Lake Michigan at the City of Milwaukee. This highly urbanized watershed encompasses all or parts of four counties and 17 cities, villages and towns and currently contains a resident population of about 400,000 persons (12 persons/ha). Existing urban land uses range from an intensely developed commercial/industrial complex in the lower quarter of the watershed to low to medium density residential areas in the center half of the watershed, while the upper quarter is in the process of being converted from rural to urban land use, as reflected by scattered urban development. The irregular topography of the watershed results from the effects of glaciation. Heterogeneous glacial drift covers the entire watershed and the dominant soil types range from well to poorly drained. The long-term average discharge from the Watershed is 2.2 m^3/sec but flood flows as high as 500 m^3/sec have been recorded. The basin has a typical humid climate, with mild summers and cold winters. The annual average temperature is 10°C with mean daily temperatures ranging from -6°C in January to 21°C in July. Annual average precipitation is 79 cm (100 cm of snow).

Several key factors entered into selection of the Menomonee River Watershed. Not only is the Watershed highly urbanized, but the Watershed and contiguous lands contain a full range of urban uses including low- to high-density residential areas, extensive commercial and industrial tracts and a considerable amount of land devoted to transportation facilities. The high degree of diversity of urban land uses in this Watershed is reflected by the existence of combined and separate sewer systems. A dynamic dimension is added by the rapid development occurring in the upper quarter of the basin where agricultural land is being converted to urban land uses. A unique facet of the Menomonee Watershed stems from the proposed plan to remove all municipal point sources of pollution by 1983, at which time the effects of land use on water quality will arise almost entirely from diffuse sources. Thus, of the major watersheds chosen for intensive study in the PLUARG program, the Menomonee Watershed serves as the focus of investigations on the impact of urban land uses on water quality.

Objectives

The overall objective of the Menomonee River Pilot Watershed Study was to investigate the effects of land drainage on the pollutional input to Lake Michigan and to develop a predictive capacity with respect to the sources, forms and amounts of pollutants reaching Lake Michigan.

The specific objectives of the Menomonee River Pilot Watershed Study were:

a. To determine the levels and quantities of major and trace constituents including, but not limited to, nutrients, pesticides and sediments reaching or moving in flow systems likely to affect the quality of Lake Michigan water.

b. To define the sources and evaluate the behavior of pollutants from an urban land use setting with particular emphasis on the impact of residential and industrial areas including utility facilities, transportational, recreational, agricultural and constructional activities associated with rapid urbanization.

c. To develop the predictive capability necessary to facilitate extension of the findings from the Menomonee River Pilot Watershed Study to other urban settings, leading to an eventual goal of integrating pollutational inputs from urban sources to the entire Great Lakes Basin.

Volume 1 contains summaries of the various major research efforts of the Menomonee River Pilot Watershed Study and recommendations for remedial measures based on the findings of the study.

Research Summary

This section consists of summaries of eight principal investigations conducted under the Menomonee River Pilot Watershed Study. The summaries are presented in logical order as follows:

- Characteristics of the Menoonee River Watershed - Volume 2
- Surface Water Quality - Volume 3
- Effects of Tributary Inputs of Lake Michigan During High FLows - Volume 10
- Land Use/Water Quality Modeling - Volumes 4 and 5
- Dispersibility of Soils and Elemental Composition of Soils and Sediments - Volume 6
- Availability of Pollutants Associated with River Sediments - Volume 11
- Groundwater Studies - Volume 7
- Atmospheric Studies - Volumes 8 and 9

These summaries highlight the most significant findings; also they can serve as an introduction and guide to the more complete and detailed discussions of the research presented in subsequent volumes.

2. CHARACTERISTICS OF THE MENOMONEE RIVER PILOT WATERSHED

Land Data Management System

The Land Data Management System (Land DMS) was developed by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in order to provide an inventory of land use characteristics to be used in investigating the impact of land uses on water quality. The Land DMS is a digital computer-based system designed to store, retrieve, analyze and display land data for the Menomonee River Watershed in tabular or graphic form.

The basic areal unit of the Land DMS is "The Cell" (see Fig. 1). The cell is divided into several land data types; thereby providing access to the data base by either the cell or land data information. Some typical applications of its use are presented in Table 1.

Some of the more important advantages of the Land DMS are: a. Handling data at the available level of detail; b. minimal manual handling of data; c. ease of update and correction; d. quick response; e. overlay capability; f. availability of a variety of tabular and graphic outputs. The principal disadvantage of the system is the initial high cost and cost of maintenance.

Remote Sensing

Since one of the important input parameters to the overland flow model LANDRUN is land cover, remote sensing was investigated as a possible method of obtaining land cover information. The most widely used remote sensing technique is manual photo interpretation. The goal of this investigation was to develop and test digital analysis of aerial photography for land cover mapping in urban areas.

Calibrated digital imagery is classified using a two-stage elliptical table-look-up algorithm which produces a tabular presentation of different land cover classes as well as a thematic representation. Accuracy of approximately 90% was determined for the digitally classified imagery when compared to ground truth.

The digital analysis of aerial imagery seems to be superior to the analysis of LANDSAT tapes in an urban area because of the better resolution and versatility in choosing the date of imagery.

Table 1. Typical applications of the land data management system developed under the IJC-Menomonee River Pilot Watershed Study: May 1976 to February 1978

	Application	Prepared for or used by
1.	1:4,800 scale computer maps showing boundaries of three monitoring stations to be used for overlaying on aerial photographs.	UW-Madison-Water Resources Center
2.	1:48,000 scale and 1:24,000 scale map of aggregated land uses in the Menomonee River Watershed.	UW-Madison-Geology Department
3.	Tabular summary of 1970 land use for all Menomonee River watershed sub-basins; 1:24,000 scale computer map of dominant 1970 land use per cell.	Marquette University
4.	Tabular summary of each combination of slope and 1970 land use existing in sub-basins of the Watershed.	Marquette University
5.	Tabular summary of percent impervious area by sub-basin.	Marquette University
6.	Tabular summary of land use by section.	UW-Madison-Water Resources Center
7.	1:24,000 scale computer map of dominant land use per cell. Tabular summary of land use by sub-basin, subwatershed and watershed and by area tributary to 12 monitoring stations.	WDNR-Madison
8.	Tabular summary of soil types with a greater than 5% distribution and slopes for each sub-basin.	WDNR-Milwaukee
9.	1:24,000 and 1:48,000 computer maps of dominant soil types.	UW-Madison-Geology Department
10.	Tabular summary of 1975 land uses for the 51 subwatersheds designated for the study.	UW-Madison-Water Resources Center
11.	Computer soils maps based upon permeability and depth to water table.	UW-Madison-Geology Department
12.	A tabular summary of 1975 land use data together with soils, slope and erosion information for the seven predominantly single land use sites monitored in the Watershed.	UW-Madison-Water Resources Center
13.	1:48,000 scale computer maps combining soils with "C" horizon data and 1975 land use data.	UW-Madison-Geology Department
14.	1:4,800 scale maps of soils, slopes, degree of erosion and 1975 land use for each of the seven predominantly single land use sites.	UW-Madison-Water Resource Center
15.	Tabular summary of soils, slope and 1975 land data by monitoring stations.	UW-Madison-Water Resources Center
16.	1:24,000 scale computer maps of soils, slope, erosion data and 1975 generalized land use for each monitoring station.	UW-Madison-Water Resources Center
17.	1:126,720 scale computer map of the 51 subwatersheds designated for the study.	UW-Madison-Water Resources Center
18.	Tabular summary of 1975 land use and degree of imperviousness for each subwatershed.	WDNR-Madison
19.	Tabular summary of 1975 land use and degree of imperviousness for the sub-basins tributary to the mainstem monitoring stations.	WDNR-Madison
20.	Use of cell system to assign density code to residential lands to estimate imperviousness of an area.	SEWRPC
21.	Tabular summary of soils, slope, imperviousness and 1975 land use data for 51 subwatersheds designated for the study.	UW-Madison-Water Resources Center
22.	1:126,720 scale computer map of the 51 subwatersheds designated for the study.	WDNR-Madison
23.	Tabular summary of soil and slope data for each subwatershed.	WDNR-Madison
24.	Tabular summary of combination of land use, soils and slope data for each subwatershed.	WDNR-Madison
25.	Tabular summary of land use, soils and slope data for the sub-basins tributary to the mainstem monitoring stations.	WDNR-Madison

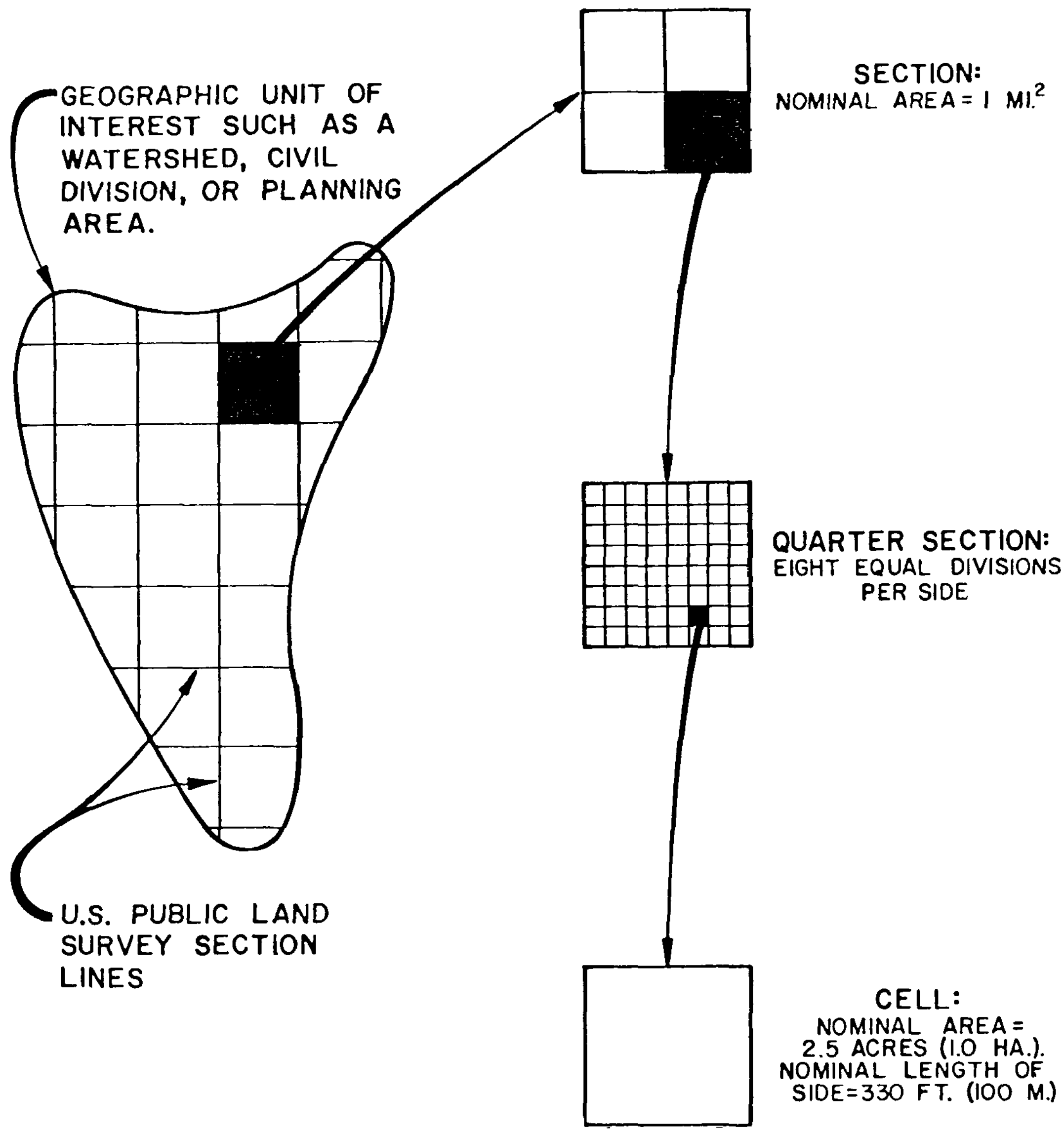

Figure 1. "The Cell," the basic areal unit of the Land DMS.

Description of the Watershed

The Menomonee River Watershed may be viewed as a large ecosystem composed of natural resources, man-made features and human and animal populations, all of which interact synergistically to alter the water quality characteristics of the watershed. The Watershed is decribed in order to establish a factual base upon which conclusions concerning the interactions of the ecosystem and impact on water quality can be drawn.

The description includes natural and cultural features such as population, land use, climate, physiography and geology, soil types and water storage areas. Urban land uses range from an intensely developed commercial/industrial complex in the lower quarter of the Watershed to low- to medium-density residential areas in the center half of the Watershed (Fig. 2). The upper quarter is in the process of conversion from rural to urban land use. A summary of land use changes from 1970 to 1975 is presented in Table 2. The description includes the characteristics and management practices existing in the drainage areas of the main stem and predominantly single land use monitoring sites.

Pollutant source identification is particularly important in a heterogeneous basin like the Menomonee River Watershed--a basin that is diverse with respect to natural features such as soil type, land slope and vegetation, and cultural features such as land use and land management practices. Watersheds that are spatially diverse with respect to natural and man-made features are more likely to exhibit wide spatial variation with respect to potential for pollution.

Important natural and cultural features of 48 subwatersheds (Fig. 3) comprising the Menomonee River Watershed are described in more detail so that variations in pollutant loadings through land surface drainage can be evaluated. Land use distribution and degree of imperviousness are shown in Table 3. Characteristics of soils and erosion potential in the subwatersheds can be found in Volume 2. Variation in erosion potential is associated closely with land use.

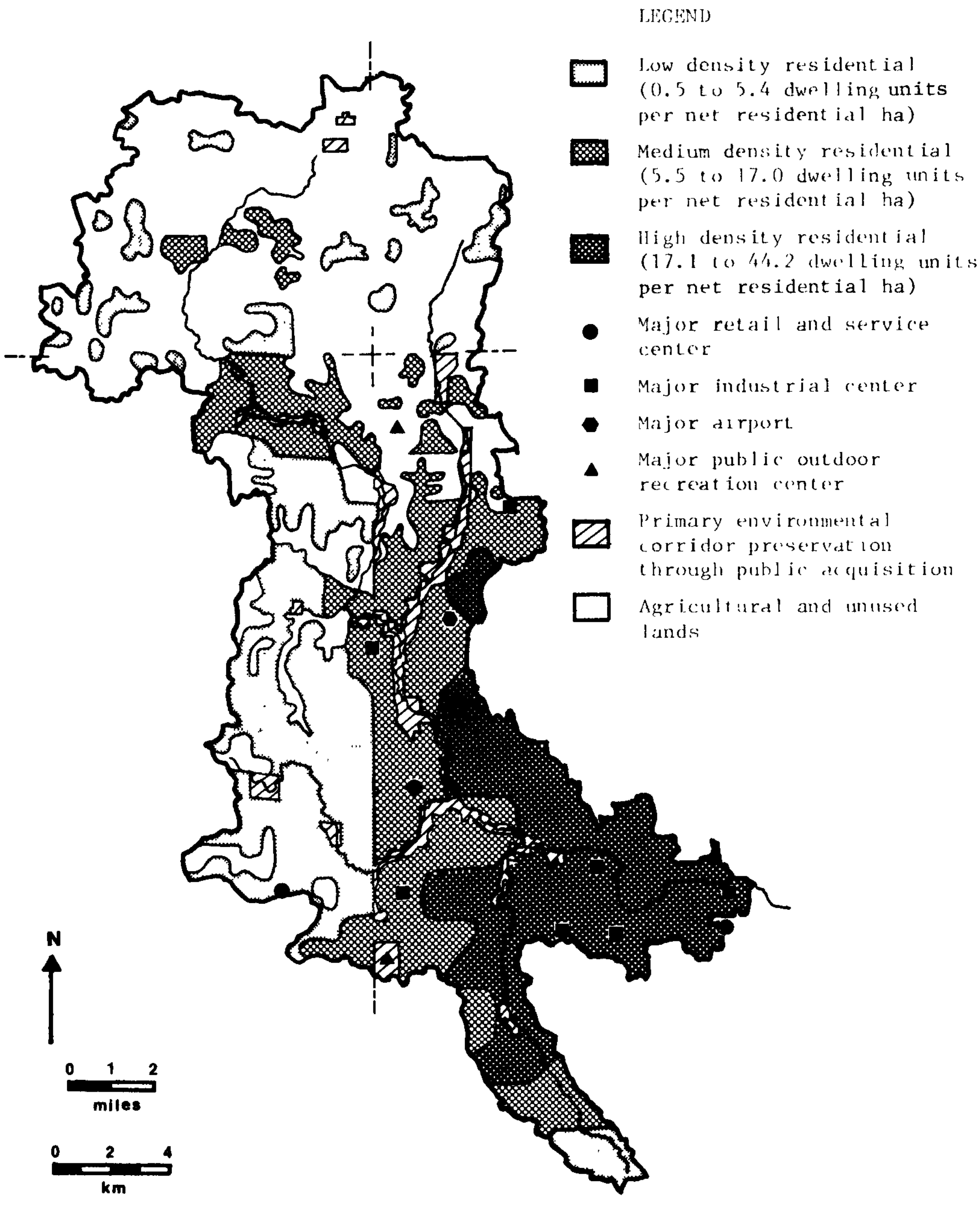

Figure 2. Generalized land use in the Menomonee River Watershed, 1975.

Table 2. Urban and rural land uses inventories for the Menomonee River Watershed in 1970 and 1975 as determined by the S.E. Wisconsin Regional Planning Commission

Land use category	Land use description	Area**, ha 1970	Area**, ha 1975	% of Watershed 1970	% of Watershed 1975
	Urban Land Uses				
1. Industrial	Manufacturing and extractive	588	612	1.67	1.75
2. Commercial*	Retail, wholesale, service, communication, utilities, transportation and off street parking excluding roads	2,517	2,864	7.15	8.17
3. Roads	Freeways, standard arterial streets and expressways and local and collector streets	4,095	3,673	11.65	10.48
4. High-density residential	Multi-family and mobile homes	332	428	0.94	1.22
5. Medium-density residential	Single family and two family dwellings	7,486	8,430	21.29	24.06
6. Low-density residential	Single family dwellings on lots > 2 ha and all farm buildings except feed lots	139	230	0.40	0.66
7. Land under development	All types of land	1,023	921	2.91	2.63
Sub total - urban		16,180	17,158	46.01	48.97
	Rural Land Uses				
8. Row crops	Row crops and vegetables	5,491	4,806	15.62	13.71
9. Pastures and small grains*	Grain crops, hay, pasture, park and recreational land, governmental and institutional and unused land	10,533	9,705	29.95	27.69
10. Forested land wood lots	Woodlands, orchards and nurseries	1,677	1,969	4.77	5.62
11. Wetlands	Swamps, marshes and wetlands	997	1,069	2.84	3.05
12. Feedlots	Feedlots	39	32	0.11	0.09
13. Landfill and dumps	Landfills and dumps	101	120	0.29	0.34
14. Water areas	Lakes, rivers, streams and canals	145	185	0.41	0.53
Sub total - rural		18,983	17,886	53.99	51.03
Total - watershed		35,163	35,044	100.00	100.00

*In the Menomonee River Watershed most governmental and institutional buildings are associated with large open parklands and are included in Category 9. In other watersheds, where these buildings are associated with a commercial district, they are better included in Category 2.
**The 1975 data are more accurate because hectare-sized cells were summed; 1970 data were based on 0.65 km^2 cells.

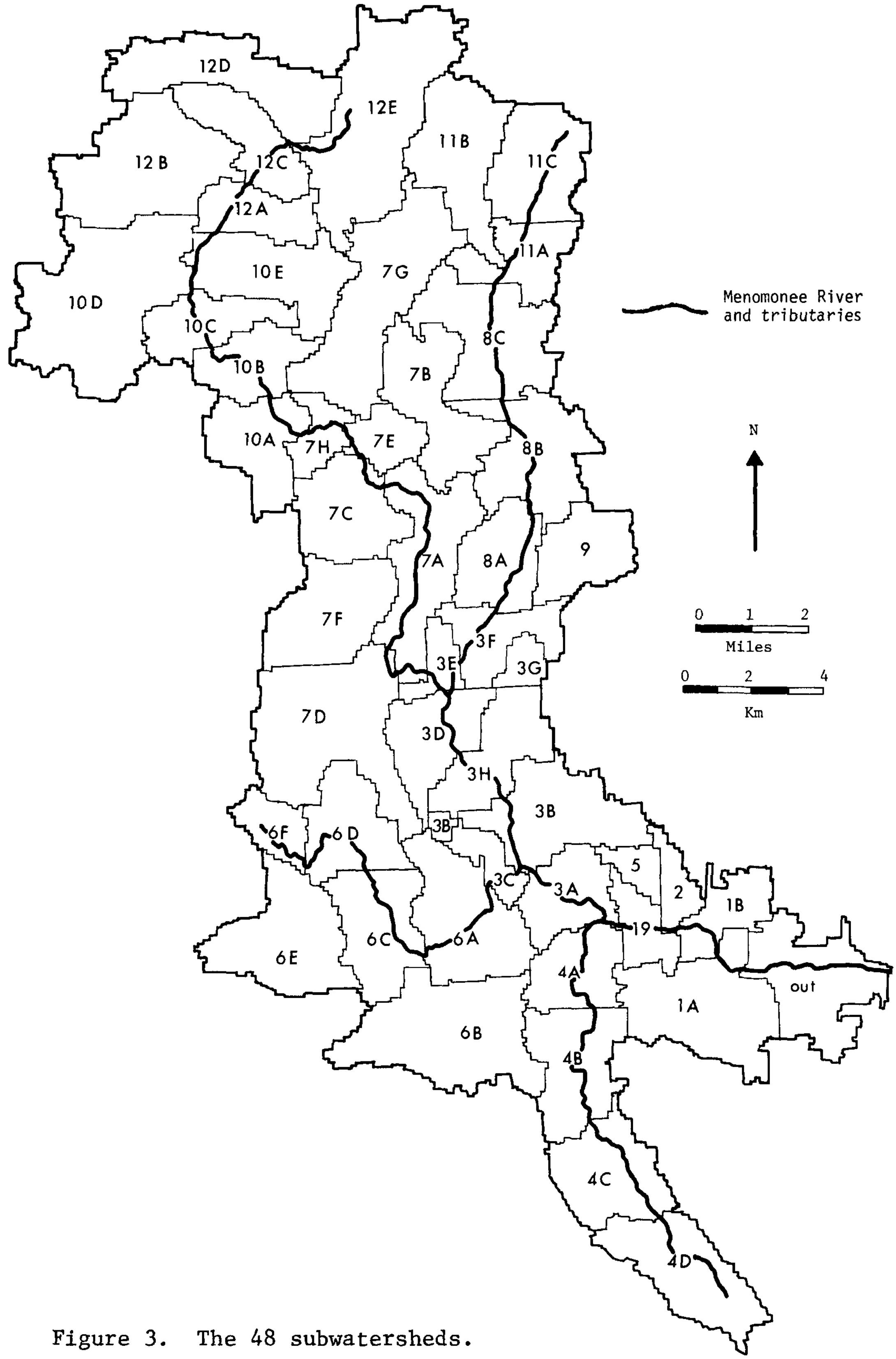

Figure 3. The 48 subwatersheds.

Table 3. Land use categories (1975) in the 48 subwatersheds of the Menomonee River Watershed

No.	Area, ha	Land use* distribution, %														Imperviousness, %	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Connected
12A	429	0.4	3.3	0	6.7	8.7	0.7	7.8	17	48	2.6	0.4	0	0	4.0	17	6
12B	1,200	4.3	3.2	1.9	0.3	6.2	1.6	3.6	36	29	6.0	7.0	0.5	0	0.2	7	1
12C	571	0.6	1.8	0	0	9.6	1.9	1.4	31	38	9.4	4.8	0.5	0	0.4	8	1
12D	981	0	2.4	0	0	3.5	1.5	0.3	45	32	12	3.2	0.3	0	0	2	1
12E	1,592	0	0.7	0	0	4.3	1.4	0.4	31	30	24	8.6	0.2	0	0	2	1
10A	599	0.2	4.0	0	2.0	37	0.2	4.4	1.3	25	1.3	24	0	0.2	0.6	23	12
10B	459	1.1	4.6	5.9	1.8	36	2.5	1.9	15	25	4.5	0.3	0	0	1.0	28	2
10C	502	0.1	3.1	2.7	0	9.6	1.4	1.8	31	32	13	5.3	0	0	0	7	1
10D	1,610	1.8	1.1	2.2	0.1	12	1.4	5.9	19	38	13	4.4	0.2	0	0.5	8	2
10E	853	0	0.2	0.8	0	14	1.2	1.7	37	26	8.5	11	0	0	0.1	6	2
7A	981	3.1	5.7	8.0	0	18	0.6	5.0	8.9	40	7.0	2.2	0	0	1.7	23	11
7B	820	5.9	5.9	2.7	0.4	6.8	1.3	1.5	18	51	2.8	0.8	0	2.6	0.6	11	1
7C	718	0	3.1	0	0.2	48	0.7	6.7	9.0	28	2.6	0.7	0	0	0	17	1
7D	1,406	1.1	3.2	0	0.1	56	0.4	6.5	5.1	19	3.6	5.0	0	0	0.3	18	1
7E	301	2.7	8.2	3.5	0	28	1.0	3.0	5.5	41	5.9	0	0	0	0.8	24	7
7F	832	1.1	6.6	0	0	24	0.9	4.9	21	37	3.9	0.4	0	0	0.2	12	1
7G	1,343	2.7	4.9	2.4	0.2	8.3	1.5	6.5	28	32	8.9	4.1	0.2	0	0.1	11	1
7H	251	0.2	8.3	0	4.5	65	0	4.6	0.1	16	0.4	1.3	0.1	0	0	34	17
11A	527	0	1.2	0	0	2.4	2.5	0.2	68	18	6.2	1.5	0	0	0.2	5	1
11B	852	0	0.2	0	0.2	7.6	1.4	2.7	33	38	10	4.0	0.8	0	1.5	5	2
11C	765	0	1.3	0	0	12	1.5	2.1	39	31	12	0.8	0.7	0	0	3	1
9	555	3.4	15	1.6	6.8	41	0.2	3.9	0.2	24	0.4	0.1	0	2.6	0.4	42	27
8A	599	0.1	2.0	7.7	2.9	36	0.4	4.5	2.6	40	3.1	0.6	0	0	0.5	26	10
8B	853	1.3	7.8	0	2.9	13	0.9	5.8	14	45	5.5	2.9	0	1.6	0	13	8
8C	1,011	2.2	9.8	0	1.9	4.3	1.0	6.2	26	28	13	6.9	0	0	0.4	12	1
6A	970	2.0	8.9	4.1	2.9	47	0	1.0	0	30	0.4	0	0	3.8	0.1	41	17
6B	1,323	4.5	15	5.7	2.6	41	0	2.8	0	26	0.8	1.0	0	0.3	0.6	39	12
6C	744	0.5	6.9	0	1.8	58	0.1	4.7	0	20	6.3	1.0	0	0	0.1	23	1
6D	669	5.1	1.0	0	1.3	53	0.4	4.9	0	24	4.4	6.3	0	0	0.1	14	1
6E	974	0	8.3	0	0	45	0.3	5.8	3.0	26	7.4	4.5	0	0	0.2	21	1
6F	294	0.3	4.3	0	0	25	0.3	0.1	0	50	10	10	0	0	0	10	1
4A	545	4.0	11	7.0	5.4	47	0	0.2	0	26	0	0	0	0	0	51	33
4B	752	2.5	9.1	0.4	2.3	69	0	0.4	0	16	0	0	0	0	0.3	48	30
4C	707	0.1	5.5	0	11	67	0	2.5	0	13	0	0	0	0	0.1	52	32
4D	799	0	6.4	2.7	5.1	49	0.1	5.2	1.9	25	1.7	1.1	0	1.6	0.1	32	20
3A	527	0.2	5.8	0	4.1	42	0	0.1	1.5	43	2.1	0	0	0	1.7	46	32
3B	940	1.3	4.5	0.2	5.0	69	0	0.3	0	19	0	0	0	0	0.7	51	30
3C	225	0	20	4.7	8.4	23	0	0.8	0	39	2.5	0	0	0	1.8	47	33
3D	605	15	24	2.1	0.5	26	0	1.4	0	30	1.1	0	0	0.1	0.6	51	18
3E	230	7.9	34	7.9	3.7	11	0	0.4	0	33	0.3	0	0	0.6	1.3	46	36
3F	496	3.0	17	1.9	9.1	32	0.1	2.4	0.6	33	0	0	0	0	0.6	46	30
3G	151	0.2	85	0	4.4	8.6	0	0	0	1.5	0	0	0	0	0	21	11
3H	642	8.1	15	1.2	4.4	32	0	1.8	0	37	0	0	0	0	0.7	47	30
5	175	0	5.6	0	0.4	87	0	2.0	0	5.3	0	0	0	0	0	55	33
2	182	0	7.2	0	3.3	77	0	0.2	0	13	0	0	0	0	0	56	34
1A	1,143	17	25	3.8	2.3	33	0.1	0	0	18	0	0	0	0	0.8	70	50
1B	389	8.3	18	5.9	5.5	40	0	0.2	0	18	0	0	0	3.2	0.8	59	41
19	305	5.0	12	0	2.5	65	0	1.1	0	13	0	0	0	0.4	0.8	56	36
Total	34,397	2.6	7.3	1.8	1.9	29	0.7	3.1	14	29	5.7	3.1	0.1	0.3	0.4	24	11

*Land use categories are: 1-industrial, 2-commercial, 3-freeway (other roads are proportionately distributed among the other land uses), 4-high density residential, 5-medium density residential, 6-low density residential, 7-land under development, 8-row crops, 9-pasture and small grains, 10-forested land and woodlots, 11-wetlands, 12-feedlots, 13-landfill and dumps, 14-water areas (land use categories are described in Table 2.

3. SURFACE WATER QUALITY

Surface water quality and quantity were monitored at 18 stations in the Menomonee River Watershed from 1975 through 1977 during baseflow and runoff events (Fig. 4). Nine of these stations were located either on the main channel of the river or on its principal tributaries. The subwatersheds monitored by these stations were relatively large (180 to 34,400 ha) and encompassed a wide variety of land uses (Table 4). These stations are referred to as the main stem or mixed land use stations. The other nine stations were located on the headwaters of small streams or storm sewer systems draining to the Menomonee River. The subwatersheds monitored by these stations were relatively small (49 to 2,150 ha) were referred to as the predominantly single land use stations (Table 5). All stations were instrumented with automated flow and sampling equipment. At the main stem stations the U.S. Geological Survey monitored flow and the WDNR monitored water quality. At the predominantly single land use stations the UW-WRC monitored flow and water quality. The Wisconsin State Laboratory of Hygiene analyzed water quality samples. Seasonal and annual pollutant loading values were calculated using a stratified random sampling technique.

Significance of Nonpoint Pollution in the Menomonee River Watershed

For the Menomonee River, the annual nonpoint contributions of water, suspended solids and total phosphorus were greater than the annual base flow and point source contributions (Table 6). Large percentages of the annual pollutant loads may be delivered in one or two large storm events, such as in 1977 when a single event delivered 37% of the total annual suspended solids and total phsophorus loads.

Pollutant concentrations during some events exceeded acceptable water quality standards for domestic water supply and/or aquatic life (Table 7). High lead concentrations impair domestic water supplies and suspended solids and zinc threaten aquatic life. Eutrophication is promoted by high concentrations of total phosphorus while swimming is impaired by high fecal coliform counts.

Variations in Nonpoint Pollution Due to Land Use Activities

On a unit area basis, the urban areas generated much greater nonpoint pollution loads than the rural areas. A high correlation existed between the degree to which a watershed was urbanized and the amount of runoff and pollutant generated. Among the most notable of these pollutants are suspended solids, total phosphorus and lead (Table 8-13). A useful indicator of the potential pollutant load from a watershed is the amount of connected impervious area. This includes all impervious areas connected to

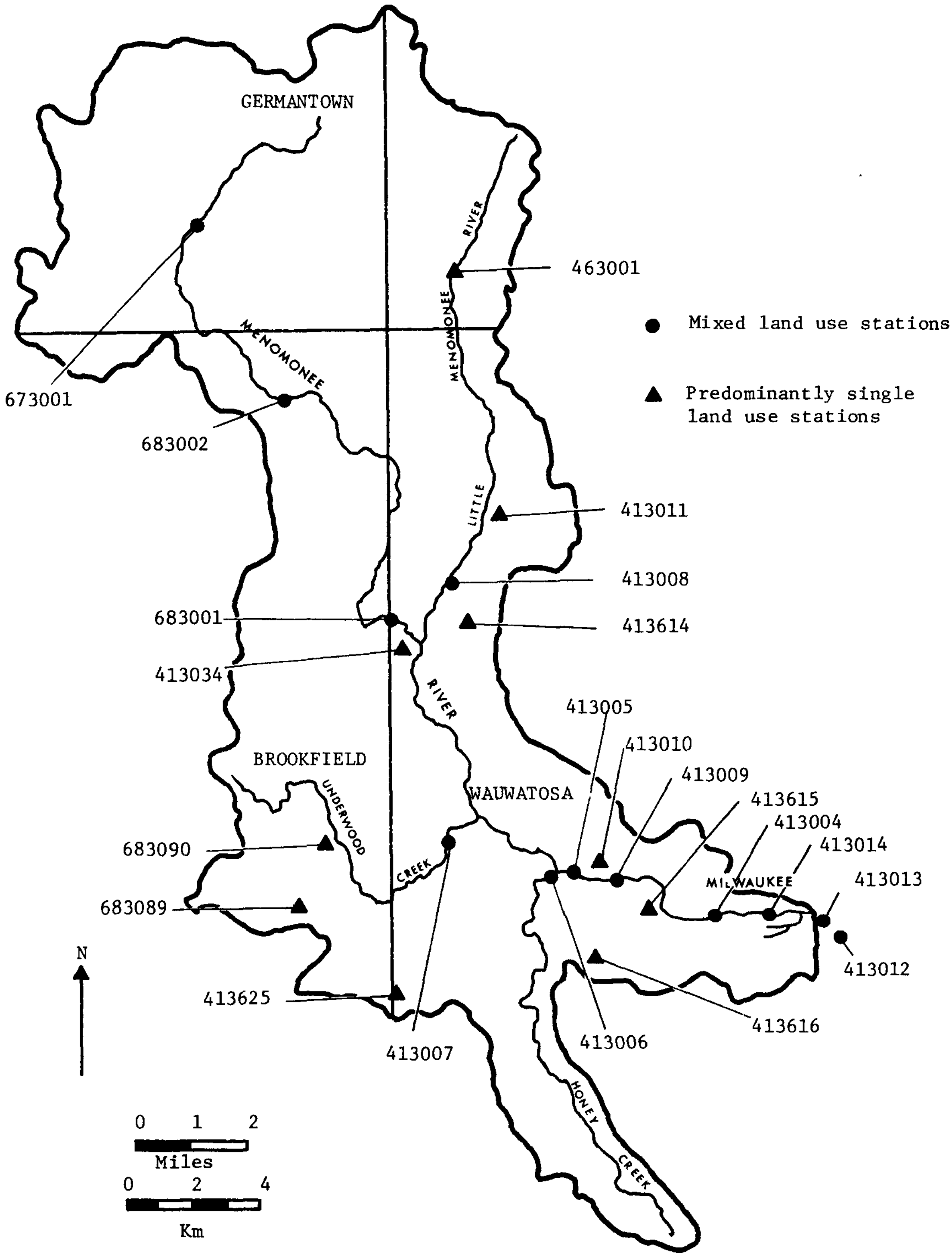

Figure 4. Locations of monitoring stations within the Menomonee River Watershed.

Table 4. Land use categories (1975) in areas tributary to the main stem monitoring stations

STORET number	Land use* distribution, ha															Imperviousness, %	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Total†	Connected††
673001	57 (1.2)**	97 (2.0)	23 (0.5)	32 (0.7)	269 (5.6)	71 (1.5)	94 (2.0)	1,621 (34)	1,566 (33)	626 (13)	281 (5.9)	14 (0.3)	0	22 (0.5)	4,774	5	1
683002***	92 (1.0)	178 (0.2)	105 (1.2)	54 (0.6)	1,016 (12)	123 (1.4)	249 (2.8)	2,484 (28)	2,835 (32)	994 (11)	611 (6.9)	17 (0.2)	1 (0.0)	38 (0.4)	8,797	8	2
683001+	239 (1.6)	517 (3.3)	248 (1.6)	74 (0.5)	2,938 (19)	181 (1.2)	599 (3.9)	3,422 (22)	5,020 (32)	1,325 (8.6)	775 (5.0)	20 (0.1)	23 (0.1)	69 (0.4)	15,450	12	3
413008	52 (1.0)	277 (5.4)	55 (1.1)	101 (2.0)	765 (15)	58 (1.1)	201 (3.9)	1,329 (26)	1,701 (33)	413 (8)	148 (2.9)	13 (0.2)	28 (0.5)	23 (0.4)	5,163	14	6
413007	118 (2.4)	437 (8.8)	116 (2.3)	84 (1.7)	2,288 (46)	8 (0.2)	171 (3.4)	29 (0.6)	1,340 (27)	193 (3.9)	138 (2.8)	0	40 (0.8)	12 (0.2)	4,974	28	7
413006	41 (1.5)	220 (7.8)	62 (2.2)	166 (5.9)	1,642 (59)	0	64 (2.3)	15 (0.5)	554 (20)	14 (0.5)	9 (0.3)	0	13 (0.5)	4 (0.1)	2,803	45	28
413005++	638 (2.0)	2,104 (6.5)	542 (1.7)	604 (1.9)	9,110 (28)	247 (0.8)	1,073 (3.3)	4,806 (15)	9,762 (30)	1,969 (6.1)	1,069 (3.3)	32 (0.1)	106 (0.3)	142 (0.4)	32,205	22	9
413009	0	13 (7.2)	0	6 (3.3)	139 (77)	0	0	0	23 (13)	0	0	0	0	0	182	56	34
413004+++	882 (2.6)	2,519 (7.3)	609 (1.8)	667 (1.9)	10,130 (29)	248 (0.7)	1,081 (3.1)	4,806 (14)	10,108 (29)	1,969 (5.7)	1,069 (3.1)	32 (0.1)	120 (0.3)	157 (0.4)	34,397	24	11

*Land use categories are: 1-industrial, 2 commercial, 3-freeway (other roads are proportionately distributed among the other land uses), 4-high density residential, 5-medium density residential, 6-low density residential, 7-land under development, 8-row crops, 9-pasture and small grains, 10-forested land and woodlots, 11-wetlands, 12-feedlots, 13-landfill and dumps, 14-water areas (land use categories are described in Table 2.

**( ) percent distribution.

***To obtain area adjacent to station subtract values for 673001 from values for 683002.

+To obtain area adjacent to station subtract values for 683002 from values for 683001.

++To obtain area adjacent to station subtract values for 683001, 413007, 413006 and 413008 from values for 413005.

+++To obtain area adjacent to station subtract values for 413005 from values for 413004.

†Total imperviousness of area adjacent to stations 683002, 683001, 413005 and 413004 are 12, 16, 47 and 65%, respectively.

††Connected imperviousness of area adjacent to stations 683002, 683001, 413005 and 413004 are 3, 3, 27 and 46%, respectively.

Table 5. Characteristics of the drainage area of the predominantly single land use monitoring stations*

STORET number	Location	Area, ha	Land use** distribution, %														Imperviousness, %	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Connected
463001	Donges Bay Road, Mequon	2,144	0	0.75	1.86	0.05	6.95	1.54	1.59	43.8	30.2	9.79	2.28	0.56	0	0.65	4.0	1.0
413010	Schoonmaker Creek at Vliet St.	179	0	4.47	22.3	0.56	65.9	0	1.68	0	5.03	0	0	0	0	0	53.5	32.7
413011	Noyes Creek at 91st St.	552	1.81	15.0	19.7	3.80	30.2	0.18	2.72	0.18	22.8	0.36	0.07	0	2.72	0.36	34.9	28.0
413625	City of New Berlin at 124th St. and Greenfield Ave.	224	0	2.68	11.2	0.89	0	56.7	2.68	0	25.0	0.89	0	0	0	0	22.5	0.30
683090	Village of Elm Grove, ditch at Underwood Pkwy.	166	0	1.81	10.2	0	0	78.9	3.61	0	3.01	2.41	0	0	0	0	24.3	0
413614	Timmerman Airport, manhole #6	140	0	95.7	3.57	0	0	0.71	0	0	0	0	0	0	0	0	18.0	6.6
413615	Stadium interchange, I-94, manhole #120	64	0	14.1	40.6	0	17.2	0	0.16	0	28.1	0	0	0	0	0	44.6	43.2
683089	Brookfield Square Shopping Center	61	0	60.7	4.92	0	8.20	0	0	0	26.2	0	0	0	0	0	50.4	44.9
413034	City of Wauwatosa, off Ferrick St.	110	22.7	49.1	8.18	0	7.27	0	0	0	12.7	0	0	0	0	0	73.8	32.1
413616	Allis Chalmers Corp., City of West Allis	49	77.6	20.4	1.43	0	0	0	0	0	0	0	0	0	0	0	89.8	89.8

*All stations have automatic sampling and continuous flow monitoring instruments.
**Land use categories in 1975 are: 1-industrial, 2-commercial, 3-roads, 4-high density residential, 5-medium density residential, 6-low density residential, 7-land under development, 8-row crops, 9-pasture and small grains (include park, recreational, institutional and unused land), 10-forested land and wood lots, 11-wetlands, 12-feedlots, 13-landfill and dumps, 14-water areas.

Table 6. Loadings and relative contributions from nonpoint and point sources of pollution for suspended sediment and total P at 70th St. (413005)

Category	1975		1976	
	Nonpoint	Point	Nonpoint	Point
		Loadings		
Water, m^3/yr	47,981,000	4,674,000	45,727,000	4,106,000
Total suspended solids, kg/yr	9,274,200	90,500	8,726,700	78,000
Total P, kg/yr			17,400	7,400
		Relative contribution, %		
Water	59	6	56	5
Total suspended solids	73	0.7	91	0.8
Total P	62	38	65	28

Table 7. Comparison of mean concentration of selected parameters during events in 1976 and 1977 with water quality criteria at the predominantly single land use monitoring sites

Parameter	Water quality criteria*, mg/L		Mean concentration (mg/L) at station:									
	Domestic water supply	Aquatic life	413010	413011	413034	413614	413615	413616	413625	463001	689089	683090
Suspended solids		80	261	154	217	164	341	293	227	257	205	27
Total P		0.05+	0.48 (99)†	0.21 (96)	0.43 (100)	0.34 (95)	0.42 (100)	1.02 (100)	0.33 (100)	0.46 (98)	0.26 (93)	0.36 (100)
NH_3-N	0.5	1.6	0.19 (0)	0.19 (0)	0.21 (0)	0.29 (0)	0.45 (0)	0.08 (0)	0.13 (0)	0.32 (0)	0.25 (0)	0.12 (0)
NO_2+NO_3-N	10		0.79 (0)	0.78 (0)	1.20 (0)	0.01 (0)	1.59 (0)	0.54 (0)	0.58 (0)	3.81 (0.9)	1.01 (0)	0.70 (0)
Chloride	250		158 (16)	141 (15)	41 (2.1)	112 (14)	278 (24)	47 (0)	61 (0)	37 (0)	57 (8.6)	63 (0)
Cd	0.01	0.012	0.011 (5.1)	0.001 (0.6)	0.005 (13)	0.006 (13)	0.007 (19)	0.019 (61)	0.005 (14)	0.002 (3.1)	0.006 (10)	0.004 (12)
Cu	1.0	0.047++	0.17 (2.6)	0.05 (0)	0.10 (1.4)	0.04 (0)	0.16 (0)	0.23 (1.9)	0.04 (0)	0.05 (0)	0.05 (0.7)	0.03 (0)
Pb	0.05	4.82++	0.37 (97)	0.09 (60)	0.52 (100)	0.27 (72)	1.66 (100)	1.34 (97)	0.19 (88)	0.06 (58)	0.44 (90)	0.06 (60)
Zn	5.0	0.082++	0.26 (0)	0.11 (0)	0.32 (0)	0.41 (0)	0.74 (0)	2.40 (13)	0.21 (0)	0.11 (0)	0.24 (0)	0.13 (0)
Cr	0.05	0.10	0.032 (14)	0.012 (1.9)	0.023 (13)	0.015 (4.4)	0.034 (19)	0.083 (46)	0.012 (2.0)	0.017 (9.4)	0.033 (9.8)	0.004 (0)
As	0.05		0.005 (0)	0.005 (0)	0.003 (0)	0.008 (1.9)	0.006 (0)	0.012 (1.3)	0.004 (0)	0.005 (0)	0.007 (1.3)	0.004 (0)
Fecal coliform	200**		265	156	††	††	††	††	††	30	††	††

*Values are U.S. water quality criteria (U.S. EPA. Quality Criteria for Water. U.S. Environmental Protection Agency, Washington, D.C., 1971. National Academy of Sciences. Water Quality Criteria 1972. Ecological Research Series, EPA-R3-73-0033, U.S. Environmental Protection Agency, Washington, D.C., 1973.) unless otherwise specified.

**Coliform limit for bathing waters expressed as MFFCC/100 ml. MFFCC is membrane filtered fecal coliform counts.

+Values for total P represent concentrations that would limit the growth of noxious plants in streams and lakes (National Academy of Sciences, 1973).

++Criteria for fathead minnows under hard water conditions.

†Percent of samples with concentrations exceeding the domestic water supply and aquatic life (total P only) criteria.

††No sample analyzed for bacteria.

Table 8. Seasonal and annual event unit area loadings* of suspended solids and flow-weighted average concentration** at mainstem river station

STORET number	Spring		Summer		Fall		Annual	
	Loading, kg/ha	Concentration, mg/L	Loading, kg/ha	Concentration, mg/L	Loading, kg/ha	Concentration, mg/L	Loading, kg/ha	Concentration, mg/L
				1975				
673001	36.7 (4.5)+	94	3.6 (0.8)	43	2.0 (5.7)	20	42.3 (6.1)	74
683002	43.2 (7.5)	68	44.1 (19.2)	201	6.8 (1.7)	52	94.1(20.8)	95
683001	56.1(21.4)	68	71.5 (12.8)	210	4.3 (1.2)	33	131 (24.7)	85
413008	238 (61.7)	243	2.2 (50.3)	605	46.4(22.5)	250	497 (81.0)	328
413007	286 (74.6)	1208	178 (55.7)	638	2.8 (9.1)	35	466 (92.8)	782
413006	288 (72.1)	511	147 (24.4)	498	45.9(14.7)	215	480 (77.3)	448
413005	127 (29.6)	129	147 (18.0)	364	14.3 (4.1)	137	288 (35.0)	189
413009	i.d.	i.d.	i.d.	i.d.	i.d.	i.d.	i.d.	i.d.
413004	i.d.	i.d.	i.d.	i.d.	13.3 (9.3)	115	i.d.	i.d.
				1976				
673001	12.7 (3.9)	47	0.2 (0.1)	27	0.06 (0.02)	29	13.0 (3.8)	46
683002	36.6(11.4)	43	1.6 (1.0)	109	0.1 (0.1)	37	38.3(11.5)	45
683001	136 (36.8)	94	6.0 (2.7)	192	0.4 (0.1)	58	143 (36.9)	96
413008	467 (131)	259	58.1 (47.6)	4407	1.4 (0.5)	106	527 (136)	288
413007	133 (42.7)	154	37.9 (27.2)	624	7.4 (6.1)	317	178 (49.5)	187
413006	835 (149)	524	76.7 (15.1)	275	10.0 (1.9)	112	922 (150)	470
413005	230 (25.7)	174	36.0 (10.5)	480	4.2 (1.7)	160	271 (27.7)	191
413009	130 (35.4)	226	30.3 (7.8)	203	i.d.	i.d.	160 (36.3)	204
413004	266 (65.8)	206	10.0 (9.0)	135	i.d.	i.d.	276 (66.4)	202
				1977				
673001	1.6 (0.6)	32	13.5 (9.0)	75	i.d.	i.d.	17 (9)++	50
683002	7.5 (4.6)	115	39.1 (9.9)	256	i.d.	i.d.	58 (11)++	190
683001	44.5 (15.2)	208	80.6(17.2)	377	45.6 (32.8)	380	171 (31.9)	330
413008	95.1 (26.2)	826	180 (35.2)	658	i.d.	i.d.	344 (43)++	620
413007	26.2 (11.2)	321	84 (37.8)	398	36 (63.3)	400	146 (56.3)	380
413006	129 (29.7)	352	452 (62.7)	557	47.2 (95.3)	240	628 (78.3)	460
413005	40.6 (8.2)	292	168 (28.7)	593	47.6 (58.4)	480	257 (51.2)	490
413009	34.4 (6.6)	189	87.6(49.8)	264	i.d.	i.d.	152 (50)++	210
413004	36.4 (28.5)	303	97.0(26.9)	336	i.d.	i.d.	167 (37)++	280

*Base flow loading during events subtracted from total event loading.
**Average concentration is the suspended solids loading divided by the water loading.
+95% confidence interval
++Loading values are estimated by adding 20% and 30% to Spring and Summer loadings, respectively.
i.d. Data insufficient for determination of loading.

Table 9. Seasonal loadings (with 95% confidence interval) of suspended solids at the predominantly single land use monitoring sites

STORET number	Spring Loading, kg/ha	Spring Conc., mg/L	Summer Loading, kg/ha	Summer Conc., mg/L	Fall Loading, kg/ha	Fall Conc., mg/L	Winter Loading, kg/ha	Winter Conc., mg/L	Total Loading, kg/ha	Total Conc., mg/L
1976										
413616	++		202.163 (79.251)	266.419	4.258 (3.489)	145.159	0.0		206.421 (79.269)	261.906
413615	++		10.465 (7.678)	82.432	4.164 (6.178)	304.099	36.231 (16.747)	393.464	50.860 (17.134)	218.538
683089	i.d.		78.240 (53.376)	218.883	6.023 (5.894)	66.959	0.0		84.263 (53.569)	188.339
413011	1422.740 (792.427)	437.362	50.769 (22.826)	216.038	3.262 (2.359)	35.846	0.0		1476.770 (792.742)	412.621
413010	142.441 (54.781)	234.664	83.458 (112.980)	575.572	3.868 (9.225)	84.087	0.0		229.766 (124.650)	287.927
413614	i.d.		64.322 (9.648)	463.509	1.187 (.233)	65.291	.958 (.225)	38.774	66.467 (9.651)	365.881
413625	++		.237 (.179)	211.402	.044 (.031)	16.000	i.d.		.281 (.178)	72.476
683090	i.d.		0.0		0.0		0.0		0.0	
463001	274.831 (112.936)	157.496	8.432 (13.915)	351.333	0.0		0.0		283.263 (113.219)	160.126
1977										
413616	80.925 (30.564)	159.113	1627.842 (596.247)	495.961	2.821 (2.561)	12.271	0.0		1711.588 (596.869)	425.696
413615	230.042 (75.568)	519.133	694.853 (271.856)	436.084	51.042 (26.066)	215.134	13.699 (4.803)	137.543	989.636 (283.498)	416.974
683089	349.662 (348.479)	511.655	187.543 (82.151)	150.446	3.548 (1.469)	34.328	0.0		540.752 (356.556)	265.946
413011	49.246 (18.971)	143.994	779.681 (744.236)	680.944	i.d.		0.0		828.926 (744.463)	557.449
413010	169.015 (281.472)	738.057	264.889 (123.628)	409.411	9.119 (125.510)	147.081	0.0		443.023 (291.100)	472.306
413034	10.179 (12.042)	471.205	48.090 (25.509)	199.598	27.002 (5.486)	396.091	0.0		85.271 (26.227)	257.844
413614	15.906 (11.287)	111.666	71.981 (27.615)	157.487	7.143 (4.545)	29.657	0.0		95.030 (29.094)	113.082
413625	6.546 (1.971)	67.829	11.241 (4.777)	352.298	.975 (.270)	103.802	0.0		18.761 (4.885)	136.143
683090	.943 (.220)	24.395	1.071 (.667)	28.138	1.042 (.066)	35.068	0.0		3.056 (.686)	28.714
463001	i.d.		114.996 (101.727)	871.182	12.640 (3.485)	188.657	0.0		127.636 (101.760)	641.387

\+ ( ) 95% Confidence interval
++ Station not operational
i.d. Data insufficient for loading determination

Table 10. Seasonal and annual event unit area loadings* of total P and flow-weighted average concentrations** at main stem river stations

STORET number	Spring Loading, kg/ha	Spring Concentration, mg/L	Summer Loading, kg/ha	Summer Concentration, mg/L	Fall Loading, kg/ha	Fall Concentration, mg/L	Annual Loading, kg/ha	Annual Concentration, mg/L
				1976				
673001	0.072 (0.012)+	0.27	0.004 (0.000)	0.55	0.002 (0.000)	0.95	0.077 (0.013)	0.28
683002	0.066 (0.043)	0.08	0.004 (0.000)	0.27	0.000 (0.000)	0.00	0.070 (0.043)	0.08
683001	0.504 (0.112)	0.34	0.030 (0.022)	1.00	0.003 (0.000)	0.43	0.538 (0.114)	0.36
413008	0.457 (0.147)	0.25	0.001 (0.000)	0.08	0.001 (0.000)	0.08	0.459 (0.147)	0.25
413007	0.307 (0.155)	0.35	0.006 (0.000)	0.10	0.004 (0.000)	0.17	0.317 (0.155)	0.34
413006	0.641 (0.482)	0.40	0.119 (0.119)	0.42	0.048 (0.009)	0.53	0.883 (0.484)	0.45
413005	0.459 (0.062)	0.35	0.065 (0.014)	0.93	0.017 (0.005)	0.57	0.541 (0.064)	0.38
413009	i.d.	i.d.	0.161 (0.078)	0.28	i.d.	i.d.	i.d.	i.d.
413004	0.236 (0.068)	0.18	0.018 (0.000)	0.26	i.d.	i.d.	0.271 (0.063)	0.20
				1977				
673001	0.004 (0.004)	0.08	0.105 (0.043)	0.58	i.d.	i.d.	0.136 (0.43)++	0.47
683002	0.016 (0.007)	0.10	0.061 (0.011)	0.40	i.d.	i.d.	0.096 (0.012)++	0.37
683001	0.085 (0.024)	0.40	0.160 (0.028)	0.85	0.073 (0.60)	.61	0.318 (0.059)	0.61
413008	0.068 (0.022)	0.59	0.134 (0.042)	0.50	i.d.	i.d.	0.252 (0.046)++	0.52
413007	0.040 (0.025)	0.49	0.110 (0.054)	0.52	0.031 (0.180)	.34	0.181 (0.079)	0.48
413006	0.282 (0.167)	0.76	0.485 (0.112)	0.60	0.095 (0.180)	.47	0.862 (0.21)	0.63
413005	0.055 (0.013)	0.40	0.211 (0.042)	0.75	0.038 (0.068)	.38	0.304 (0.054)	0.58
413009	0.235 (0.047)	1.30	0.538 (0.449)	1.63	i.d.	i.d.	0.966 (0.451)++	1.52
413004	0.050 (0.029)	0.42	0.186 (0.079)	0.64	i.d.	i.d.	0.295 (0.083)++	0.58

*Base flow loading during events subtracted from total event loading.
**Average concentration is total P loading divided by water loading
+95% confidence interval.
++Loading values are estimated by adding 20% to the Spring and Summer loadings.
i.d. Data insufficient for determination of loading.

Table 11. Seasonal loadings (with 95% confidence interval) of total phosphorus at the predominantly single land use monitoring sites

STORET number	Spring		Summer		Fall		Winter		Total	
	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L
1976										
413616	++		1.041 (.205)	1.371	.032 (.013)	1.079	0.0		1.072 (.205)	1.360
413615	++		.022 (.009)	.173	.013 (.063)	.935	.076 (.012)	.827	.111 (.020)	.477
683089	i.d.		.095 (.051)	.267	.024 (.031)	.267	0.0		.419 (.057)	.266
413011	1.287 (.446)	.396	.069 (.017)	.294	.015 (.008)	.165	0.0		1.370 (.447)	.383
413010	.276 (.076)	.455	.122 (.168)	.841	.017 (.022)	.370	0.0		.415 (.183)	.520
413614	i.d.		.099 (.025)	.713	.008 (.002)	.467	.007 (.000)	.288	.115 (.025)	.631
413625	++		.001 (.000)	.481	.001 (.001)	.295	i.d.		.001 (.000)	.349
683090	i.d.		0.0		0.0		0.0		0.0	
463001	.633 (.170)	.363	.014 (.014)	.583	0.0		0.0		.647 (.170)	.366
1977										
413616	.454 (.085)	.892	3.712 (.863)	1.131	.129 (.087)	.561	0.0		4.295 (.866)	1.068
413615	.239 (.070)	.538	.629 (.169)	.395	.060 (.039)	.254	.012 (.016)	.120	.946 (.191)	.399
683089	.263 (.217)	.384	.216 (.159)	.174	.007 (.003)	.067	0.0		.486 (.264)	.239
413011	.075 (.017)	.219	.614 (.362)	.536	i.d.		0.0		.689 (.362)	.463
413010	.243 (.376)	1.061	.352 (.087)	.544	.022 (.105)	.355	0.0		.617 (.378)	.658
413034	.016 (.012)	.742	.042 (.012)	.175	.072 (.011)	1.058	0.0		.130 (.018)	.394
413614	.030 (.018)	.207	.084 (.027)	.185	.051 (.027)	.210	0.0		.165 (.034)	.196
413625	.039 (.042)	.407	.012 (.002)	.386	.002 (.000)	.217	0.0		.054 (.042)	.389
683090	.008 (.001)	.213	.017 (.001)	.437	.009 (.008)	.295	0.0		.034 (.007)	.316
463001	i.d.		.174 (.099)	1.318	.025 (.010)	.373	0.0		.200 (.099)	1.005

\+ ( ) 95% Confidence interval
++ Station not operational
i.d. Data insufficient for loading determination

Table 12. Seasonal event unit area loadings* of lead and flow-weighted average concentrations** at main stem river stations

STORET number	Spring		Summer		Total	
	Loading, kg/ha	Concentration, mg/L	Loading, kg/ha	Concentration, mg/L	Loading, kg/ha	Concentration, mg/L
			1975			
413005			0.168(0.808)	0.420	0.410(0.262)	0.275
			1976			
413006	0.289(0.484)+	0.182	0.101(0.659)	0.361	0.416(1.288)	0.212
413005	0.125(0.213)	0.095			0.132(0.228)	0.093
			1977			
673001			0.001(0.002)	0.022	0.008(0.002)	0.024
683002			0.003(0.001)	0.020	0.007(0.001)	0.023
683001			0.007(0.002)	0.037	0.022(0.009)	0.042
413007			0.075(0.135)	0.357	0.124(0.262)	0.326
413006			0.378(0.314)	0.467	0.524(0.504)	0.380
413005			0.063(0.045)	0.225	0.114(0.093)	0.219

*Base flow loadings during events subtracted from total event loading.
**Average concentration is the lead loading divided by the water loading.
+95% confidence interval.
Blank means no data.

Table 13. Seasonal loadings (with 95% confidence interval) of lead at the predominantly single land use monitoring sites

STORET number	Spring		Summer		Fall		Winter		Total	
	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L	Loading, kg/ha	Conc., mg/L
					1976					
413616	++		1.440 (.986)	1.897	.023 (.019)	.780	0.0		1.462 (.986)	1.855
413615	++		.038 (.021)	.300	.026 (.039)	1.935	.256 (.088)	2.775	.320 (.091)	1.376
683089	i.d.		.189 (.151)	.528	.041 (.054)	.456	0.0		.230 (.160)	.514
413011	.180 (.111)	.055	i.d.		i.d.		0.0		.180 (.111)	.05
413010	.061 (.017)	.100	.077 (.365)	.531	i.d.		0.0		.138 (.371)	.184
413614	i.d.		.081 (.026)	.584	.004 (.001)	.209	.004 (.001)	.161	.089 (.026)	.489
413625	++		.000 (.000)	.200	.000 (.000)	.056	.010 (.003)	1.464	.010 (.003)	.957
683090	i.d.		0.0		0.0		0.0		0.0	
463001	.007 (.005)	.004	.000 (.000)	.000	0.0		0.0		.007 (.005)	.004
					1977					
413616	.307 (.122)	.604	6.664 (2.910)	2.030	.041 (.006)	.178	0.0		7.013 (2.912)	1.744
413615	1.095 (.345)	2.471	3.659 (2.009)	2.296	.337 (.240)	1.421	.078	.783	5.169 (2.060)	2.178
683089	.714 (.581)	1.044	.443 (.161)	.356	.010 (.006)	.101	0.0		1.167 (.600)	.574
413011	.025 (.007)	.073	.191 (.075)	.167	i.d.		0.0		.216 (.076)	.145
413010	.507 (.538)	2.214	.285 (.087)	.440	.014 (.048)	.226	0.0		.805 (.550)	.858
413034	.021 (.054)	.975	.072 (.019)	.298	.109 (.040)	1.604	0.0		.202 (.041)	.611
413614	.025 (.014)	.179	.086 (.050)	.189	.038 (.008)	.157	0.0		.150 (.051)	.178
413625	.007 (.008)	.074	.006 (.002)	.192	.001 (.000)	.086	0.0		.014 (.008)	.102
683090	.001 (.000)	.030	.003 (.000)	.072	.002 (.000)	.060	0.0		.006 (.000)	.053
463001	i.d.		.008 (.007)	.061	.004 (.001)	.060	0.0		.012 (.007)	.060

\+ ( ) 95% Confidence interval
++ Station not operational
i.d. Data insufficient for loading determination

the basin outfalls by an impermeable storm sewer drainage network. An urban area drained by a conventional curb and gutter storm sewer system generates much larger stormwater flows and pollutant loads than would a similar area drained by adequately maintained natural drainage swales. Natural drainage allows infiltration and reduces the total amount of runoff. Further, vegetated drainage swales appear to effectively filter particulate pollutants. Because total phosphorus and lead are closely associated with suspended solids, control of suspended solids will effectively reduce phosphorus and lead loadings.

The degree of correlation between the relative amount of runoff and the amount of connected impervious area increases as the size of the connected impervious area increases. In highly impervious areas the relative effects of infiltration, evapotranspiration and depression storage are minimized. Thus, the amount of runoff--as a percent of rainfall--is relatively high and consistent, regardless of the magnitude of the rainfall. In more pervious areas, the percent runoff is considerably lower and fluctuates far more widely, apparently in response to the size and intensity of an event, antecedent soil moisture conditions and evapotranspiration.

In addition to an increase in the volume of runoff with urbanization, there is a concomitant increase in the rate of flow. The concentrations of many pollutants, most notable suspended solids, increase as flow rates increase (Fig. 5). Thus, the increased volume of runoff, coupled with higher pollutant concentrations, yields much higher pollutant loads. The concentrations of some pollutants--i.e., dissolved phosphorus--do not appear to increase with increasing flow rates, but remain relatively constant from base flow to event flow. Chloride concentrations often showed an inverse relationship with flow.

In urban areas, higher loads of lead were observed at the freeway and heavy industrial sites (Nos. 413615 and 413616) and greater total phosphorus and suspended solid loads occurred at a medium density residential area experiencing development, and at the freeway and heavy industrial sites (Nos. 413011, 413615 and 413616) (Table 9, 11 and 13).

Temporal Variations in Nonpoint Pollutant Loads

Large variations in seasonal and annual pollutant concentrations and loads were observed at all stations (Table 8-13). While a positive correlation generally exists between pollutant concentrations and loading rates, a far stronger correlation is observed between flow rates and pollutant loading rates. Event flow is the best predictor of pollutant loading; hence seasonal and annual rainfall is the best indicator of seasonal and annual pollutant loads.

Excluding seasonal loading variations due to differences in rainfall, the highest loads of chlorides were observed in spring and of suspended solids in summer. Total phosphorus showed inconsistent seasonal trends, but dissolved phosphorus remained fairly constant from season to season. Concentrations of most parameters were lowest in the fall.

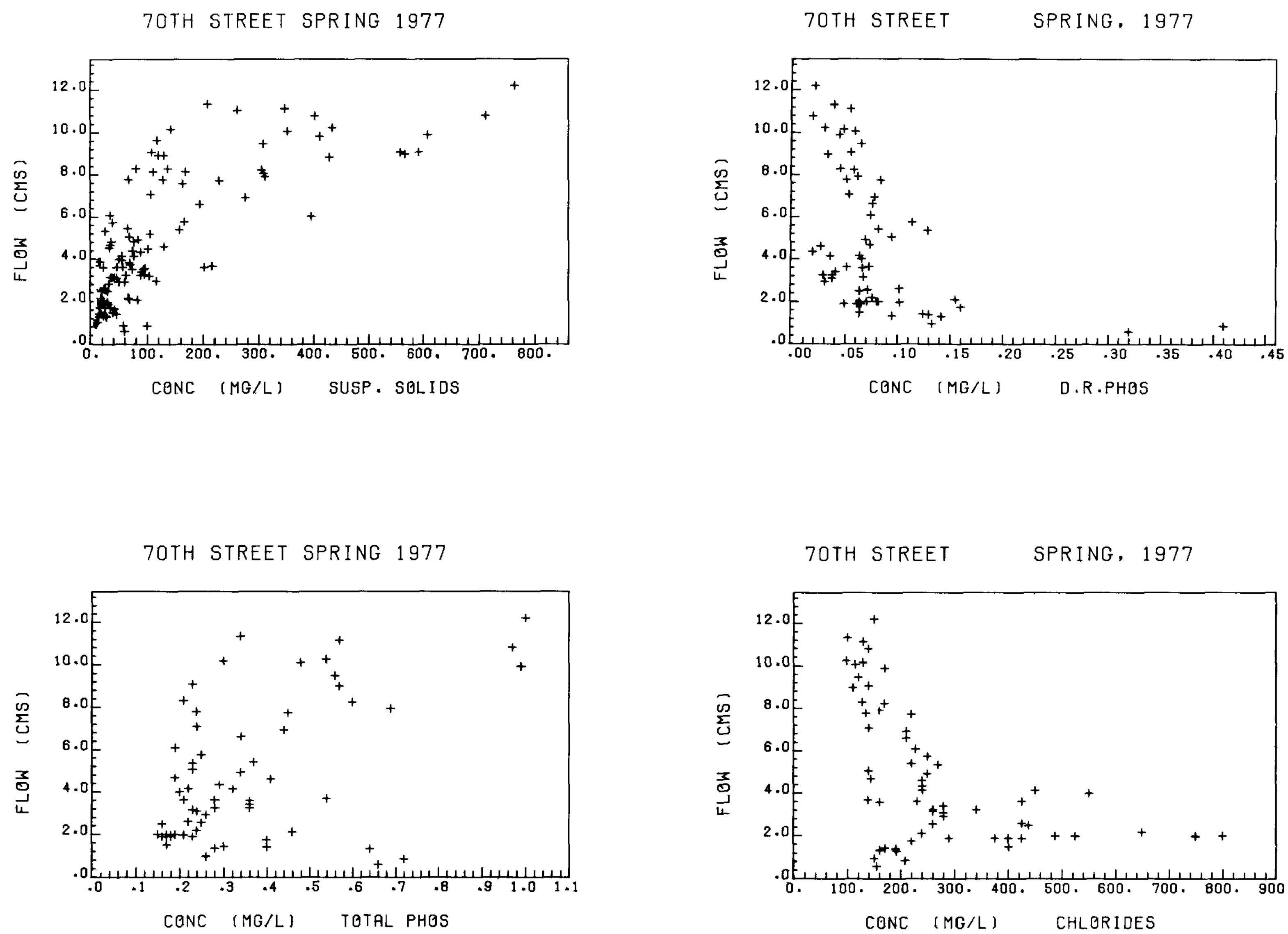

Figure 5. Relationships of event flow and parameter concentrations at 70th St. (413005) during spring 1977.

Pollutant loads and antecedent conditions (days since last significant rainfall) were not correlated. Possible relationships that may have existed were perhaps obscured by overriding variables, i.e., rainfall magnitude and intensity.

Pollutant concentrations generally were correlated with flow rates. During an event, however, concentrations at given flow rates were typically higher on the rising limb of the hydrograph than at equivalent flow rates on the falling limb. This was most consistently evident with particulates, but because of the positive correlation between levels of suspended solids and total phosphorus and lead, the latter also exhibited this phenomena. Dissolved phosphorus did not respond in this manner.

This first flush phenomenon was often but not always observed. Overall, the cumulative pollutograph (percent of total pollutant load that has passed at any point in an event) surpassed or preceded the cumulative hydrograph. The relative magnitude of first flush was not correlated with the size of an event since pollutant concentrations remained high throughout very large events. This first flush effect also was noted more strongly among the predominantly single land use stations, probably because the larger areas at the main stem stations tended to normalize concentrations.

4. EFFECTS OF TRIBUTARY INPUTS ON LAKE MICHIGAN DURING HIGH FLOWS

The effects of the combined inputs from the Menomonee, Milwaukee and Kinnickinnic Rivers on Lake Michigan water quality were investigated. Estimates of annual river loadings indicated that the Menomonee River usually discharged 50% of the annual river loadings reaching the Milwaukee Harbor and the effect of the Menomonee River on Lake Michigan water quality could not be isolated from that of the Milwaukee and Kinnikinnic Rivers (Table 14). The study focused on the area around the Milwaukee Harbor. The area was divided into four regions, namely, inner and outer harbors and inshore and offshore zones (Fig. 6). The inner harbor was bounded upstream by the point on the river where the lake and harbor seiche effects were no longer apparent and downstream by the outermost point of the shipping channel. The breakwater separated the outer harbor from the inshore zone; the inshore zone extended 5 km (3.1 miles) into the lake. Water quality surveys were conducted in the study area during periods of high and low flow in the rivers. The parameter list included nutrients, suspended solids and metals.

Water quality surveys indicated that the concentration levels of measured parameters decreased as distance from the confluence of the rivers increased. Each of the four regions was characterized by a different set of concentrations. Average concentrations of suspended solids in the inner and outer harbors and inshore and offshore zone were 19, 9, 3, and 1 mg/L, respectively (Table 15). This phenomenon occurred during baseflow and runoff event flow periods. The large concentration gradient of the parameters from the outer harbor to the inshore zone indicated how effectively the breakwater prevented mixing of water between the two zones. This pattern of water quality degradation indicates that the rivers and the Jones Island Sewage Treatment Plant (STP) are sources of pollutants to the harbor and the inshore zone. The STP has a mean annual flow of 6.2 cms (219 cfs) and contributes a major portion of the total annual pollutant loading to the harbor (Table 14). The runoff events surveyed immediately affected harbor water quality. However, for most events only the concentrations for suspended solids and total organic nitrogen were higher than the baseflow values in the inner harbor. The water quality of the inshore zone usually was not degraded during high flow periods. Although more pollutants were available in the harbor for transport to the inshore zone, most events did not transport a large enough portion of the pollutants to increase concentrations in the inshore zone. Only the February 13 and 25, 1976 snowmelt runoff surveys showed slightly elevated suspended solids concentrations, and the exceptionally large rain event on July 18, 1977 elevated suspended solid and chloride concentrations in the inshore zone. The event surveys indicated that the current patterns in the harbor and harbor structures were modifying pollutant transport to the inshore zone.

Table 14. Annual water ($m^3 \times 10^7$) and pollutant ($kg \times 10^4$) loadings to the Milwaukee Harbor

Source	Water	Solids		P		(NO_3+NO_2)-N	Cl	Pb
		Total	Suspended	Total	Soluble			
Menomonee River*	8	6,200	1,500	2.8	1.2	13	1,250	0.87
Milwaukee River*	36	16,000	1,430	7.6	5.5	36	1,200	3.5
Three rivers combined**	45	23,000	3,000	10.7	6.9	50	2,520	4.5
STP	20	16,000	780	12.8	2.9		3,900	

*Menomonee River pollutant values were based on 1976 data, Milwaukee River values were based on 1973, 1974, 1975 data and the STP values were 1976 data. The water data were averages of long-term records.

**The Kinnickinnic River loading was considered to be 3% of the total loadings from the other two rivers.

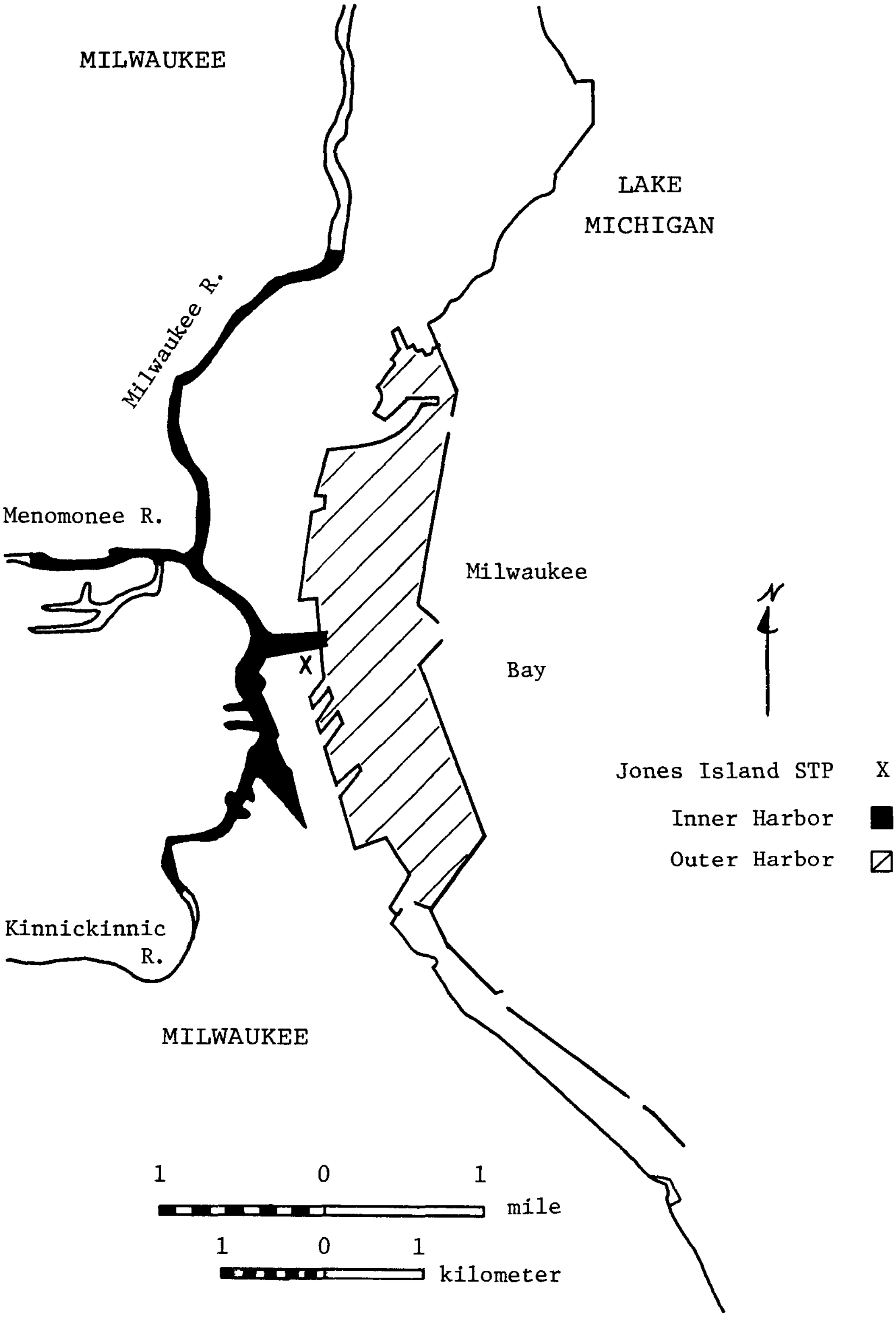

Fig. 6. Milwaukee Harbor.

Table 15. Mean annual surface concentrations of pollutants in mg/L in the harbor region*

Region or tributary	Mean flow, cms	Solids		P		(NO_3+NO_2)-N	Cl
		Total	Suspended	Total	Soluble		
Inner harbor	--	405	19	0.17	0.070	0.70	54
Outer harbor	--	245	9	0.06	0.016	0.40	31
Inshore zone	--	180	3	0.02	0.003	0.22	8
Menomonee River	2.5	780	190	0.35	0.15	1.7	160
Milwaukee River	11.3	460	40	0.21	0.15	1.0	33
Combined rivers**	14.4	510	67	0.24	0.15	1.1	56
Jones Island STP	6.2	840	40	0.66	0.15	—	200

*Means include values from this study and the literature.
**Combined Menomonee, Milwaukee and Kinnickinnic Rivers.

Current directions and velocities at the harbor mouth opening (between the inner and outer harbors) and at the central breakwater opening (between the outer harbor and the inshore zone) were measured to characterize the mechanism controlling pollutant transport between regions. Measurements indicate that the action of the lake and harbor seiches controls transport more than does combined flow from the rivers. Seiche has been observed to cause the direction of flow for different strata or for the entire water column to reverse itself during runoff events at the harbor mouth and at the central breakwater opening (Table 16). This oscillation of flow between regions results in a pulsing of the event-generated pollutants from the more polluted region to the less polluted region across these two boundaries. The pulsing phenomenon also was verified by the water quality at the central breakwater opening alternating between that of the inshore zone and the harbor. The size of the plug of pollutants depends largely on the seiche characteristics for any period. This apparent pulsing occurs during times of event and baseflow. An exception to the pulsing, seiche-controlled pattern probably occurs during times of exceptionally large event flow, when a relatively consistent flow of water could be expected to move outward into the inshore zone with short residence time in the harbor. On July 18, 1977 the flow at the surface was not observed to reverse direction for the measurement period. Although the results of watershed studies have indicated that a large portion of the pollutants were discharged to the harbor during high flow periods, the net transport of event and baseflow water to the inshore zone apparently depended more on harbor current patterns. The harbor current patterns and structures were able to impose a significant residence time on all pollutants discharged into the harbor before entering the inshore zone.

A mass balance equation was used to quantify the average annual amounts of pollutants reaching the inshore zone. Residence times were estimated to be 5 and 6 days for the inner and outer harbors, respectively. The residence times were averages for all conditions and probably decreased significantly for the portions of pollutants discharged to the inner harbor during periods of high flows. The percentage of the total annual loadings to the harbor entering the inshore zone was estimated to be 45% for suspended solids, 61% for total phosphorus and 35% for soluble phosphorus. Although the percentages were only gross estimates, they demonstrated that the harbor retained a significant portion of the annual loading from the river and STP. Although the portion of the event pollutants retained in the harbor was not known, it was estimated that 70% of the suspended solids discharged from the Menomonee River during events was retained annually in the inner harbor. The amount of suspended solids in the plume for the July 18, 1977 event was estimated to be 5% of the total suspended solids entering the inshore zone each year. The pollutants associated with the particulate matter settled out during their residence time in the harbor. Higher concentrations of total phosphorus, organic nitrogen and metals in the harbor bottom sediments relative to the river and lake sediments provided further evidence that pollutants were deposited in the harbor.

The dispersion pattern of pollutants reaching the inshore zone was manifested as small islands of turbid water in the inshore zone or a narrow band of turbid water long the outside of the breakewater. Only during the

Table 16. Water quality data, current velocities and directions at harbor stations during three events

Time, hr	Depth, m	Suspended solids, mg/L	P, mg/L Total	P, mg/L Soluble	Cl, mg/L	DO, mg/L	Temperature, °C	Current Velocity, kmph	Current Direction, degrees
			STATION NO. 1 - HARBOR MOUTH - 6/28/1977						
1510	0	12	0.11	0.039	--	5.0	19	1.3	100
1515	7	14	0.07	<0.004	--	8.6	12	0.28	350
1630	0	10	0.12	0.031	--	3.8	20	0.74	80
1635	7	9	0.04	0.004	--	8.6	12	0.56	285
1815	0	9	0.09	0.017	--	4.6	19	0.46	65
1830	7	6	0.05	0.004	--	9.4	11	0.46	310
1905	0	8	0.10	0.014	--	8.0	18	0.46	75
1910	7	6	0.04	0.004	--	12.0	12	0.46	265
			STATION NO. 2 - BREAKWATER CENTRAL OPENING - 6/28/1977						
1530	0	6	0.04	<0.004	--	10.0	16	0.93	90
1540	7	4	0.02	<0.004	--	9.8	14	0.56	135
1720	0	6	0.05	0.006	--	8.2	17	0.37	140
1725	7	3	<0.02	<0.004	--	9.1	8	0.46	250
1845	0	4	0.04	<0.004	--	11.2	16	0.93	120
1850	7	4	0.04	<0.004	--	12.0	10	0.37	140
1925	0	4	0.04	<0.004	--	9.0	16	0.83	115
1935	7	2	0.02	<0.004	--	12.0	8	0.28	140
			STATION NO. 3 - 0.8 km EAST OF BREAKWATER - 6/28/1977						
1550	0	3	0.03	<0.004	--	12.0	15	--	--
1555	7	3	<0.02	<0.004	--	12.0	12	--	--
			STATION NO. 4 - 1.6 km EAST OF BREAKWATER - 6/28/1977						
1400	0	2	<0.02	<0.004	--	10.8	12	--	--
1405	7	2	<0.02	<0.004	--	11.6	10	--	--
			STATION NO. 1 - HARBOR MOUTH - 6/30/1977						
1515	0	35	0.12	0.011	--	8.9	16	0.56	277
1520	7	40	0.16	0.040	--	8.8	13	0.56	240
1700	0	27	0.12	<0.004	--	3.7	18	1.20	90
1710	7	34	0.12	0.012	--	5.7	16	0.65	208
1905	0	23	0.11	0.009	--	4.8	17	0.74	37
1915	7	25	0.08	0.009	--	7.4	13	0.30	218
			STATION NO. 2 - BREAKWATER CENTRAL OPENING - 6/30/1977						
1615	0	26	0.04	<0.004	--	10.5	10	0.37	283
1620	7	22	0.02	<0.004	--	10.7	10	1.57	227
1730	0	25	0.03	<0.004	--	10.5	10	0.74	158
1740	7	22	0.02	<0.004	--	10.4	10	0.83	345
1845	0	25	0.04	0.004	--	--	12	0.65	104
1850	7	26	0.04	0.006	--	--	12	0.46	172
			STATION NO. 1 - HARBOR MOUTH - 7/18/1977						
1330	0	57	0.20	0.041	36	3.0	24	1.11	90
1335	7	41	0.10	0.012	24	9.4	14	0.37	70
			STATION NO. 2 - BREAKWATER CENTRAL OPENING - 6/30/1977						
1445	0	25	0.12	0.019	26	6.3	20	0.56	120
1450	7	6	0.02	<0.004	11	11.0	10	0.83	290
1715	0	16	0.06	<0.004	20	--	19	0.46	330
1720	7	2	0.02	<0.004	9	--	8	0.93	250
1740	0	22	0.08	0.010	21	6.6	20	1.11	95
1745	7	15	0.06	0.050	20	8.5	15	1.20	90

July 18, 1977 event was a continous plume observed (4 km directly east into the lake from the breakwater central opening) (Fig. 7). A plume from the breakwater's northern opening extended approximately 2.5 km in a northeasterly direction on July 18, 1977. On July 19, the visible plume from the breakwater's central opening had grown slightly larger (to 5 km in east-west extent) and a plume out of the breakwater's southern opening extended approximately 2.5 km parallel to the shore. Since surface values of suspended solids were higher than bottom values, it is assumed that the plume extended to the thermocline. Pollutant dispersion in the inshore zone would be highly variable and dependent on wind direction. The summer current has a weak tendency to go in a southerly direction and the winter currents have a strong tendency to go in a northerly direction.

Resuspension and/or shoreline erosion elevated the levels of suspended solids along the shore in the vicinity of the Milwaukee Harbor on April 8, 1976. A significant runoff event had not occurred for almost 2 weeks. The values for suspended solids were higher than those observed in the inshore zone during the July 18, 1977 rain event. Approximately twice as much suspended solids was in the water column of the inshore zone in the vicinity of Milwaukee as a result of this resuspension/erosion event than was in the July 18, 1977 rain event plume. The amount of suspended solids in the inshore zone on April 8, 1976 represented about 12% of the annual suspended solids loading to the lake from the harbor. Resuspension and shoreline erosion could significantly increase suspended solids loading to the inshore zone each year.

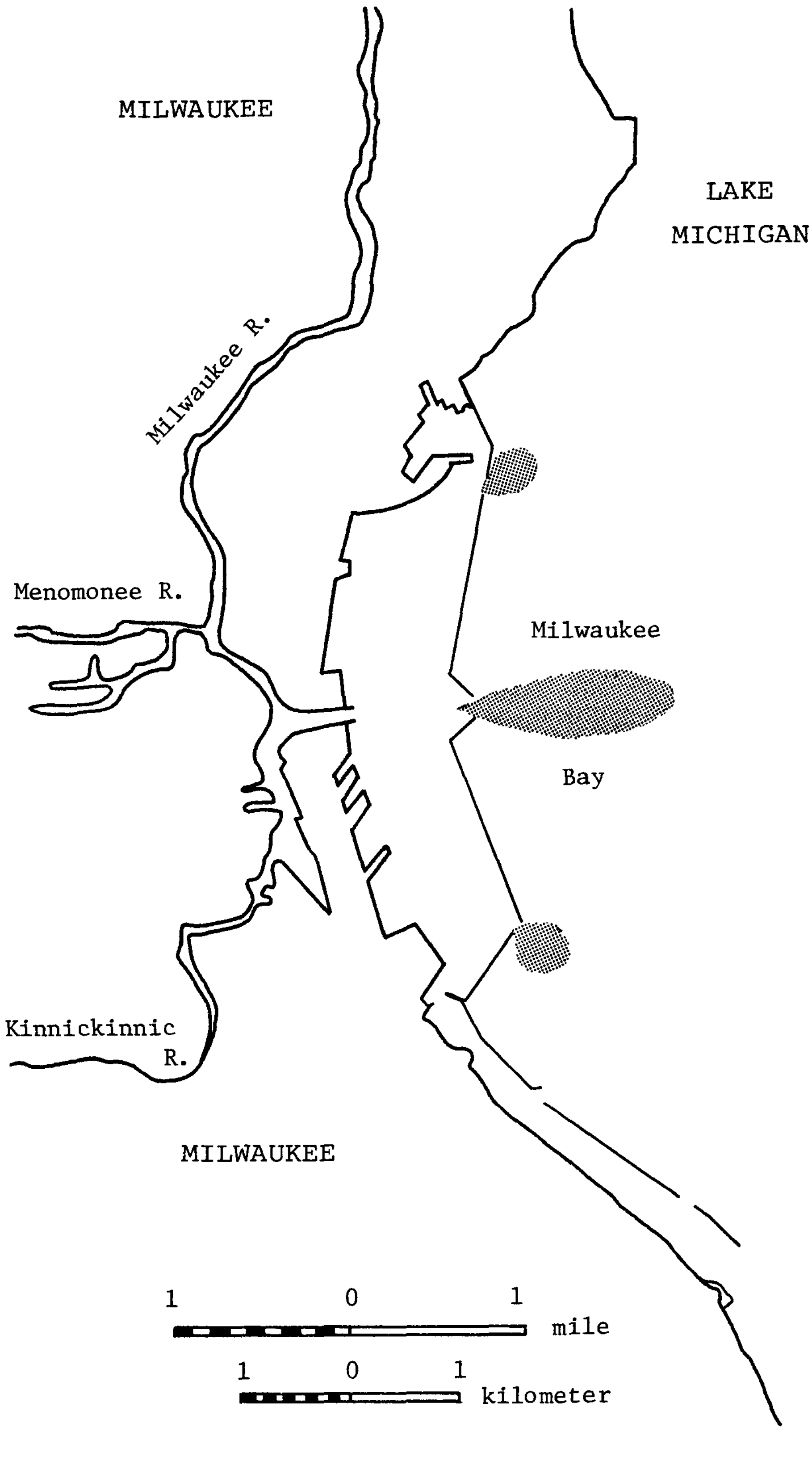

Fig. 7. Visible plumes following 7/18/1977 event.

5. LAND USE/WATER QUALITY MODELING

One objective of the Menomonee River Pilot Watershed Study was to develop a predictive capability for estimating pollutant loadings from land drainage related to land use. Two modeling methods were developed; one model involved the simple empirical modeling of runoff quality from small watersheds and the other was the more sophisticated model known as LANDRUN.

LANDRUN

LANDRUN, a dynamic hydrologic-sediment transport model, was developed to estimate the quantity and composition of runoff water and particulates emanating from watersheds that have mixed land uses. The model simulates the overland hydrologic transport of pollutants (Fig. 8) and accounts for: a. land uses including imperviousness, land surface characteristics and soil characteristics; b. local meteorology, including rainfall, snowmelt, temperature, evaporation and evapotranspiration; c. pollutant input, i.e., dust and dirt fallout and adsorbed pollutants in the soil. The model can estimate stormwater runoff volume, sediment transport from pervious and impervious areas, volatile suspended solids and soil-adsorbed pollutants contained in runoff. LANDRUN is a continuous simulation model which also may be used to analyze single storm events.

To ensure results that resemble a real-world situation a model must be calibrated and verified. LANDRUN was calibrated and verified with extensive monitoring data from pilot subwatersheds in the Menomonee River Watershed. The model then demonstrated its ability to reproduce field data for medium and large storms with adequate accuracy for such parameters as runoff, sediment, volatile suspended solids and adsorbed phosphorus.

A soil adsorption subroutine describing the overland transport of phosphorus was incorporated into LANDRUN. This subroutine can be calibrated for simulating pesticide and toxic metal loadings and routing.

Application of LANDRUN to Watershed Studies

A simulation model calibrated and verified with extenstive field measurements and monitoring data could be a useful tool for predictive purposes in watersheds with similar physical and meteorological characteristics. The LANDRUN model was ued to a. obtain unit pollutant loadings for typical land uses to better understand the processes and factors involved in pollutant generation and transport from urban and rural areas and b. assess pollutant loadings from 48 subwatersheds in the Menomonee River Watershed in an attempt to identify critical source areas.

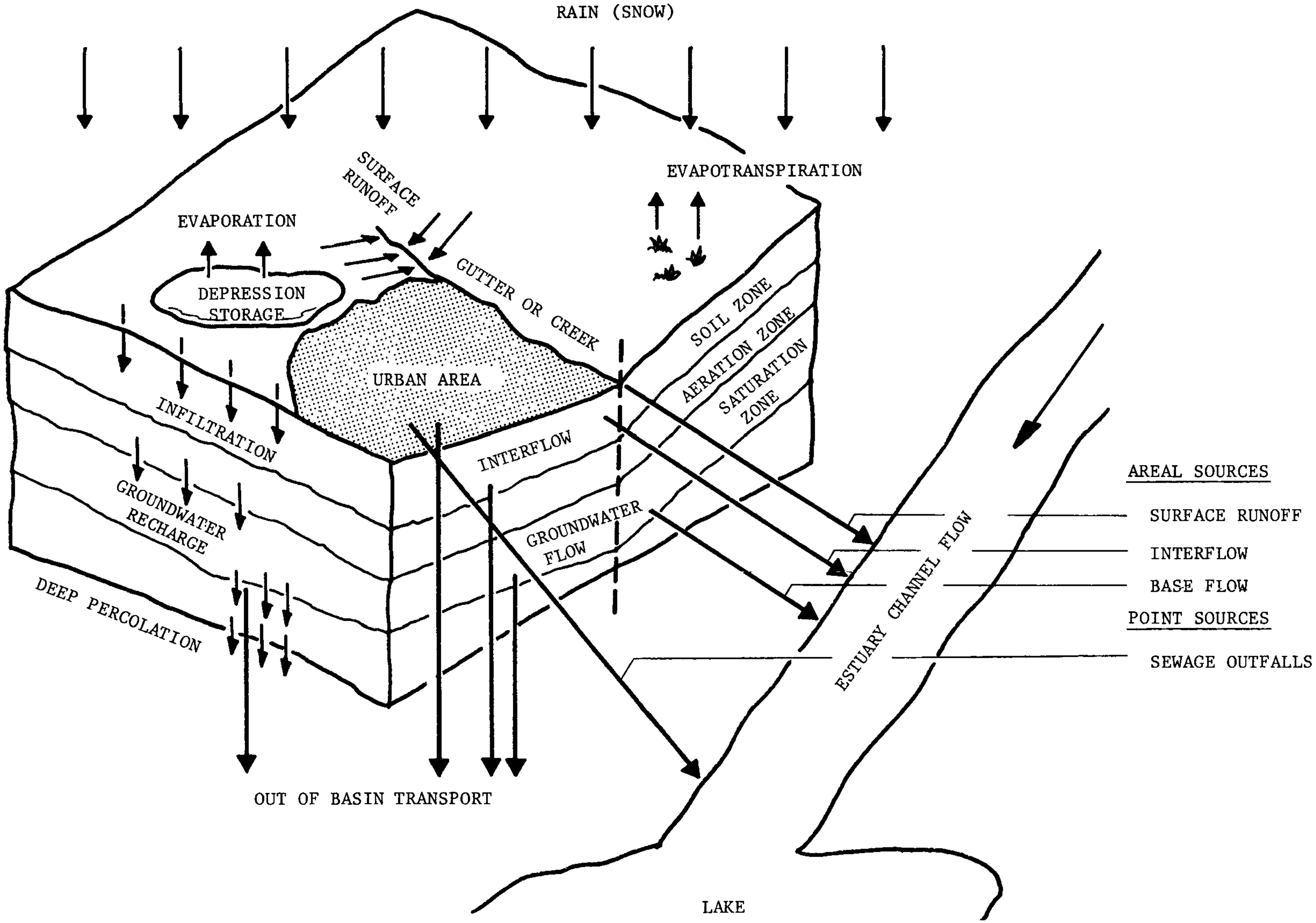

Figure 8. A schematic representation of pollutant transport.

MEUL

The Model Enhancing Unit Loading (MEUL) analysis assesses pollutant loadings from various land uses on a directly comparative basis. LANDRUN provided the simulation of loadings for seven urban and five rural land uses.

To simulate pollutant loadings, each land use was assigned typical values for variables such as degree of imperviousness, fraction of impervious areas directly connected to a channel, depression storage, permeability of pervious areas, slope, soil moisture characteristics, etc. In addition, variables describing atmospheric fallout, litter accumulation, street sweeping practices and the Universal Soil Loss Equation (USLE) inputs were selected. The values were based on Menomonee River Pilot Watershed data or on literature values typical of midwestern urban areas. Each land use was simulated as if located on four hydrologically different soils representative of standard hydrologic categories. Simulation runs yielded loading diagrams which were used to estimate average year or long-term average pollutant loadings for 12 land uses (Table 17 and 18). Developing urban areas, high density urban areas with no cleaning practices, livestock feedlots and steep-sloped crop lands have the highest polluant potential, while the pollutant potential of parks and recreational areas, low density residential areas and most urban areas with good cleaning practices is much less.

Differences in pollutant loadings among land uses were attributable to the variability of causative factors affecting loadings. Sensitivity analyses were used to test the effects of various factors on loadings. The most significant parameters were extent of imperviousness of urban areas, fraction of impervious areas directly connected to a runoff channel, depression and interception storage, average length of the dry period preceding a rain, and curb height for urban areas and soil type, slope and vegetation cover for pervious urban and rural areas.

A comparative assessment of unit loadings for various land uses could provide a means of ranking them as hazards in terms of pollution contribution. Simulated loadings of suspended solids, total phosphorus and lead were used to weigh the pollution contribution of various land uses in the Menomonee River Watershed. The simulated loadings were based on the predominant soil type (Ozaukee silt loam) and on an average soil slope range of 2 to 6%.

Average loadings for suspended sediment, total phosphorus and lead, based on the 12 major land use categories in the Menomonee River Watershed, are given in Table 19. These loadings reflect potential pollutant generation at the sources and are given as kg/ha/yr. By comparing river mouth loadings (70th St.) obtained from the monitoring program with total loadings generated at the sources, it was estimated that the delivery ratios for suspended sediment, total phosphorus and lead were about 10%.

River mouth loadings for each land use were obtained for suspended sediment, total phosphorus and lead applying the delivery ratio. Data are

Table 17. Simulated loadings* for an average year (1968) for soils of slope category B, 2 to 6%

Soils and maintenance	Imperv., %	Sediment, kg/ha				Volatile susp. solids, kg/ha				PO_4-P, kg/ha				Pb, kg/ha			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Low Density Residential																	
Poor soils, poorly maintained area	25	24	300	450	150	2.0	19.0	22.0	**	0.016	0.44	1.10	0.34	0.035	0.29	0.25	0.24
Poor soils, well maintained area	25	16	130	365	100	1.25	5.0	13.0	**	0.01	0.36	1.00	0.20	0.035	0.036	0.057	0.012
Permeable soils, poorly maintained area	25	24	225	240	130	2.0	15.0	13.0	**	0.016	0.15	0.18	0.12	0.23	0.29	0.25	0.24
Permeable soils, well maintained area	25	16	55	180	35	1.25	3.0	4.0	**	0.01	0.04	0.12	0.03	0.023	0.036	0.056	0.012
Medium Density Residential																	
Poorly maintained area	60	221	900	1,100	600	17	70	80	98	0.14	1.25	1.36	0.98	0.32	1.31	1.43	0.90
Well maintained area	60	141	275	540	120	11	19	34	19	0.09	1.10	1.00	0.13	0.21	0.31	0.50	0.11
High Density Residential																	
Poorly maintained area	95	294	2,090	2,040	1,700	22	180	158	498	0.20	1.62	1.44	1.50	0.43	3.40	2.98	2.80
Well maintained area	95	187	304	800	200	14	20	60	28	0.13	0.33	0.70	0.16	0.27	0.49	0.67	0.28
Commercial																	
Poorly maintained area	90	264	1,950	1,920	1,720	16	121	115	287	0.11	1.00	1.30	1.00	1.06	8.16	7.08	6.63
Well maintained area	90	167	283	516	200	10	17	28	34	0.07	0.30	0.60	0.20	0.66	1.03	1.60	0.25
Industrial																	
Poorly maintained area	90	403	2,970	2,770	2,600	29	229	201	520	0.21	2.00	2.40	2.18	0.54	4.25	3.71	3.48
Well maintained area	90	256	420	1,200	330	18	298	83	65	0.13	0.60	1.10	0.30	0.33	0.54	1.50	0.40

*Simulated loadings were obtained assuming dust fallout rates of 0.8 tonnes/km^2/day except for park and recreational areas where the value was increased to 1.4 in the Spring and to 3.5 tonnes/km^2/day in the Fall because of the effect of dead vegetation.

**60 to 85% of the total sediment was in the form of vegetation.

Table 18. Simulated pollution loadings for land uses on essentially pervious areas

Soil and slope*	Sediment, kg/ha			PO_4-P			Sediment, kg/ha			PO_4-P		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
	Park and Recreation--SC+ = 0.01						Pasture--SC = 0.03					
BMA	18	23	17	0.02	0.03	0.02	25	54	21	0.02	0.05	0.02
BMB	44	64	26	0.04	0.07	0.03	102	178	47	0.10	0.17	0.05
BMC	120	186	82	0.12	0.10	0.07	330	543	216	0.33	0.54	0.22
HMA	30	52	26	0.04	0.08	0.03	60	142	48	0.09	0.21	0.07
HMB	94	160	46	0.14	0.24	0.06	252	466	107	0.36	0.68	0.16
HMC	275	477	174	0.41	0.72	0.25	795	1,420	492	1.19	2.12	0.73
OUA	55	64	30	0.09	0.13	0.05	134	206	60	0.23	0.37	0.11
OUB	172	235	55	0.30	0.42	0.09	487	690	135	0.87	1.22	0.24
OUC	501	692	217	0.80	1.25	0.38	1,470	2,060	620	2.65	3.71	1.11
OUD	1,290	1,770	599	2.31	3.19	1.07	3,830	5,300	1,770	6.89	9.53	3.18
ASA	61	115	31	0.17	0.35	0.08	152	330	62	0.47	1.03	0.19
ASB	184	340	57	0.55	1.05	0.15	522	1,000	140	1.60	3.11	0.43
ASC	532	1,010	225	1.63	3.11	0.68	1,560	3,000	645	4.85	9.30	1.99
	Woodland--SC = 0.005						Wetland--SC = 0.03					
BMA	<1	<1	<1	<0.001	<0.001	<0.001	26	45	4	0.03	0.05	<0.001
BMB	1.5	1.0	<1	0.0015	0.001	<0.001	97	144	12	0.10	0.14	0.01
BMC	14	35	9.4	0.014	0.035	0.010	**	**	**	**	**	**
HMA	<1	<1	<1	<0.001	<0.001	<0.001	69	124	11	0.10	0.19	0.02
HMB	3.3	2.2	<1	0.005	0.003	<0.001	256	395	34	0.38	0.59	0.05
HMC	28	80	19	0.041	0.012	0.027	**	**	**	**	**	**
OUA	<1	<1	<1	<0.001	<0.001	<0.001	119	248	19	0.21	0.45	0.03
OUB	8.3	6.2	<1	0.015	0.011	<0.001	441	655	58	0.79	1.18	0.11
OUC	85	150	32	0.153	0.270	0.059	**	**	**	**	**	**
OUD	1,400	1,300	2,850	2.52	2.34	0.52	**	**	**	**	**	**
ASA	<1	2.9	<1	<0.001	0.009	<0.001	140	350	25	0.43	1.09	0.08
ASB	7.1	32	2.1	0.022	0.098	0.007	519	1,090	80	1.61	3.37	0.25
ASC	94	334	50	0.28	1.35	0.16	**	**	**	**	**	**
	Row Crops--SC = 1.0 or 0.08						Developing Urban--SC = 1.0					
BMA	<10	<10	<10	<0.01	<0.01	<0.01	830	1,800	700	0.83	1.80	0.70
BMB	303	16	<10	0.30	0.02	<0.01	3,400	5,900	1,600	3.40	5.90	1.60
BMC	2,800	560	150	2.8	0.56	0.15	11,000	18,100	7,200	11.0	18.1	7.20
HMA	<10	<10	<10	<0.01	<0.01	<0.01	2,000	4,700	1,600	3.00	7.05	2.40
HMB	655	36	<10	0.98	0.05	<0.01	8,400	15,500	3,600	12.6	23.3	5.40
HMC	5,500	1,280	296	8.25	1.92	0.44	26,500	47,200	16,400	39.7	71.0	24.6
OUA	<10	10	<10	<0.01	0.02	<0.01	4,500	6,900	2,000	8.10	12.4	3.60
OUB	1,665	100	<10	3.00	0.18	<0.01	16,200	23,000	4,500	29.2	41.4	8.10
OUC	17,000	2,400	518	30.6	4.31	0.94	49,100	68,700	20,700	88.4	123	37.3
OUD	280,000	20,900	4,565	505	37.5	8.28	128,000	177,000	59,000	229		106
ASA	<10	46	<10	<0.01	0.14	<0.01	5,100	11,000	2,100	15.8	34.1	6.51
ASB	1,420	505	34	4.39	1.56	0.11	17,400	33,500	4,700	54.0	104	14.6
ASC	18,700	5,340	800	57.9	16.9	2.50	52,200	100,000	21,500	161	310	66.7
	Feedlots--SC = 1.0											
BMA	936	1,490	452	1.82	2.97	0.90						
BMB	2,450	3,240	1,360	5.89	6.48	2.71						
BMC	7,200	8,750	5,430	14.4	17.4	10.9						
HMA	2,440	3,600	1,130	7.33	10.8	3.39						
HMB	6,390	7,860	3,395	19.2	23.6	10.2						
HMC	18,800	21,200	13,600	56.4	63.8	40.7						
OUA	8,200	18,200	3,000	29.5	65.5	10.8						
OUB	21,000	39,600	9,000	75.6	142	32.4						
OUC	61,400	107,000	36,000	221	385	129						
OUD	142,000	245,000	100,000	511	882	360						
ASA	3,380	8,700	1,380	21.0	52.1	8.53						
ASB	8,840	18,900	4,130	54.8	117	25.6						
ASC	26,000	51,200	16,500	161	317	102						

*BM is Boyer ls, HM is Hochheim l, OU is Ozaukee sil, and AS is Ashkum sicl; A is 0 to 2%, B is 2 to 6%, C is 6 to 12% and D is 12 to 20% slope.
**Not applicable.
+SC is the cropping factor used in USLE.

Table 19. Average parameter loadings (potential erodibility at source) for the land use categories designated in the Menomonee River Watershed

Land use category	Area*, ha	Loading, kg/ha/yr Sediment	Total P	Lead
Industrial	638	5,450	4.46	7.38
Commercial	2,104	3,500	3.15	13.2
High density residential	604	3,800	3.04	5.66
Medium density residential	9,110	1,950	3.02	2.54
Low density residential	247	610	1.03	0.47
Land under development	1,073	43,700	78.7	0
Row crops	4,806	1,780	3.19	0
Pastures and small grains	5,253	1,310	2.33	0
Park and recreation**	4,509	460	0.81	0
Forested lands and woodlots	1,969	15	0.03	0
Wetlands	1,069	1,150	2.08	0
Feedlots	32	69,600	250	0

*Total area of watershed reckoned at 70th St. monitoring station (413005) is 32,305 ha; landfills and dumps, water and freeway areas comprised of 106, 142 and 542 ha, respectively.

**Park and recreation included in land use category pastures and small grains is segregated.

shown in Table 20 and include estimated amount and percent contribution of each land use to the total loadings at the river mouth.

The highest unit area loadings for suspended solids and total phosphorus were for feedlot operations. Only developing urban land areas approached the same order of magnitude of loadings. It should be pointed out that developing urban areas represent only 3.3% of the total land area of the Watershed but contribute about 47 and 51%, respectively, of the suspended solids and total phosphorus at the river mouth. Examination of Table 20 clearly shows that feedlot operations do not significantly contribute to the total river mouth loadings for suspended sediment and total phosphorus. Thus, when considering the relative degree of hazard, unit area loading and percent loading at the river mouth for each of these pollutants, care must be taken in interpreting the significance of any given land use.

However, the issue is more straightforward when considering lead. The unit area loading for lead was highest in commercial areas. About 50% of the total river mouth loading of lead originated from commercial areas. Thus, the commercial land use category has the highest degree of hazard, the highest unit loading and by far the greatest contribution to the total river mouth loadings. The commercial land use category (including transportation) accounts for about 7% of the total area of the Menomonee River Watershed.

The relative degrees of hazard (impact on water quality) for the land use categories are interpreted on the basis of a logarithmic scale. Using suspended sediment as an example, the loading at the river mouth for wetlands (115 kg/ha/yr) is about 100 times greater than that for forested land and woodlots (1.5 kg/ha/yr) and is assigned a hazard degree ranking of 3.

The delivery ratios used in the analysis are not precise values but only represent rough estimates because they are based on comparison of the monitoring data for a limited time frame with simulated loadings based on long-term averages. However, this information could have important consequences for the development of management strategies since a reduction of about 50% in suspended solids and total phosphorus might be achieved by treatment of about 3% of the land area. Similarly, about 50% reduction in lead reaching the river mouth might be achieved by treatment of 7% of the land area. Thus, in the development of remedial measures, decisions must be made on the relative importance of land use and different parameters as they impact lake quality and use. Therefore, it should be possible to define the minimum area in a watershed to be controlled in order to achieve a predetermined reduction in loading.

Simulation of loadings in 48 subwatersheds

LANDRUN was used to predict runoff and sediment loadings from 48 subwatersheds of diverse land uses and physical characteristics. Results from the simulation should help demonstrate what land features, land uses or land activities contribute to high pollutant lodings and eventually identify critical source areas of nonpoint pollution within the Watershed.

Table 20. Relative degree of hazard and parameter loadings at river mouth for suspended sediment, total phosphorus and lead for various land use catgories in th Menomonee River Watershed utilizing unit load values at the 70th St. (413005) monitoring station

Land use category	Unit loads* at river mouth, kg/ha/yr	Loading at river mouth kg/yr/land use	Loading at river mouth % Land use	Land use area, %	Relative degree of hazard
		Suspended sediment			
Forested land and woodlot	1.5	2,950	0.03	6.1	1
Park and recreation	46	207,400	2.1	14.0	2
Low density residential	61	15,000	0.15	0.8	2
Wetlands	115	122,900	1.2	3.3	3
Pastures and small grains	131	688,100	7.0	16.3	3
Row crops	178	855,500	8.6	15.0	3
Medium density residential	195	1,776,500	18.0	28.3	3
Commercial	350	736,400	7.4	6.5	3.5
High density residential	380	229,500	2.3	1.9	3.5
Industrial	545	347,700	3.5	2.0	3.5
Land under development	4,370	4,689,000	47.4	3.3	5.5
Feedlots	6,960	222,700	2.3	0.1	
		9,893,650		97.6**	
		Total Phosphorus			
Forested land and woodlot	0.003	6	0.04	6.1	1
Park and recreation	0.081	365	2.2	14.0	2
Low density residential	0.103	3	0.02	0.8	2.5
Wetlands	0.208	222	1.3	3.3	2.5
Pastures and small grains	0.233	1,224	7.4	16.3	2.5
Medium density residential	0.302	2,751	16.7	28.3	2.8
High density residential	0.304	184	1.1	1.9	2.8
Commercial	0.315	663	4.0	6.5	2.8
Row Crops	0.319	1,533	9.3	15.0	2.8
Industrial	0.446	284	1.7	2.0	3
Land under development	7.87	8,444	51.2	3.3	4
Feedlots	25.0	800	4.9	0.1	5
		16,479		97.6**	
		Lead			
Forested land and woodlot	0	0	0	6.1	0
Park and recreation	0	0	0	14.1	0
Pastures and small grains	0	0	0	16.3	0
Wetlands	0	0	0	3.3	0
Row crops	0	0	0	15.0	0
Feedlots	0	0	0	0.1	0
Land under development	0	0	0	3.3	0
Low density residential	0.047	12	0.20	0.8	1
Medium density residential	0.254	2,314	39.1	28.3	2
High density residential	0.566	342	5.8	1.9	2
Industrial	0.738	471	8.0	2.0	2
Commercial	1.32	2,777	46.9	6.5	2.5
		5,916		97.6**	

*10% delivery ratio was assumed from potential transportable pollutants shown in Table 19.
**Landfill and dump, water and freeway areas comprise 2.4% of area of basin.

To perform LANDRUN simulations for the 48 subwatersheds, three types of data are needed: a. land use and associated characteristics in each subwatershed; b. meteorological information within or near the Watershed; c. dust and dirt data. The model required subwatersheds to be divided into uniform areas based on land use and soil characteristics. A land use within a subwatershed with two different hydrologic soil groups was considered as two sub-areas. Summation of values for sub-areas and land uses constituted the loading for a particular subwatershed.

Sediment loadings were simulated during the summer of 1977. Loading estimates reflect potential sediment generation at the source. Critical source areas were identified by estimating a delivery ratio for each land use in each subwatershed based on the extent of connected imperviousness, physical characteristics and proximity to the stream of that land use. Sediment data were adjusted accordingly, accounting for the delivery ratios. The range of values are shown in Fig. 9. Nine subwatersheds located in the urbanized southern portion of the Watershed contribute significant amounts of sediment. These high source areas constitute 16% of the total area but contributed almost 50% of the total sediment loadings. The high sediment yields from these subwatersheds can be ascribed mainly to developing areas and--to a cetain degree--to medium density residential areas. Developing areas were present in almost all of the subwatersheds. However, high amounts of sediments were transported from developing areas in the critical subwatersheds essentially because of their short distances to the stream and extensive connected imperviousness. Although high amounts of sediment can be potentially eroded in other subwatersheds--particularly those in the rural portion of the Watershed--delivery of sediment to the stream could be impeded as a result of low connected imperviousness and/or greater distance to the stream. Medium density residential areas, the predominant land use in the critical subwatersheds, were significant sources of sediment loadings. Due to extensive impervious surfaces in these areas, dust and dirt washoff was prevalent.

Integration of the loadings from various land uses for the entire Watershed indicates that developing areas occupying 3% of the total area (Table 21) contribute over 50% of the total sediment loadings. Contribution from medium density residential areas--which is the largest land use in the Watershed--amounted to 23%.

Simulated sediment loadings compared reasonably well with those monitored at the mainstem stations (Fig. 10). The close agreement between the simulated and monitored data indicates the validity of the delivery ratios used for each land use and the integrity of the sediment estimates for each subwatershed.

It has been shown that the model is a useful tool in identifying critical nonpoint source areas of sediment in the Menomonee River Watershed. Results indicate that developing areas in ubanizing subwatersheds are the most cost-effective to manage. The method is applicable to other watersheds. However, the difficulty of simulating sediment loadings on pervious areas requires some recalibration and reverification of the model in other watersheds using monitored data. The

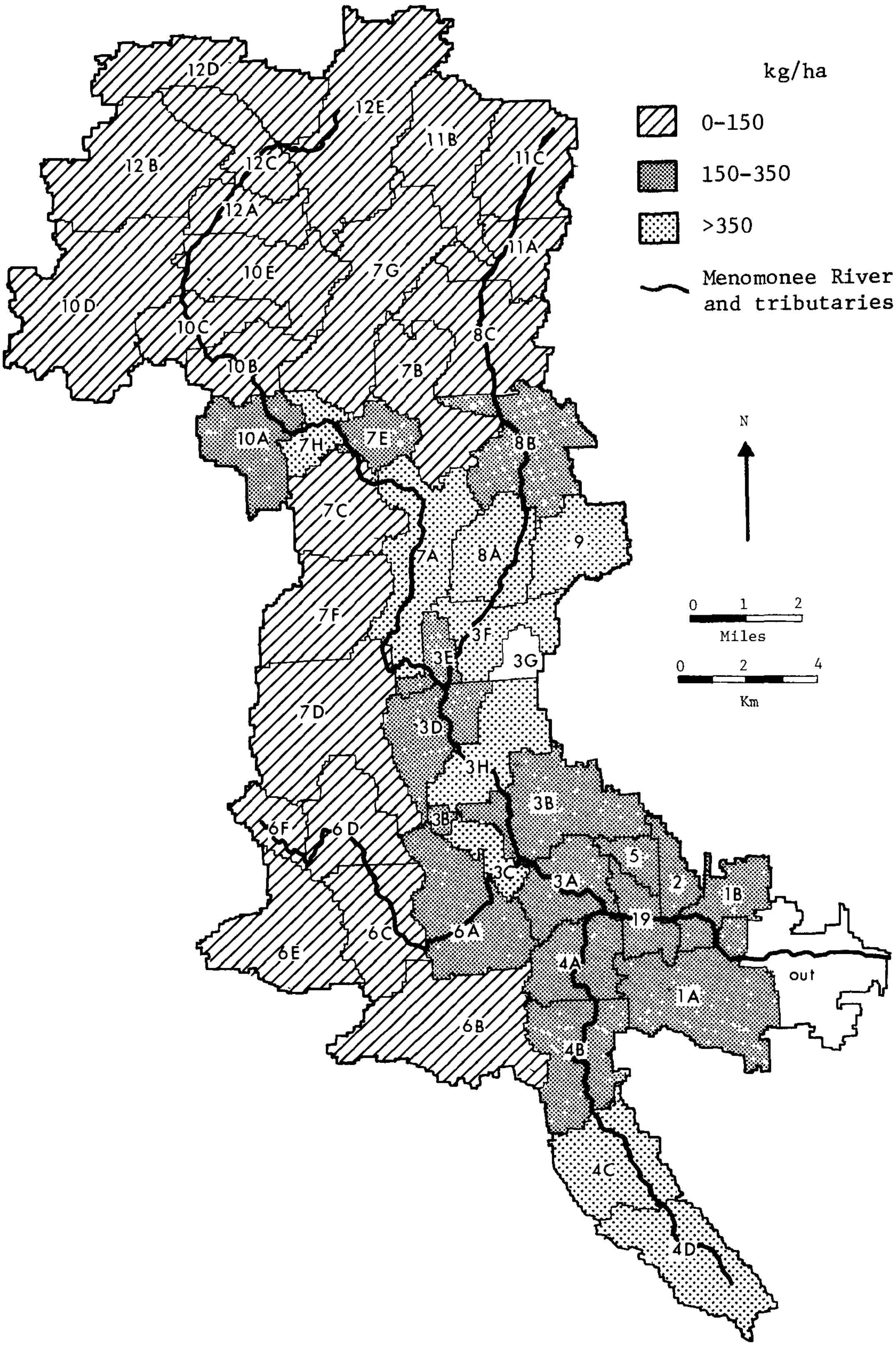

Figure 9. Distribution of simulated sediment loadings in the Menomonee River Watershed--summer 1977.

Table 21. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in the Menomonee River Watershed (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	108658. 2.3%	998707. 7.6%	1107365. 6.2%	5449. .1%	117205. 7.8%	122654. 2.2%	189. .8%	449. 6.4%	638. 2.0%
COMMERCIAL	530245. 11.4%	3023765. 23.1%	3554010. 20.1%	50976. 1.3%	350339. 23.4%	401315. 7.3%	770. 3.1%	1334. 19.0%	2104. 6.5%
MED/DENS/RES	1318740. 28.4%	5813647. 44.5%	7132387. 40.2%	592661. 14.8%	662801. 44.3%	1255462. 22.8%	6039. 24.0%	3071. 43.8%	9110. 28.3%
LO/DENS/RES	32057. .7%	4453. .0%	36510. .2%	3841. .1%	475. .0%	4316. .1%	220. .9%	27. .4%	247. .8%
HI/DENS/RES	139462. 3.0%	972818. 7.4%	1112280. 6.3%	30810. .8%	110318. 7.4%	141128. 2.6%	245. 1.0%	359. 5.1%	604. 1.9%
DEVELOPING	1087328. 23.4%	258787. 2.0%	1346115. 7.6%	2802398. 69.8%	28106. 1.9%	2830504. 51.4%	801. 3.2%	272. 3.9%	1073. 3.3%
ROW CROPS	77469. 1.7%	0. .0%	77469. .4%	316601. 7.9%	0. .0%	316601. 5.7%	4806. 19.1%	0. .0%	4806. 14.9%
PK/REC/PASTR	1093929. 23.5%	677001. 5.2%	1770930. 10.0%	178430. 4.4%	78421. 5.2%	256851. 4.7%	8949. 35.5%	813. 11.6%	9762. 30.3%
FORESTS	49089. 1.1%	0. .0%	49089. .3%	4903. .1%	0. .0%	4903. .1%	1969. 7.8%	0. .0%	1969. 6.1%
WETLANDS	170156. 3.7%	0. .0%	170156. 1.0%	6695. .2%	0. .0%	6695. .1%	1069. 4.2%	0. .0%	1069. 3.3%
FEEDLOTS	16278. .4%	0. .0%	16278. .1%	19268. .5%	0. .0%	19268. .3%	32. .1%	0. .0%	32. .1%
LANDFILL	26359. .6%	0. .0%	26359. .1%	1004. .0%	0. .0%	1004. .0%	106. .4%	0. .0%	106. .3%
WATER	0. .0%	655984. 5.0%	655984. 3.7%	0. .0%	72644. 4.9%	72644. 1.3%	0. .0%	142. 2.0%	142. .4%
FREEWAYS	0. .0%	670673. 5.1%	670673. 3.8%	0. .0%	77354. 5.2%	77354. 1.4%	0. .0%	542. 7.7%	542. 1.7%
TOTALS	4649770. 100.0%	13075835. 100.0%	17725605. 100.0%	4013036. 100.0%	1497663. 100.0%	5510699. 100.0%	25196. 100.0%	7009. 100.0%	32205. 100.0%

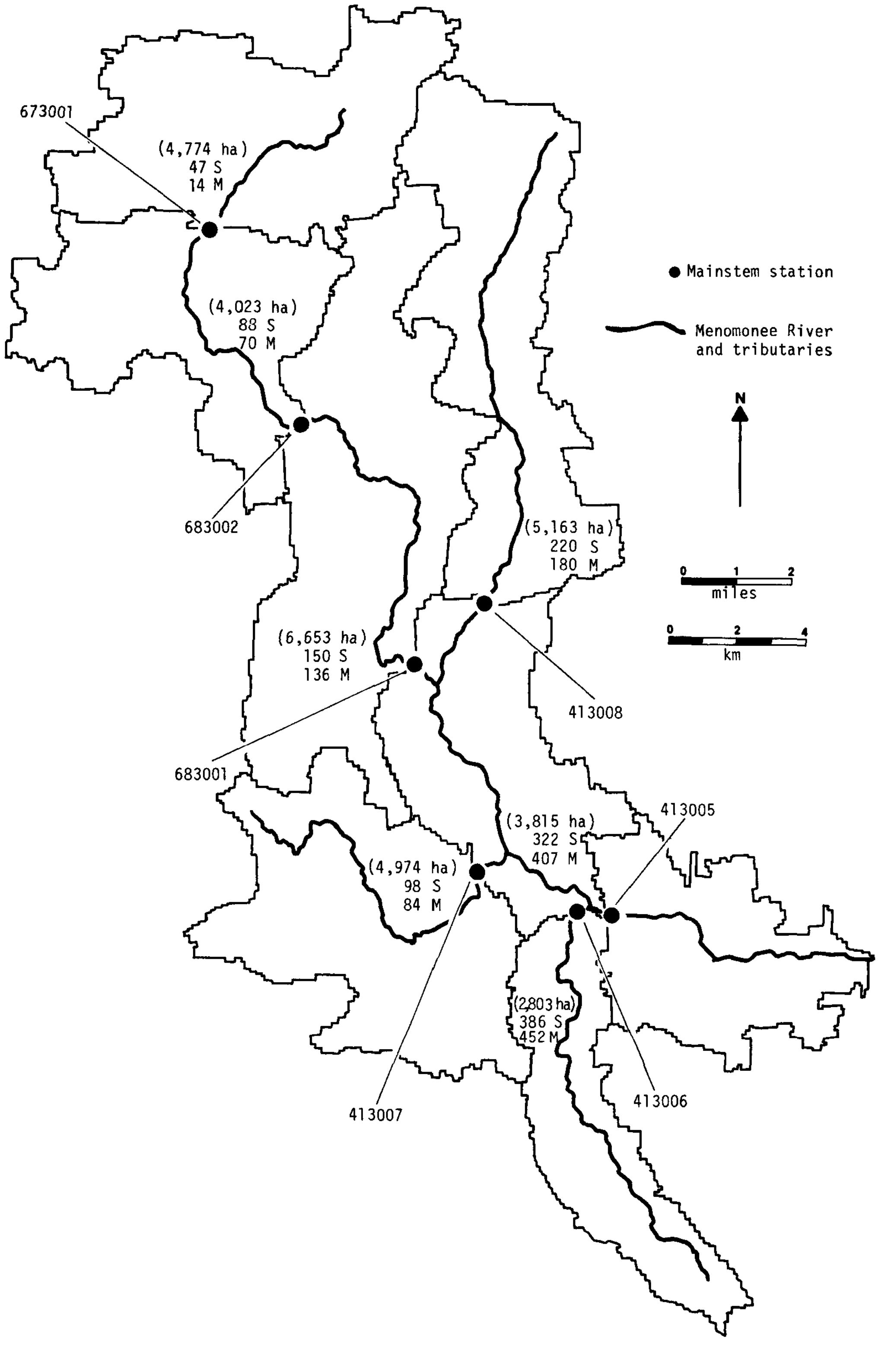

Fig. 10. Simulated (S) and monitored (M) sediment loadings (kg/ha) from area adjacent to mainstem monitoring stations--summer, 1977 (monitored data taken from Bannerman, R., J. G. Konrad, D. Becker and G. V. Simsiman. Surface Water Monitoring Data. Part II: Quality of Runoff from Mixed Land Uses. Final Report of the Menomonee River Pilot Watershed Study, Vol. 3, U.S. Environmental Protection Agency, 1979).

delivery ratio must be considered for precise assessment of critical land uses.

Empirical Modeling of Runoff Quality

A simple empirical model was developed for calculating the time distribution of suspended solid loads in a runoff event. The initial step in developing the model was to determine what independent variables control water quality in surface runoff. Instantaneous concentrations of suspended solids were found to be related to discharge per unit drainage area, rainfall intensity, antecedent dry period and stage of urban develoment. Similar processes could be carried out in other water quality parameters. A set of empirical curves developed from observations on small watersheds within the Menomonee and Milwaukee Rivers watersheds yielded regression coefficient for the independent variables (Fig. 11). Data in Fig. 11 can be used to create a multiple regression equation for a small watershed for which degree of urbanization is known, allowing suspended solids concentrations for any percentage of urbanization to be calculated (Table 22). These concentrations can then be combined with discharges predicted by some standard means to provide loading.

After calibration, the model was tested in watersheds from a variety of climatic, geologic and topographic regions (Table 23). For storms within the calibration limits of the model, it predicted loads with reasonable accuracy. Certain limitations of the model are: a. It must be used on watersheds larger than those used for calibration (< 28 km^2) without introducing substantial error; b. the model is valid only for the range of rainfall intensities and totals for which it is calibrated; c. the effect of active construction is not accounted for in the model.

Two conclusions can be drawn from the apparent flexibility of this statistical model. First, the regression coefficients developed for small watersheds in the Menomonee and Milwaukee River Watersheds are valid for a wide range of conditions. Local calibrations should be made to refine the coefficients for local conditions. Secondly, it can be inferred that rainfall conditions (intensity and duration of antecedent dry conditions), amount of runoff and degree of urbanization are much more important in determining suspended solids in urban areas than are local conditions such as topography, geology and vegetation. If this were not the case, the regression information transferred from one area to another would bear no relationship with reality. The principal value of this model is the ease with which it can be calibrated on urban areas with data that are easily obtained.

Location coding: BD - Brown Deer; BV - Beaver; DB - Donges Bay; HO - Honey;
NO - Noyes; SC - Schoonmaker; T - Trinity

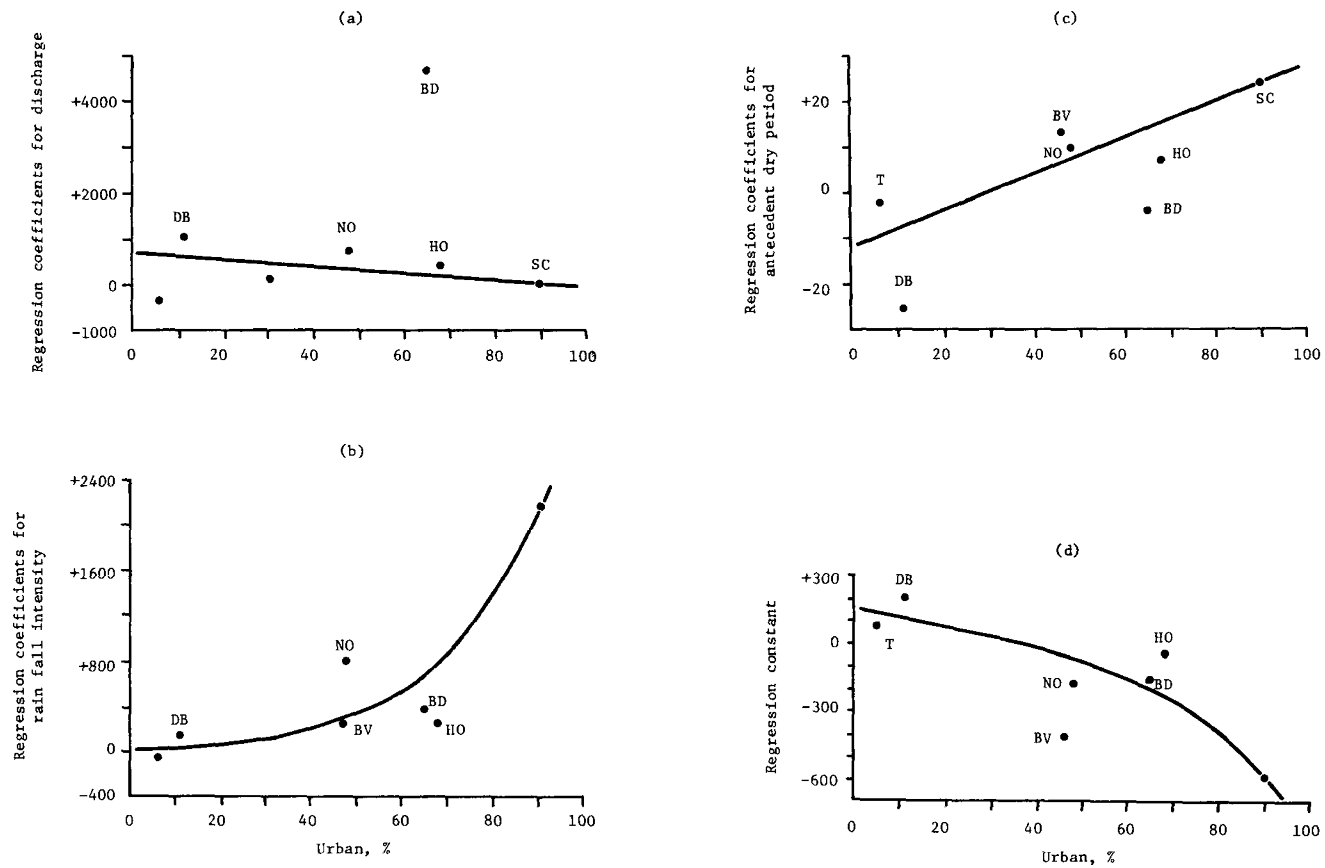

Figure 11. Regression coefficients for model for total suspended solids.

Table 22. Coefficients for final regression equations for various degrees of urbanization

Watershed urbanized, %	Coefficient for QA, $m^3/sec/km^2$ (a)	Coefficient for I, cm/hr (b)	Coefficient for A, days (c)	Regression contant (d)
0	+700	0	-12	+160
20	+550	+80	-3.5	+80
40	+400	+200	-4.5	0
60	+250	+520	+12.5	-120
80	+100	+1420	+21	-400
100	-50	+3000	+29	-820

*SS = a(QA) + b(I) + c(A) + d, where SS is suspended solids concentration (mg/L), QA is discharge/unit drainage area ($m^3/sec/km^2$), I is rainfall intensity (cm/hr), A is antecedent dry period (days).

Table 23. Comparisons of predictive capabilities of model for suspended solid loads

Date or event no.	Drainage basin: Area, km^2	Drainage basin: Urban, %	Rainfall: Amount, cm	Rainfall: Intensity, cm/hr	Rainfall: Antecedent dry period, days	Loads: Observed, kg/km^2	Loads: Predicted, kg/km^2	Loads: Difference, %	Comments
					Brown Deer, Milwaukee, Wisconsin				
6/8/77	7.5	65	1.3	0.25	3	2,900	2,290	-21	Meets all conditions of calibration
					Underwood, Milwaukee, Wisconsin				
4/23/76	49.7	54	5.4	0.30	1	2,100	850	-60	In calibration watershed but too large
					Third Fork, Durham, North Carolina				
27*	4.3	80	3.8	1.14	11	46,200	27,400	-41	Outside calibration area
29*			6.0	0.86	5	14,300	19,300	+35	
32*			2.0	0.48	2.5	3,800	3,500	+8	
					Bloody Run, Cincinnati, Ohio				
9/25/70	9.6	77	1.7	0.73	1	3,220	5,280	+64	Outside calibration area
10/20/70			2.3	0.45	6	2,800	5,000	+79	
					Baker Street, San Francisco, California				
11/5/69	0.73	100	1.6	0.33	19	1,130	6,765	+500	Outside calibration area
11/5/69			1.6	0.33	1**	1,130	1,730	+53	

*Taken from Colston (Colston, N. V., Jr. Characterization and Treatment of Urban Land Runoff. U.S. Environmental Protection Agency Report No. EPA 670/2-74-096, 1974).
**Antecedent dry period of 1 day was substituted for the 19 days.

6. DISPERSIBILITY OF SOILS AND ELEMENTAL COMPOSITION OF SOILS AND SEDIMENTS

The importance of particle-size fractions in evaluating pollutant carrying capacity of sediments was investigated. Elemental composition (Al, Cd, Cr, Cu, Fe, Mn, Mi, P, Pb and Zn) in the sand-, silt- and clay-sized fractions of major soil types, bottom sediments, suspended sediments and urban street dust and dirt were analyzed. Ultrasound was used to determine particle-size distribution because it leaves dispersed particles with their associated pollutants unchanged. Sediments and dust and dirt samples with elemental composition greater than the levels found in the major soil types of the watershed were suspected of receiving additional inputs of pollutants from sources other than soils.

The Cd, Pb and Zn concentrations in some bottom- and suspended-sediment samples were found to be higher than in soils. Concentrations of these elements were correlated significantly with each other in the clay-sized fraction of sediments but not in soils. This indicates that soils were not the primary source of these metals, but that other sources--i.e., vehicular emission and atmospheric fallout--were major inputs.

Locations of pollutant input to the Menomonee River can be identified by comparing elemental composition of the clay-sized fractions of bottom sediments collected at different locations. Total elemental composition of unfractionated bottom sediment samples did not identify the location of pollutant input as precisely.

In an agricultural land use area, bottom sediment samples with P levels greater than the soil level but without a corresponding increase in metal composition were found. In the urban area, P, as well as Cd, Cr, Cu, Ni, Pb and Zn levels, increased at a sediment sampling site located below the outfall of a sanitary treatment plant (STP) with secondary treatment capability. Clay fractions of bottom sediments from sites located below the outfall of STPs with tertiary treatment capability showed lower levels of P as well as metals than those found at the sampling site located below an STP with secondary treatment capability. Apparently, the waste water treatment for the removal of P also removed metals from the effluent.

The average P, Pb and Cd concentrations in suspended sediment samples of the Monomonee River collected during storm events were: 1,840)g/g P, 350)g/g Pb and 1.9)g/g Cd in the clay-sized fractions; 780)g/g P, 180)g/g Pb and 0.48)g/g Cd in the silt-sized fractions; and was calculated to contain 1,620)g/g P, 290)g/g Pb and 1.4)g/g Cd in the unfractionated sample. The average annual storm event loadings from suspended sediments in the Menomonee River to Lake Michigan was calculated to be 16,200 kg/yr P, 3,000 kg/yr Pb and 15 kg/yr Cd with about 90% of the P, Pb and Cd in the clay-sized fraction.

The Al, Fe and Mn concentrations in the clay-sized fraction of urban street dust and dirt samples were found to be lower than in the major mineral soil types of the watershed, while Cd, Cr, Cu, Ni, Pb and Zn levels were higher. Distribution of elements into the particle-size fractions fell into two main groups. One group had 78 to 87% of the metals in the sand fraction (Cr, Cu, Fe, Mn and Ni) and the other had 41 to 58% in the sand fraction (Al, Cd, P and Pb) while Zn was intermediate between these two groups (70% in the sand fraction).

The Cr, Cu, Fe and Ni concentrations in the coarse particles of the dust and dirt samples occasionally nearly equaled concentrations in fine particles (sand vs. silt and silt vs. clay-sized particles). Similarly, Ni concentrations in the silt-sized fractions of suspended sediments occasionally nearly equaled the concentration in the clay-sized fraction. This may result from their presence in large particles such as metal chips from abrasion of vehicular parts or from disintegration of impervious surfaces.

Soil dispersibility--a contributing factor to soil erosion and sediment loading to waterways--was evaluated for the major soil types of the Menomonee River Watershed. Soil samples were dispersed by shaking with water to simulate natural water erosion conditions and by ultrasound to provide complete dispersion. The shaking treatment consisted of agitating a 1:10 w:v soil:water mixture for 0.5 to 128 hr. The ratio of the amount of clay-sized particles disloged by shaking to the amount obtained by ultrasound treatment measured the dispersibility of soils (Table 24). The organic carbon content (0.5 to 44%) was best correlated with the soil dispersion ratio in a negative inverse relationship. If the 4-hr shaking treatment simulates the onset of soil erosion conditions in the field, as much as 90% of the primary clay-sized particles remain in silt-sized or larger aggregates during the overland transport. Thus, retaining aggregates containing a high amount of clay-sized particles can control the amount of clay reaching the waterways.

Resuspension of bottom sediments as simulated by end-over-end shaking (1 to 128 hr) desorbed about 0.06% Pb and 0.7% Cd of the total in the solid phase. Under extreme agitation, as simulated by 15 min of ultrasound treatment, the desorption was 1.5% Pb and 2.0% Cd of the total in the solid phase. Thus, resuspension of bottom sediments to the overlying water possibly permits desorption of elements from the solid surfaces.

Table 24. Dispersion ratio of the clay-sized fraction (shaking/ultrasonic)

Time of shaking, hr	Soils*								
	Ozaukee sil	Ozaukee subsoil	Mequon sil	Mequon subsoil	Hochheim sil	Ashkum sicl	Pella sil	Theresa sil	Houghton muck
0.5	0.06	0.15	0.03	0.15	0.07	0.05	0.06	0.08	
1	0.10	0.22	0.05	0.21	0.07	0.07	0.08	0.13	
4	0.19	0.35	0.10	0.33	0.16	0.11	0.13	0.19	0.03
16	0.26	0.59	0.15	0.57	0.24	0.18	0.19	0.26	0.05
32	0.32	0.65	0.27	0.62	0.30	0.24	0.24	0.29	0.10
64	0.40	0.82	0.39	0.76	0.40	0.29	0.28	0.38	0.15
128	0.37	0.81	0.41	0.73	0.48	0.35	0.33	0.43	0.22

*Organic carbon contents of soils are: Ozaukee sil - 1.8%, Ozaukee subsoil - 0.50%, Mequon sil - 4.5%, Mequon subsoil - 0.49%, Hochheim - 2.5%, Ashkum sicl - 5.7%, Pella sil - 3.4%, Theresa sil - 1.2% and Houghton muck - 44.2%.

Blanks indicate no data.

7. AVAILABILITY OF POLLUTANTS ASSOCIATED WITH RIVER SEDIMENTS

Suspended sediment samples from five Great Lakes tributaries were collected and analyzed for pollutant availability of phosphorus, nitrogen and trace metals. Each suspended sediment sample was composited from several subsamples collected over an event. Several events were collected throughout the year, with the majority of samples collected during spring runoff. Sampling stations were located near the river mouths, but above large urban areas to minimize the point source impact.

The suspended sediment samples were separated into size fractions of < 0.2, 0.2 to 2, 2 to 20, and > 20 µm. These fractions correspond to the dissolved, clay, silt and sand sizes, respectively. The mean concentrations of suspended sediment samples were representative of the respective tributaries. Even though total suspended sediment concentrations varied over a wide range, the particle size distribution was fairly uniform for a given tributary. The suspended sediment samples provided an adequate sample set for an evaluation of the availability of phosphorus, nitrogen and trace metals associated with suspended sediment.

In addition, bottom sediment dredge samples were collected from the Menomonee, Genesee and Nemadji Rivers. They were also split into clay, silt and sand fractions and were likewise analyzed for pollutant availability.

Availability of Phosphorus in Suspended Sediments and Recessional Shoreline Soils

Characteristic differences exist in the availability of inorganic P in suspended sediments among the tributaries to the Great Lakes. Available P (NaOH-P), expressed as a percent of total P, averaged 14% for the Nemadji, 19% for the Genesee and about 35% for the Maumee, Menomonee, and Grand Rivers (Table 25). Coefficients of variation ranged from 5 to 35%. Availability is relatively uniform among the clay, silt and sand particle size fractions. Consequently, the available P loading for each tributary can be estimated as the product of availability (NaOH-P expressed as fraction of total P) and the total P loading of the tributary.

Available P, measured as NaOH-P, corresponds to non-apatite inorganic P and represents the maximum amount of inorganic P expected to be made available through release of inorganic P to solution (desorption). Desorption could occur within a period of a few hours. Conversion of other forms to available P requires mineralization of organic P or weathering of apatite P. These processes occur at slow rates and are considered unimportant following deposition of suspended sediments on the lake bottom. Available P, measured as resin-P, represents inorganic P released

Table 25. Percentage of phosphorus in suspended sediments in available and non-available fractions*

Tributary	n**	P as % of sediment total P			Coefficeint of variation, %		
		Resin-P	NaOH-P	HCl-P	Resin-P	NaOH-P	HCl-P
Genessee	14	9	19	34	60	37	33
Grand	4	16	37	16	48	5	29
Maumee	4	17	34	20	34	14	16
Menomonee	6	16	37	27	30	12	39
Nemadji	11	7	14	49	34	37	20

*NaOH-P + HCl-P = total inorganic P; resin-P is a part of the P in the NaOH-P fraction.
**Number of samples.

to solution more readily than the total NaOH-P. Resin-P is released at solution inorganic P concentrations of about 1 μg/L, while complete release of NaOH-P requires lower solution concentrations. Consequently, resin-P may be a better estimate than NaOH-P of the amount of P typically released in the Great Lakes. Resin-P represents 40 to 50% of the NaOH-P fraction.

While availability is relatively uniform for the different particle size fractions, particle size can be an important factor in availability through controlling the residence time of sediment in the water column. Relatively rapid settling might limit the availability of the sand (> 20 μm) fraction. Conversely, the clay (0.2 to 2 μm) fraction might remain permanently suspended and be subject to long-term processes which increase the availability of particle P. For a suspended sediment containing equal amounts of clay, silt and sand and 35% available P (% of total P), complete availability of inorganic P in the clay fraction would result in an available P level corresponding to 57% rather than 35% of the sediment total P.

In addition to availability (available P as a fraction of total P), suspended sediment concentration and sediment total P concentration are major factors controlling particulate available P concentrations in tributary waters. Furthermore, tributary discharge rate is a major factor in the loading of available P from the tributary.

Depending on the tributary, available P (NaOH-P) in suspended sediments represents about 25 to 75% of the total available P loading (Table 26). For the U.S. portion of the Great Lakes Basin, available P in suspended sediments is estimated to represent about 50% of the available P loading and about 25% of the total P loading.

The availability of inorganic P in the recessional shoreline samples investigated was low (< 3% of total P). If these samples are representative, the contribution of shoreline erosion to available P loadings to the Great Lakes is relatively low.

Availability of Nitrogen in Suspended and Bottom Sediments

The available nitrogen, consisting of the inorganic nitrogen (except fixed ammonium) and a portion of the hydrolyzable organic nitrogen, ranged from 52 to 73% (mean values) of the total nitrogen in the suspended sediments (Table 27). The highest and lowest percentage of available nitrogen occurred in the Maumee and Nemadji sediments, respectively. An intermediate percentage (mean of 65 to 67%) of available nitrogen occurred in the Genesee, Grand and Menomonee sediments. High proportions (mean of 16 to 21%) of the available nitrogen consisted of available inorganic nitrogen in the Grand, Maumee and Menomonee sediments. Conversely, the percentage of inorganic nitrogen was lower (mean of 5 to 10%) in the Genesee and Nemadji sediments.

Mean concentrations of available nitrogen were 8.3, 4.1, 3.7, 2.0 and 1.6 mg/g in the Grand, Maumee, Menomonee, Nemadji and Genesee sediments,

Table 26. Comparison of dissolved and particulate available P loadings in tributaries

Tributary	Discharge*	Suspended sediment*	Available particulate inorganic P**: Concentration in sediment	Available particulate inorganic P**: Concentration on volume basis	Available particulate inorganic P**: Of total particulate P	Available P from diffuse sources***: Annual loading		Available P from diffuse sources***: Distribution: Dissolved	Available P from diffuse sources***: Distribution: Particulate
	m^3/sec	mg/L	μg/g	μg/L	%	Tonnes	%++	%	%
Genesee+	78	259	110	28	19	97	23	23	77
Grand	114	19	825	16	37	202	58	57	43
Maumee	141	283	469	132	34	1034	46	40	60
Menomonee	2.7	138+++	460	64	37	15	52	40	60
Nemadji	11	312	114	36	14	52	41	77†	23

*Mean "historical" values (Sonzogni, W. C., T. J. Monteith, W. N. Bach and V. C. Hughes. United States Great Lakes Tributary Loadings. PLUARG Tech. Report to Task D, Ann Arbor, Michigan, 1978, 187 pp.).

**NaOH-P; measured in this investigation; concentration on a volume basis was calculated from the measured concentration in sediment and the mean "historical" suspended sediment concentration.

***Calculated from the dissolved and total particulate P loadings for 1975 (Sonzogni et al. 1978) and the mean available P level (NaOH-P as % of total particulate P) found for each tributary in this investigation (see column 5 above). Dissolved P is considered to be completely available.

+Avon station samples only.

++Expressed as % of the total P loading.

+++Mean value during sampling intervals in this investigation.

†Based on unit area loading (Sonzogni et al. 1978).

Table 27. Comparison of dissolved and particulate available N loadings

		Available particulate N*			Available N from diffuse sources**			
	Suspended			Total	Annual		Distribution	
Discharge***	sediment***	Concentration		particulate N	loading		Dissolved	Particulate
m^3/sec	mg/L	mg/L	mg/g	%	Tonnes	%†	%	%
				GENESEE††				
78	259	0.42	1.62	67	3,836	82	69	31
				MENOMONEE				
2.7	138	0.50	3.65	65	177	90	78	22
				MAUMEE				
141	283	1.16	4.10	73	44,175	96	91	9
				GRAND				
114	19	0.16	8.28	66	6,468	81	66	34
				NEMADJI				
11	312	0.62	2.00	52	222	66	55	45

*Includes particulate NO_2 + NO_3 + NH_4 + amino acid N + hexosamine N measured in this investigation. Concentration (Volume) was calculated from the observed nitrogen concentration (wt) in the sediment and the mean historical suspended sediment concentration.

**Genesee, Grand and Maumee values are calculated from the dissolved and particulate diffuse N loadings for 1975, reported by Sonzogni et al. (1978, see Table 26) and the mean available N distribution (available N as % of the total particulate N) found for each tributary in this investigation (see column 6). Menomonee and Nemadji values based on unit area loadings (Sonzogni et al. 1978). The amount of dissolved organic N is considered relatively insignificant.

***Mean historical values from Sonzogni et al. (1978), except Menomonee River values which are from Bannerman, R., J. Konrad and D. Becker. Effect of Menomonee River Inputs on Lake Michigan During Peak Flow. Wisconsin Dept. of Natural Resources, Madison, Wis. 1977.

†Expressed as a % of the diffuse total N.

††Avon station only.

respectively. Those rivers containing high available nitrogen concentrations (mg/g) also had high concentrations (mg/L) of dissolved inorganic nitrogen and a large portion of the total sediment nitrogen occurred as available inorganic nitrogen. The concentration of all forms of nitrogen usually increased during low flow events. This resulted from an increased proportion of fine particulates and an increased nitrogen concentration in the fine particulates. The Nemadji and Genesee Rivers contained low concentrations (mg/g) of all forms of nitrogen. This was related to the forested character of the Nemadji Watershed and the high proportion of nitrogen-poor sand in the Genesee sediment.

The annual available nitrogen loading from different sources was calculated using historical values for suspended sediment concentrations, discharge and dissolved nitrogen and the measured concentrations of particulate available nitrogen. The annual loads were 180, 220, 3,800, 6,500 and 44,200 metric tons for the Menomonee, Nemadji, Genesee, Grand and Maumee Rivers (Table 27). These values represent 66 to 96% of the total nitrogen load. The annual average nitrogen loadings were influenced most strongly by discharge rate and concentration of dissolved inorganic nitrogen. The dissolved inorganic nitrogen contributed 55 to 91% of the annual available N load. The low loadings in the Menomonee and Nemadji reflected the low discharge and moderate concentration (mg/L) of particulate available nitrogen. The Genesee and Grand Rivers had intermediate available nitrogen loads. This resulted from high discharge even though the particulate available nitrogen concentration (mg/L) was relatively low. The Maumee River exhibited the highest annual loading which was due to a high discharge rate and a high particulate and dissolved available nitrogen concentration (mg/L).

Availability of the Trace Metals, Copper, Lead and Zinc in Suspended and Bottom Sediments

The availability of Cu, Pb and Zn in sediments was estimated as the fraction extracted by a hydroxylamine hydrochloride (HH-metal) or a chelating cation exchange resin (resin-metal). The HH-metal is considered the best estimate of the available fraction of the total trace metals in the sediment. Available metal (HH-metal) concentrations in suspended sediments generally represents an average of 25 to 45% of the total metal (Table 28). Availability may be higher in sediments influenced by local sources of metals. For example, mean available metal levels ranged from 46 to 76% of the total metal for Cu, Pb and Zn in the Menomonee River samples. Other exceptions may also occur, such as Pb in the Genesee which averaged 60% of the sediment total Pb.

Differences in availability among the different particle size fractions may exist, but were not significant in the samples investigated. The resin-metal fraction generally represents a smaller fraction than the HH-metal of the total metal concentration. However, a consistent relationship between HH-metal and resin-metal was not found.

Table 28. Mean concentrations of total and available Cu, Pb and Zn in tributary suspended sediments*

Tributary	Total metal		HH-Metal	Resin-metal
	µg/L	µg/g	---------- %	----------
		Copper		
Genesee	27	61	41	25
Menomonee	25	146	46	37
Maumee	11	66	26	25
Grand	3	80	—	—
Nemadji	10	45	24	15
		Lead		
Genesee	23	51	60	71
Menomonee	87	628	76	16
Maumee	17	97	37	7**
Grand	5	140	—	—
Nemadji	7	32	24	5
		Zinc		
Genesee	67	150	25	8
Menomonee	65	471	56	19
Maumee	48	279	22	12
Grand	9	265	—	—
Nemadji	32	150	25	10

*Calculated from the mean concentrations in the three particle size fractions and the average size distribution and concentrations of the suspended sediments.
**Based on one sample.

8. GROUNDWATER

Field Data Quantifying Groundwater-Surface Water Interaction

The research was a comprehensive study of the quantity and quality of groundwater discharged into the Menomonee River System, southeastern Wisconsin utilizing 38 observational wells. The Menomonee River Watershed comprises three aquifer systems: the deep artesian sandstone, the Niagara dolomite and the glacial aquifers. Groundwater discharge into the river system is supplied mainly by the shallow glacial aquifer, with only a minor component of discharge supplied by the dolomite aquifer. During the 1-year study, groundwater accounted for 45 to 65% of the non-event flow in the Menomonee River. Discharges from sewage treatment plants and of industrial wastewaters supplied the remainder of the non-event flow.

Groundwater discharge into the Menomonee River System was calculated in two ways. The first method involved the subtraction of all major wastewater discharge from stream discharges during non-event periods. The second method used Darcy's Law.

Surface water discharges were obtained from the U.S. Geological Survey (USGS). Wastewater discharge rates were obtained from the WDNR and the Municipalities of Germantown, Menomonee Falls and Butler. The subtraction of wastewater discharges from non-event surface flow allowed an estimation of true base flow, or the groundwater input into the river. This technique is the most accurate way to estimate the groundwater component of stream flow. Stage-discharge relationships for some reaches of the Menomonee River System have been developed for over 10 years and non-event discharges are measured accurately. A summary of groundwater calculations using the two methods is presented in Table 29.

Estimation of the groundwater component of stream flow using Darcy's Law is less accurate because of the general lack of homogeneity of the aquifer and the relatively short time period for which the groundwater-surface water relationships were investigated. While the technique is less quantitative it provides a better understanding of the groundwater flow paths and relationships between land use and quality of groundwater discharge into the river system.

It is speculated that urbanization has significantly changed the hydrochemistry of the glacial aquifer as compared to the regional average for eastern Wisconsin. Chloride and sulfate are the dominant ions in solution, while carbonates dominate the regional water quality. Dissolved solids increased as much as 100%, with chloride and sulfate increasing by as

Table 29. Summary of calculations of groundwater discharge to the Menomonee River System (m^3/d)

	Fall 1976		Winter 1976/77		Spring 1977	Summer 1977	
	A	B	A	B	A	A	B
Total	23,360	25,040	15,650	16,580	53,600	40,300	39,380
Average	24,000		16,200		53,600	39,840	

A is use of groundwater data.
B is use of surface water data.

much as 900 and 200%, respectively, over regional averages. It was estimated that groundwater accounts for 51 to 82% of the total chloride concentration found in the base flow of the Menomonee River.

Inorganic nitrogen was found in concentrations of < 1 mg/L of N. Relatively high concentrations of nitrate generally were found in the agricultural portions of the Watershed while ammonia was found in the urbanized portion. Groundwater was estimated to supply 12 to 24% of the base flow loadings of inorganic nitrogen while the remainder was discharged from sewage treatment plants. Phosphate was found in low concentrations in the groundwater.

Heavy pumpage of the Niagara dolomite and glacial aquifers from wells near the Menomonee River has caused certain reaches of the river to lose water to the shallow aquifer (Fig. 12). Approximately 2,840 m^3/d (0.75 mgd) of stream flow is lost to the groundwater system. Bacterial analyses of the groundwater in these areas indicated severe fecal contamination. Dye tracer studies showed that some--if not all--bacteria in the groundwater may be derived from leaky sewer lines.

Although metals and other toxic chemicals were not found in significant concentrations in the groundwater, the change in hydrochemistry from carbonate to chloride/sulfate-dominated waters indicates a deterioration in groundwater quality. Chloride found in the shallow groundwater system is probably produced from road salt runoff. Sulfate may arise from oxidation of industrially produced sulfides or from landfills bordering stream channels. To date, few base line data have been compiled for urban watersheds and the data suggest the need for additional investigations.

Potential Impacts from Land Use Activities

This portion of the Menomonee River Pilot Watershed Study was directed toward obtaining data which are useful in identifying those areas of the Watershed where land use activities could have an impact on groundwater which discharges to the river system.

Basic data were obtained from SEWRPC, WDNR, USGS, the Wisconsin Public Service Commission (WPCS), the U.S. Soil Conservation Service (SCS), private trade associations, municipal governments and a variety of other sources. Overlay map techniques were employed as an intepretive tool in many cases. Seventeen contaminant potential maps represent the principal final product of this analysis.

Final evaluations, as presented on the maps, fall into two major categories: Consideration of the overall input from an areally distributed land use (i.e., concentrations of septic tanks or croplands); or from distinct use sites (i.e., salt storage or solid waste disposal areas). In the former case, ranking the potential for contaminants to be released from an area through soils interpretations appeared to be the most logical approach in preliminary evaluation. The current lack of information on groundwater flow in the separate subwatersheds made it impossible to go

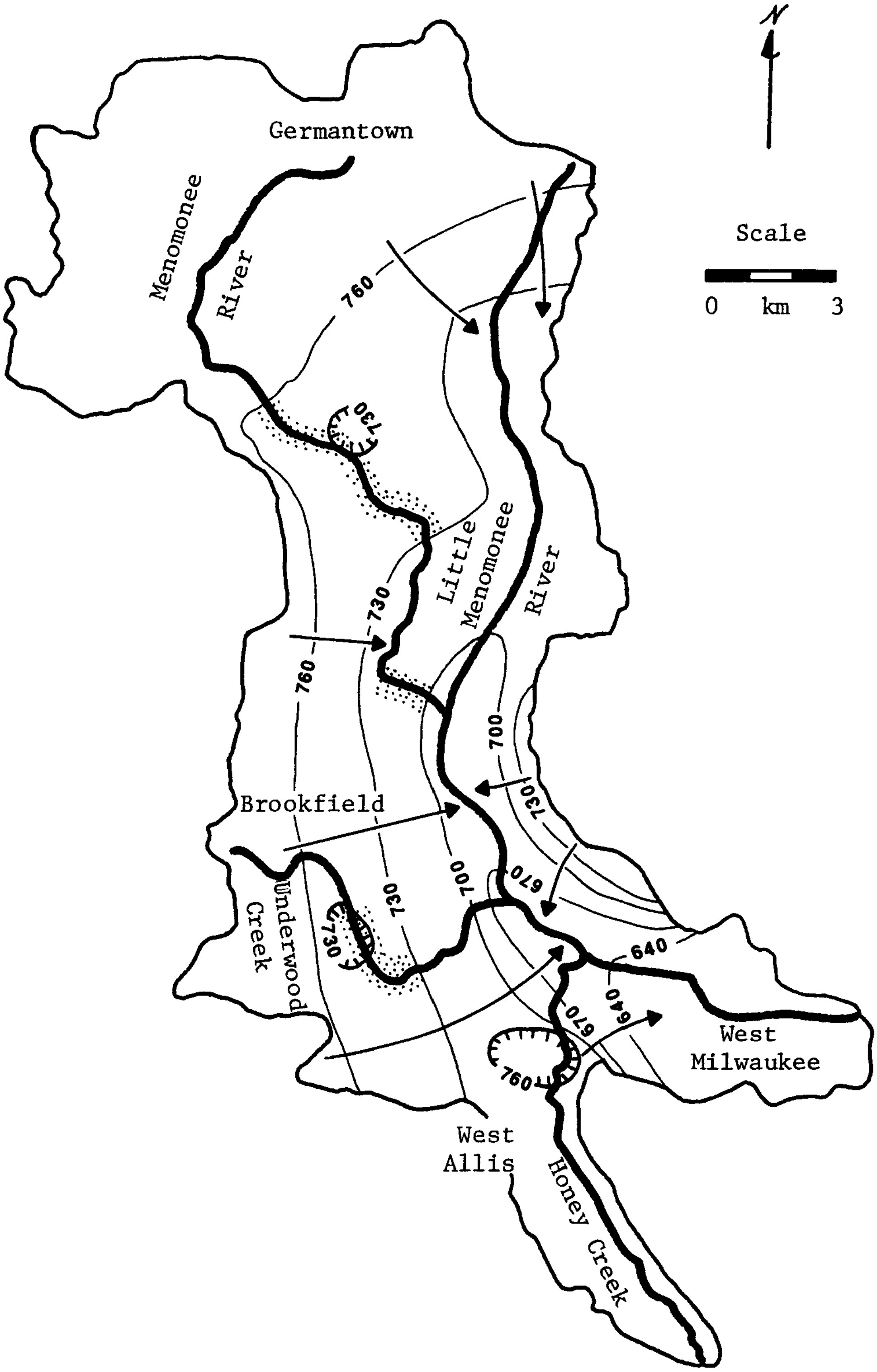

Fig. 12. Watertable of glacial aquifer - Fall 1976. Shaded areas represent losing reaches of Menomonee River System.

beyond this first step. Assessing the contaminant potential from site-specific uses necessitates comparing the relative probabilities for pollutants to be released from those areas and transmitted to surface waters. This involved an intepretive evaluation of the operational history of the site, its position within the geologic framework and in-field, reconnaissance analysis.

Perhaps the most significant influence on groundwater quality is the weathering of geologic materials. However, certain quality trends can be related to the presence of specific land use categories in the watershed. The application of road salts is believed to be the cause of major, widespread modification of groundwater quality. Land uses causing more subtle changes include fertilizer and pesticide applications on cropland, regional septic tank use, sewerline leakage and solid waste disposal practices. It should be stressed that the analyses in this study represent a qualitative evaluation of land use and geologic settings rather than the outcome of comprehensive monitoring. The assessments are directed at understanding the role of contaminant transfer to surface waters by subsurface flow. A summary of what is believed to constitute the relative significance of various sources is included in Table 30.

Continued research in the Watershed is warranted. From a groundwater perspective, several different approaches can be taken. Three examples are:

a. Continue the thrust of the IJC goals having accelerated programs of in-field groundwater monitoring carried out at various land use sites.

b. Groundwater monitoring could be conducted as part of an overall program to control a specific pollutant problem in the river system.

c. Consideration of many land uses as to their local impacts on groundwater rather than, as was done in this program, on the eventual impact to surface waters.

Although the various kinds of land use activities which can contribute to groundwater contamination have been identified for the Menomonee River Watershed, the relative importance of these activities may be considerably different in other watersheds undergoing development. The study proposes a typical sequence of steps which might be useful in evaluating sources of contamination in other watersheds.

Groundwater Modeling and Extrapolation to Other Watersheds

Groundwater-surface water interactions in the Menomonee River Watershed were examined and potential sources of contamination which contribute pollutant loads to the Menomonee River System through groundwater discharge were identified. The third goal of the IJC project was to develop the predictive capability necessary to facilitate extension of the findings from the Menomonee River Watershed Study to other urban settings. The purpose of the third phase of the groundwater subproject was to identify and test a

Table 30. Groundwater contributions to surface water quality for the Menomonee River Basin: potential impacts from land use activities

Rank	Use or other category	Assessment	Probable significance			Areal impact		Principal pollutants							
			Major	Inter.	Minor	Local	Regional	Cl	SO_4	Metals	Nitrogen	PO_4	Harmful bacteria	Hazardous organics	Hydrocarbons
1	Weathering of geologic materials	Impact assured	X				X	X	X						
2	Road runoff	"	X				X	X	X	X	X	X	X	X	X
3	Fertilizer and pesticide applications on croplands	Impact inter- preted		X			X				X	X		X	
4	Septic tanks	"		X			X	X			X	X			
5	Sewer line leakage	"		X		X	X	X			X	X	X		
6	Solid waste disposal areas	"		X	X	X		X	X	X	X			X	
7	Barnyards	"			X		X	X			X				
8	Salt storage areas	"			X	X		X							
9	Industrial wastewater disposal	"			X	X		X	X						X
10	Sewage sludge spreading	"			X	X		X		X	X	X			
11	Air pollutant fallout	"			X		X	X	X						
?	Metal storage areas	Impact unknown			X	X		X	X	X					X
?	Oil and gas facilities	"			X	X		X	X						X
?	Residential lawns	"		X	X		X				X	X		X	
?	Other users	"		?		?	?				?				

model to aid in the extrapolation process.

A groundwater quality model was identified to aid in the task of extrapolating the findings of the IJC-Menomonee River Pilot Watershed Study to other watersheds in the Great Lakes Basin. The model was applied to the Menomonee River Watershed and calibrated using field data obtained from the groundwater monitoring activities summarized earlier. For modeling purposes the Watershed was divided into eight areas with similar land use and hydrogeology (see Fig. 13). Because chloride from road salt runoff was determined to be the major contaminant transported to the river in groundwater, the response of the aquifer to application of road salt was simulated in each of the modeling areas. A summary is presented in Table 31.

In 1977-78, the low density residential urban area on the west side of the river contributed the most chlorides to the river. This area also had the highest groundwater discharge rate, although chloride concentrations in groundwater were not especially high. The results of the model suggest that in most areas of the Watershed, average chloride concentrations will increase for several years if application of road salt remains at least as high as during 1968, the year for which chloride loading rates were estimated for use in the model. In the future, loading rates from suburban areas could surpass the loading rate for low density residential urban land use. Because of the high percentage of paved surfaces in the heavy urban areas in the lower Watershed and the resulting low groundwater recharge rates, groundwater loading rates from these areas were relatively low.

In other watersheds, the nature and amount of contaminants transported to the river in groundwater will depend upon the types of distribution of land use and the hydrogeology, espcially the groundwater recharge rate. However, in most developed watersheds, it is expected that chlorides from road salt runoff will be a major source of contamination. In addition to groundwater discharging to streams entering the Great Lakes, direct discharge of groundwater to the lakes should be considered.

The model used during the present study can be used as a tool in estimating the average concentration of a contaminant in groundwater discharging to a stream. Groundwater loading rates may be calculated and probable changes in groundwater quality caused by changes in land use can be predicted. Ideally, a record of several years documenting groundwater quality changes is needed to calibrate and establish confidence in the model

In areas for which no groundwater quality data are available, the validity of the actual concentrations calculated by the model will depend upon the accuracy of the input parameters. It is recommended that where possible, an historical record be used to calibrate the model. When this is not possible, the model is best used to gain insight into the relative response of the system to land use changes or changes in management practices.

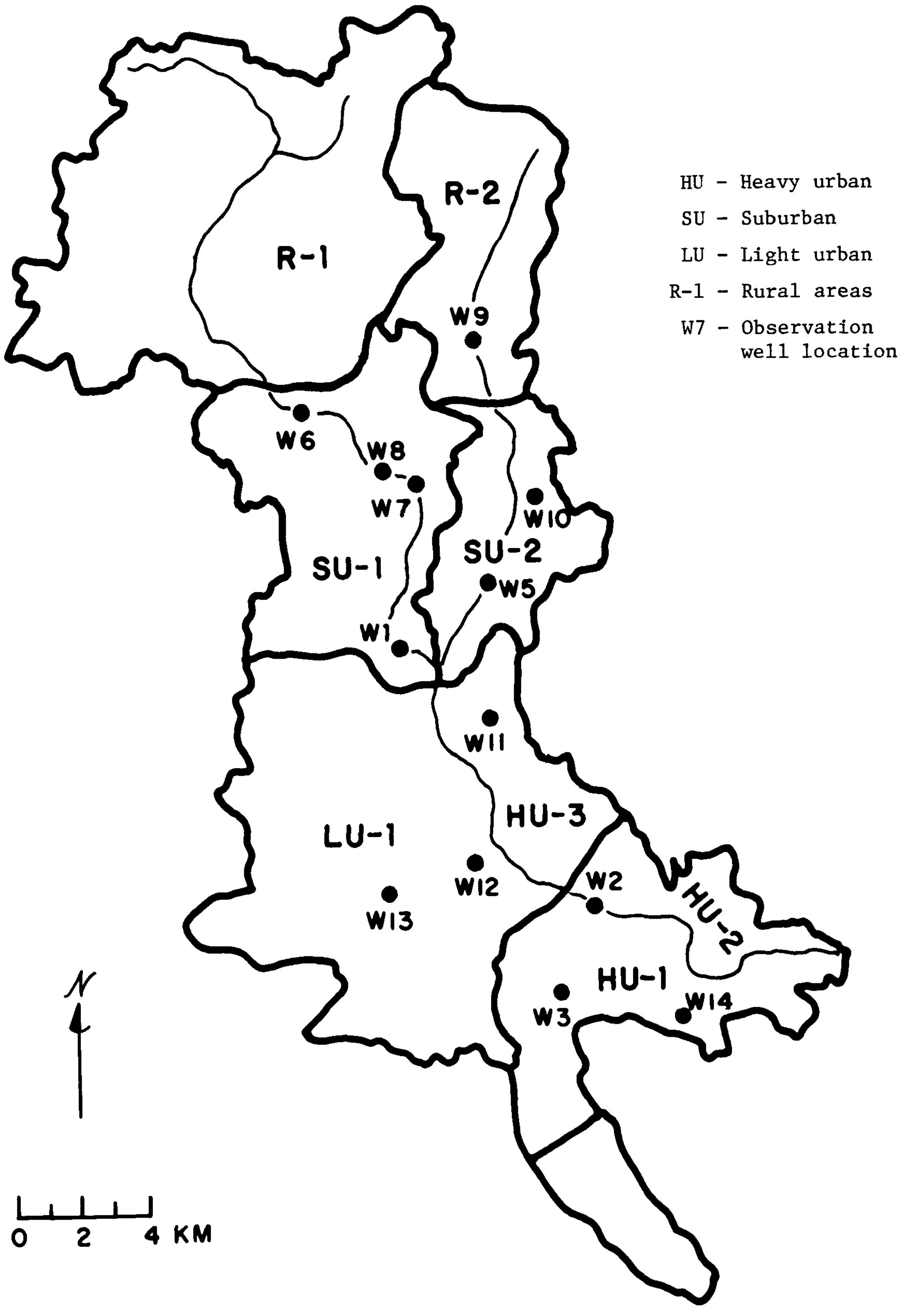

Figure 13. Modeling areas and observation well locations.

Table 31. Simulated chloride concentrations compared to field data*

Area	A Yearly average Cl concentrations at well sites near the river, mg/L	B Average for the area, mg/L	C Simulated Cl concentrations, mg/L
HU-1	Site: W2 West 235	167	187
HU-2	Site: W2 East 147	---	214
HU-3	---	---	205 150
LU-1	Site: W12 58	64	52
SU-1 West	Site: W1 W6 W7 39 106 121	89	64 88
SU-1 East	Site: W1 W6 W7 W8 270 113 115 20	130	90 125
SU-2	Site: W5 338	174	165
R-1	---	---	23
R-2	Site: W9 34	---	42

*Compare columns A and B with C.

9. ATMOSPHERIC CHEMISTRY

Lead and Phosphorus

Measurements of suspended particulate matter and several elements contained in those particles indicate that anthropogenic activities in the Menomonee River Watershed contribute significant amounts of material to the atmosphere. For most elements, however, atmospheric deposition to Lake Michigan or the Menomonee River is not as great as the amount discharged from terrestrial sources. Atmospheric deposition of lead to Lake Michigan is important. The amount of lead deposited directly in Lake Michigan during the study period is given in Table 32.

Much of the lead exhausted from within the Watershed probably remains there. This amounted to about 80 tonnes/yr at the time of the study. Although soils sequester lead efficiently, a large fraction of the lead deposited is on connected impervious surfaces (i.e., roadways). Hence, a significant portion of the exhausted lead may reach the Menomonee River, particularly in areas of high pavement density. Additionally, most of the atmospheric lead collected on the snow surface probably reaches the river during snowmelt.

Phosphorus concentrations in rain vary widely, from undetactable levels to well over 100 μg/L. A median value is in the range of 10 to 20 μg/L. Annual input of phosphorus to the Watershed by all forms of precipitation is at least 75 g/ha/yr.

Particulate phosphorus accounts for an average of 0.1% of the total suspended mass. The fraction is lowest in winter and highest in late summer. It is concluded that much of the phosphorus in air originates from continental dust.

Dry deposition of phosphorus is calculated to be 108 g/ha/yr. The sum of dry and wet deposition is somewhat lower than previous estimates.

A model utilizing multivariate regression analysis is used to predict major emission sources contributing to the suspended dust in the Menomonee River airshed. This source reconciliation model is sensitive to changes in ambient aerosol composition caused by inputs of various emission sources.

PCBs and PAHs

Measurements of atmospheric PCBs over Lake Michigan suggest that more than 70% of the amount entering the lake is deposited from the atmosphere. The processes that control the deposition of PCBs to the water surface are not well defined. Hence, several different models have been used to

Table 32. Dry deposition of atmospheric lead to Lake Michigan from Milwaukee, Wisconsin, November 1, 1976 to April 28, 1977

Portion of lake	Pb, Tonnes
Northern-two-thirds	54
Southern-one-third	69
Total	123

mathematically describe deposition. Table 33 includes previous estimates and the calculated rates of deposition from this study using gas and liquid phase control models.

The composition of the PCB mixture of aerosol samples collected over Lake Michigan contained a greater proportion of volatile isomers on suspended particles than samples collected in Milwaukee or Chicago. Theoretical calculations indicated that PCBs are associated with small particles (< 0.1 μm).

Many PAHs occur naturally. However, anthropogenic combustion processes have increased emission of PAH's including some potent carcinogens. Measurements of PAHs on suspended particulate matter collected over Lake Michigan were used to estimate deposition rates during rainfall and dry periods for 12 separate compounds (Tables 34 and 35). There was a high deposition level of benz[a]pyrene--a potent carcinogen--in the southern part of Lake Michigan.

Chemical reactions, including photooxidation which is intensified in the presence of sulfur oxides, are a major mode for removing PAHs from the atmosphere. This study investigated the importance of the re-emission of PAHs from the surface microlayer of Lake Michigan to the atmosphere by bubble ejection. This mechanism may re-introduce significant amounts of PAHs to the atmosphere during high wind conditions. Further calculations indicated that volatilization of PAHs from the water column is a relatively small flux compared to wet and dry deposition to the lake surface.

Table 33. Inputs of PCBs (kg/yr) to Lake Michigan

Sources	Prior to 1975		1977	
	LPC*	GPC*	LPC	GPC
Industrial discharges	25,000**	25,000**		
Atmopsheric	2,848	8,655	2,848	8,655
Streams and wastewater	750**	750**	700**	700**
TOTAL	28,598	34,405	3,548	9,355

*LPC and GPC are liquid and gas phase control, respectively.
**Estimates made by Murphy, T. J. and C. P. Rzeszutko. Polychlorinated Biphenyls in Precipitation in the Lake Michigan Basin. EPA Grant-803915. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Duluth, Minnesota, 1977.

Table 34. Dry flux of polycyclic aromatic hydrocarbons to Lake Michigan

Compound	Northern 2/3 of lake, kg/yr	Southern 1/3 of lake, kg/yr
Fluorene	72 to 1,150	160 to 2,500
Phenanthrene	36 to 580	90 to 1,400
Anthracene	24 to 380	90 to 1,400
Fluoranthene	48 to 770	140 to 2,200
2,3-Benzofluorene	36 to 580	230 to 3,600
Pyrene	24 to 380	170 to 2,800
Benz[a]anthracene	48 to 770	130 to 2,000
Perylene	24 to 380	210 to 3,300
Triphenylene	24 to 380	43 to 680
Benzo[a]pyrene	--	120 to 1,900
O-phenylenepyrene	--	110 to 1,100
Benz[ghi]perylene	--	280 to 4,400

Table 35. Wet flux of polycyclic aromatic hydrocarbons to Lake Michigan

Compound	Northern 2/3 of lake, kg/yr	Southern 1/3 of lake, kg/yr
Fluorene	110	240
Phenanthrene	57	130
Anthracene	37	130
Fluoranthene	73	200
2,3-Benzofluorene	57	350
Pyrene	37	260
Benz[a]anthracene	73	180
Perylene	37	310
Triphenylene	37	65
Benz[a]pyrene	--	180
O-phenylenepyrene	--	170
Benz[ghi]perylene	--	330

10. RECOMMENDATIONS

Urban storm water pollution poses a serious threat to the water quality of much of the Great Lakes. Any program to ameliorate water quality problems should be directed most intensively at those areas where the problems are most critical. Prerequisite to any remedial planning then is the identification of those pollutants which exert or will likely exert a significant impact on water quality and the identification of those areas within the Lakes which are or will be affected by these pollutants.

Based upon unit loadings and present in-lake water quality, large tracts of land in the Great Lakes basin will require little or no non-point source control unless major land use changes occur in the future. At first approximation, these likely include almost the entire Lake Superior basin, much of Lake Huron, and significant portions of Lake Michigan and Lake Ontario. However, near-shore localized water quality problems near major urban centers along each of the Great Lakes may require localized storm water pollution control.

Cost effective pollution control is generally greatest at those locations where or times when pollutants are most concentrated. These typically include, first and foremost, point source discharges, plus construction sites, heavy industrial sites, stack emissions, deicing salts, leaf drop, etc.... An assessment of the contribution of point sources, and the probable point source reductions to be achieved, will indicate the likely degree of non-point source reductions required. Where point source controls alone will not achieve the desired level of reduction, as is probably the case with sediment, phosphorus, lead and certain other toxins, non-point source controls will be required. These controls should be directed at critical land uses where pollutants are most concentrated and cost effective control is most feasible.

Critical land uses in urban areas include construction sites (sediment and its associated pollutants), transportation corridors (chlorides, lead and other heavy metals), and industrial areas (heavy metals and other toxins). Further, residential areas may contribute large amounts of phosphorus and other nutrients during periods of leaf or seed drop. Control of the above pollutants would be most readily achieved by controls on the above land uses.

A strong point must also be made concerning the close correlation between the amount of runoff from a given area and the associated pollutant loads. The pollutant load associated with urban storm water is closely tied to the amount of runoff from an area, which in turn is largely determined by the area's physical development. Developing and redeveloping areas should be designed to retain predevelopment drainage charactersitics. Such designs will minimize the amount of peak rates of runoff, the associated pollutant loads, downstream flooding and streambank erosion, and will maximize groundwater recharge. Further, not only can such construction occur at costs often comparable to conventional drainage design, it can also preclude or minimize possible subsequent costs associated with storm water pollution control.

The evaluation of storm water pollution must also be addressed in developing facility plans for upgrading combined sewered areas. Sewer separation could result in excessive levels of storm water pollutants being delivered to the Lakes. Sewer separation would also require extensive reconstruction of combined sewers, which in addition to the huge social costs, would generate large amounts of construction-related sediments. Lastly, it may then necessitate implementation of storm water pollution controls. Alternatively, storage and treatment of combined sewer overflows would allow for the removal of the majority of storm water pollutants before they enter the Lakes, would allow for the extensive use of an already existing transport system, would not necessitate extensive sewer reconstruction, and would preclude the need for future storm water pollution controls.

Essential to the successful implementation and acceptance of a storm water pollution control program is an effective information/education program. Such a program should be developed to promote a general awareness of urban storm water pollution and to educate target audiences concerning their role in reducing the same. It should be geared to many different audiences, i.e., adults, youth, engineers and urban planners, municipal governments, etc.

Lastly, there are significant gaps in our present understanding of various management alternatives for control of storm water pollution. The costs and effect of specific control strategies should be carefully evaluated. Only with such an information base can intelligent decisions regarding cost effective pollution control be advanced.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-905/4-79-020-A	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Menomonee River Pilot Watershed Study Volume I Summary and Recommendations		5. REPORT DATE December 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) John G. Konrad, G.V. Simsiman, Gordon Chesters		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wisconsin Department of Natural Resources P.O. Box 7921 Madison, Wisconsin		10. PROGRAM ELEMENT NO. 2BA645
		11. CONTRACT/GRANT NO. R005142
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Great Lakes National Program Office 536 South Clark St., Room 932 Chicago, Illinois 60605		13. TYPE OF REPORT AND PERIOD COVERED Final -May 1974-Dec.1979
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
University of Wisconsin-Water Resources Center and Southeastern Wisconsin Regional Planning Commission assisted

16. ABSTRACT
This project was in support of the U.S./Canada Great Lakes Water Quality Agreement. The objectives are discribed under the reference-Pollution from Land Use Activities Reference Group(PLUARG). This work was done under Task C of the work plan. Several special study areas within the Menomonee River Watershed were sampled, analyzed, and evaluated. The water quality was measured, both surface and groundwater. Air deposition was measured to see how the quality of atmoshperic inputs effected the water quality of the surface runoff.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Land use, Atmospheric deposition, Phosphorus, Groundwater, Sediment, Heavy metals, Runoff, Rainfall		

18. DISTRIBUTION STATEMENT Distribution to Public-Available through NTIS-Springfield, Virginia 22151	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE