QUANTITY AND QUALITY OF URBAN STORM RUNOFF IN THE IRONDEQUOIT CREEK BASIN NEAR ROCHESTER, NEW YORK

Part 2. Quality of Storm Runoff and Atmospheric Deposition, Rainfall-Runoff-Quality Modeling, and Potential of Wetlands for Sediment and Nutrient Retention

By William M. Kappel, Richard M. Yager, Phillip J. Zarriello

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
521 W. Seneca Street
Ithaca, New York 14850
(607) 272-8722

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CONVERSION FACTORS AND ABBREVIATIONS

For readers who prefer to use inch-pound units rather than metric (International System) units, the conversion factors for the units used in this report are listed as follows:

Multiply Metric Unit	By	To Obtain Inch-Pound Units
	Length	
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter per second (m/s)	3.281	foot per second (ft/s)
micrometer (mm)	0.00003937	inch
	Area	
square meter (m^2)	10.76	square foot (ft^2)
	1.196	square yard (yd^2)
	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	1.308	cubic yard (yd^3)
	0.0008107	acre-foot (acre-ft)
	264.2	gallon (gal)
liter (L)	1.0567	quart (qt)
	Flow	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
milligram (mg)	0.00003527	ounce (oz)
gram (g)	0.03529	ounce (oz)
	0.002205	pound (lb)
kilogram (kg)	2.205	pound (lb)
megagram (Mg)	1.102	ton (short)
metric ton per hectare (t/ha)	892.4	pound per acre (lb/acre)
	0.4461	short ton per acre
	Temperature	
degree Celsius (°C)	°F = (9/5 °C) +32°	degree Fahrenheit (°F)
	Concentration	
milligram per liter (mg/L)	1.0	parts per million (ppm) (approximately)

GLOSSARY

Channel conveyance A measure of the ability of a channel to transport flow; determined by the cross-sectional area of the channel, the hydraulic radius (wetted perimeter), and the roughness (Manning's n) of the channel.

DR_3M Distributed Rainfall-Runoff Routing Model, an urban hydrology computer model developed by the U.S. Geological Survey.

Effective impervious surface A surface that prevents the infiltration of water into the soil and is connected to a stormwater-conveyance system.

Noneffective impervious surface A surface that prevents the infiltration of water but drains to an adjacent area where infiltration occurs, such as a roof that drains to a lawn.

NURP National Urban Runoff Program, a study of urban stormwater hydrology funded by the U.S. Environmental Protection Agency.

NURP site A land-use site at which streamflow, precipitation, and water quality were measured continuously. Site characteristics (land-use practices, topography, and stormwater-conveyance systems) were also documented.

NURP subbasin A subbasin at which streamflow, precipitation, and water quality were measured continuously. Subbasin characteristics (land-use practices, topography, and stormwater-conveyance sytems) were also documented.

Partial-record site Generally headwater-monitoring sites where water-quality samples are collected manually and discharge is determined by direct measurement or from a rated staff gage; not a continuous monitoring station.

Land-use site An area of homogeneous land use smaller than 2.5 km^2 and instrumented for streamflow measurements and water-quality-data collection.

Load Amount of material or constituent in solution, suspension, or in transport; expressed as mass or volume.

Snowfall water equivalent The amount of water contained within a standard unit area of snow; the melted water of a snowpack.

Station Monitoring location at the outlet of a land-use site, partial-record site, or subbasin. General monitoring activities include streamflow-, water-quality-, and rainfall-data collection.

Station storm A storm during which a continuous record of streamflow is made and water samples collected continuously at a given site.

Subbasin An area of heterogeneous land use larger than 2.5 km^2 and instrumented for streamflow measurement and water-quality-data collection.

Yield A measurement of load or discharge per unit area.

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ABSTRACT

Water-quality data collected at 16 sites in urbanized and rural parts of the 438-square kilometer (km^2) Irondequoit Creek basin from July 1980 through August 1981 were used to compute annual loads of eight selected constituents--suspended sediment, total phosphorus, total kjeldahl nitrogen, chemical oxygen demand, dissolved chloride, and total lead, cadmium, and zinc. Of the total annual basin loads of these constituents, 50 to 75 percent was tranported to Irondequoit Bay during a 3.5-month period from late January through early May. The high loads during this period are attributed to constituent buildup in the snowpack and soil erosion and sediment transport during sustained high flows resulting from snowmelt and spring runoff. Of the six subbasins containing mixed land uses, the two most highly urbanized had the highest loads of all constituents. Of the four sites representing single land uses, a high-density residential site and a housing-construction site had the highest loads of all constituents.

The U.S. Geological Survey Distributed Rainfall-Runoff-Routing Model (DR_3M) was used to simulate 13 storms in three small subbasins--one commercial and two residential (all less than 1 km^2)--and in a large (78-km^2) mixed-land-use subbasin. Resulting predictions of storm-runoff volume and peak discharge for three small basins were within 10 to 30 percent of the measured values; predictions of storm-runoff loads of suspended solids, total phosphorus, total chloride, total kjeldahl nitrogen, lead, and cadmium were within 40 to 60 percent of the measured values. The accuracy of predicted runoff volume and peak discharge for the large mixed-land-use subbasin was similiar to that obtained for the small watersheds. Predicted loads of suspended sediment, total phosphorus, and total lead were within 40 to 60 percent of the measured values; the remaining constituents could not be as accurately predicted.

The Irondequoit Creek wetlands, just above the mouth of Irondequoit Creek, were evaluated as a potential settling area for stormwater runoff. The present flow pattern within the wetlands allows little dispersion of stormflow into the main body of the wetland. Stormflow modification by two different hypothetical control structures, at a natural constriction between the upper and lower wetland, was simulated. The increased ponding in the upper wetland unit would be sufficient to promote settling of suspended sediments and associated chemical constituents and thereby reduce their discharge to Irondequoit Bay.

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INTRODUCTION

The water quality of Irondequoit Bay and Irondequoit Creek near Rochester, N.Y. (fig. 1) has been documented for nearly 100 years. Kuichling (1889) noted

> ...the limited amount of partially clarifed sewage which now finds its way [to the Bay] has already produced an appreciable pollution of its waters and the atmosphere in the vicinity of the mouths of the stream into which some of the large sewers now empty.

The continued deterioration of the bay and creek is documented in Tressler and Austin (1940) and Tressler and others (1953), the New York State Department of Health (1964), and unpublished data of the Monroe County Health Department. The Rochester Committee for Scientific Information published more than 30 reports during 1964-82 on the chemical quality of Irondequoit Bay and its tributaries. These studies and reports have drawn community attention to Irondequoit Creek and the bay and emphasize the need to improve the water quality of the Irondequoit basin tributaries.

In response to this concern, Monroe County has invested millions of dollars since 1971 to prevent the discharge of sewage into Irondequoit Creek and the discharge of Rochester's combined sewers into the Irondequoit wetlands and Irondequoit Bay.

During the 1970's, the U.S. Geological Survey and the U.S. Environmental Protection Agency (USEPA) studied urban hydrology nationwide. Results of these studies indicated that storm runoff is a significant contributor of pollutants to receiving waters. In response, the USEPA began the Nationwide Urban Runoff Program (NURP) to define on a regional basis the sources, transport, and accumulation patterns of selected stormwater contaminants, and to document the available control methods and the effects of these contaminants on receiving waters and aquatic ecosystems.

In 1979, the USEPA entered into a cooperative agreement with the New York State Department of Environmental Conservation and Monroe County to establish the Irondequoit basin as one of 28 regional study areas. The Monroe County Department of Engineering administered the program locally for the Irondequoit Bay Pure Waters District. In 1979, the U.S. Geological Survey entered into a cooperative agreement with the county to study the quantity and quality of storm runoff in the Irondequoit basin. The U.S. Geological Survey collected the field data for this study in cooperation with the Monroe County Department of Health. Other agencies participating in the study were the Monroe County Environmental Health Laboratory, Monroe County Planning Department, O'Brien and Gere Consulting Engineers, and the University of Rochester.

The purpose of the U.S. Geological Survey study was to relate the chemical constituents of storm runoff from representative land-use areas to the chemical quality of Irondequoit Creek and its tributaries. The study also sought to (1) evaluate total annual loads of eight selected constituents transported to Irondequoit Bay, and (2) evaluate the potential of the Irondequoit wetlands as a settling area for removal of sediment and nutrients from stormwaters of Irondequoit Creek.

Purpose and Scope

This report, the second in a two-part series, describes (1) the chemical quality of precipitation and resulting storm runoff in catchment areas representing selected land uses, (2) the use of the distributed rainfall-runoff-routing model (DR_3M) in analyzing the water-quality data collected at the various catchment areas, (3) the results from the DR_3M model, and (4) the analysis of the physical characteristics of the upper Irondequoit Creek wetland and the proposed regulation of flow through this wetland as a means to improve the water quality of Irondequoit Creek.

The first report in this series (Zarriello and others, 1984) discusses data-collection techniques, the quality-assurance and quality-control programs, and the format of all flow, precipitation, and water-quality data contained in various computer files. The two reports summarize 2.5 years of data collection and analysis and serve as a basis for development of a water-quality-management plan for the Irondequoit Creek basin.

Previous Studies

A limnologic survey of Irondequoit Bay by Bannister and Bubeck (1978) summarizes results of water-quality and limnologic investigations in the bay and its contributing watershed. The U.S. Army Corps of Engineers (1975, 1981, 1982) reported on flow characteristics of Irondequoit Creek and its tributaries in relation to flood protection and prevention. The Rochester Committee for Scientific Information published more than 30 reports during 1964-82 that document the hydrology and water quality of Irondequoit Creek, its tributaries, and Irondequoit Bay. Reports by Fairchild (1935), Young (1980), and Waller and others (1982) describe the geology of the basin, and Dunn (1962) describes several time-of-travel studies in the basin. The companion to this report (Zarriello and others, 1984) describes the data-collection network and methods, the quality-assurance program, and the resulting data.

Acknowledgments

The Monroe County Environmental Health Laboratory maintained samplers, collected, split, and analyzed water samples, and verified the data used in the development of this report. Richard Burton, chief chemist of the laboratory, provided guidance, suggestions, and interpretations throughout the study. Margaret Peet and Richard Rising of the Monroe County Planning Department assisted in obtaining local demographic data and developing contacts with various governmental units and individuals throughout the basin and county. David Carleo of O'Brien and Gere, Consulting Engineers, provided information, data, and equipment throughout the project. Robert Gallucci, NURP Project Manager for the Monroe County Department of Engineering, provided administrative direction, and Robert Jonas, representing the Irondequoit Basin technical team provided local information throughout this study.

BASIN DESCRIPTION

The Irondequoit Creek basin encompasses a 438-km^2 area in Monroe, Ontario, and Wayne Counties in north-central New York (fig. 1). The basin lies along the east side of the City of Rochester and drains into Lake Ontario. The headwater areas of the basin are rural and agricultural; the central and northern parts are urbanized. Census figures for 1980 (Sherwood, 1981) indicate a population of 243,000.

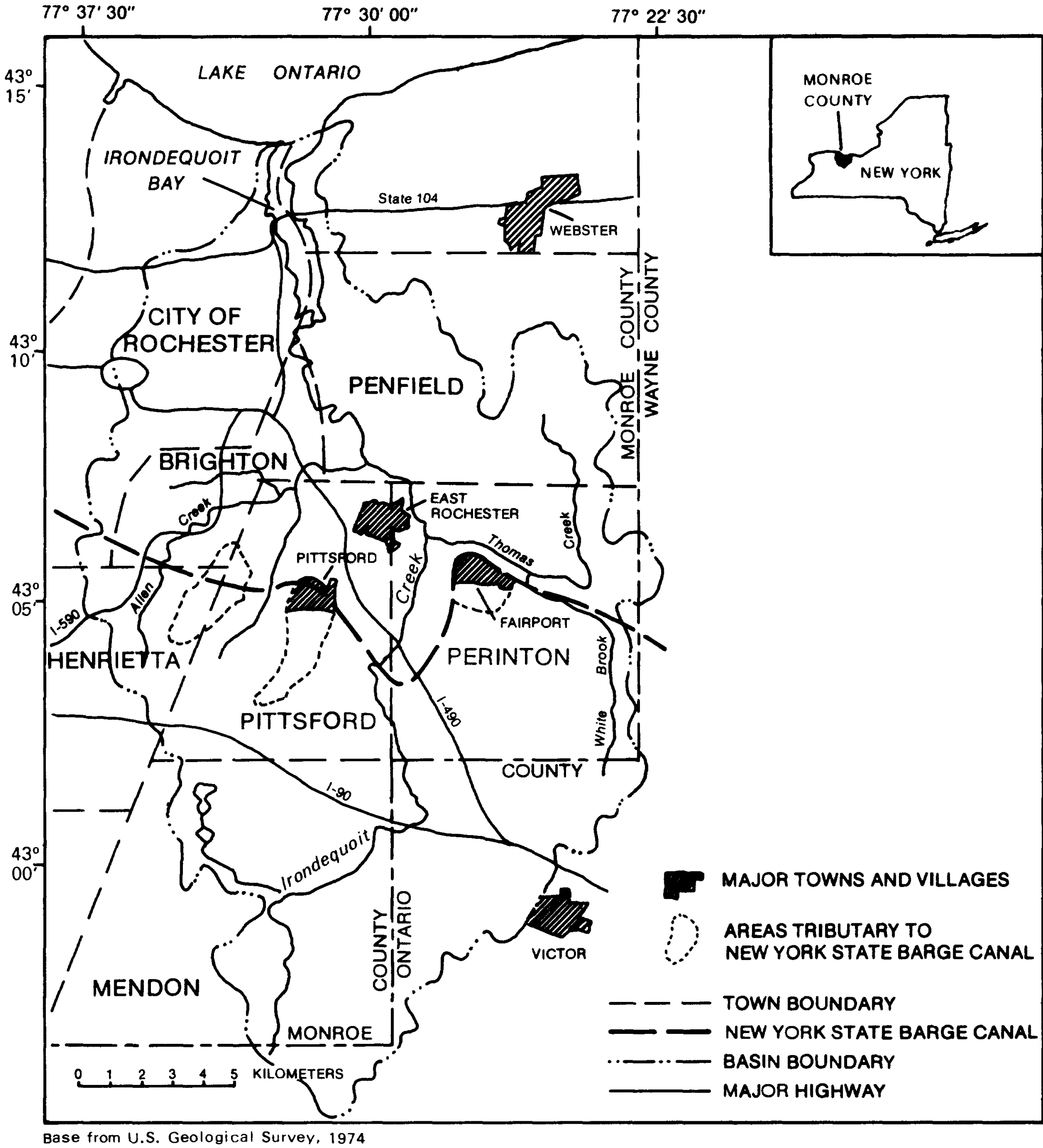


Figure 1.--Major geographic features of Irondequoit Creek basin.

Storm-Water and Sanitary Sewer Systems

The discharge of sewage to Irondequoit Creek and its tributaries was eliminated in 1979, and all sewage is now diverted outside the basin to the County wastewater-treatment facility along the shore of Lake Ontario. All other major discharges from industrial and commercial businesses are discharged to the same wastewater-collection system, with pretreatment if necessary.

The stormwater and sanitary-sewer systems in most of the basin are independent of each other. The older, developed parts of the basin have some cross-connections, however, and the City of Rochester has combined sewers that overflow into the Irondequoit basin during stormflow periods. These combined sewer overflows (CSO's) drain to the Irondequoit Creek wetlands from Thompson CSO and directly to Irondequoit Bay from Densmore CSO (fig. 2). These discharges will become less frequent as the County wastewater-collection system is completed.

Drinking-Water Supplies

Municipal drinking water is supplied from three sources--reservoirs outside the basin, Lake Ontario, and aquifers. Approximately 80 percent of the basin is supplied by surface-water sources and 20 percent from ground-water sources (New York State Department of Health, 1981).

A countywide water authority supplies several water districts within the basin, and the Water Bureau of the City of Rochester supplies the area within the corporate limits of the city. The Town of Fairport obtains its water supplies from reservoirs south of the Irondequoit Creek basin. The towns of Pittsford, East Rochester, and Webster (fig. 1) draw their water from a sand and gravel aquifer that underlies the central part of the basin.

Surficial Geology

Several glacial advances and retreats have reshaped the landscape of the Irondequoit basin. The headwaters and middle of the basin contain terminal moraines, drumlins, till plains, and small lake plains. The northern part of the basin, near Lake Ontario, contains beach ridges and plains formed during several postglacial-lake stages. Altitudes in the basin range from 274 m above sea level in the headwaters to approximately 150 m in the midsection and, in the northern part, from approximately 75 m to 120 m. The present mean water-surface altitude of Lake Ontario is 75 m.

A major physical feature of the Irondequoit basin is the preglacial Irondogenesee river valley. This buried valley is filled with more than 100 m of glacial material in the southwestern and central parts of the basin. The only surficial expression of the former river valley is the present Irondequoit Creek valley, which extends from East Rochester north through Irondequoit Bay to Lake Ontario. The bay itself overlies the preglacial Irondogenesee valley. Altitude differences of 45 m between the present valley floor and the higher postglacial plains surrounding it are the only surficial suggestion of this major river valley. The filled valley serves as an aquifer that now supplies more than 9.5 m^3/min to several well fields, but only a few towns use it as a primary water source (Waller and others, 1982).

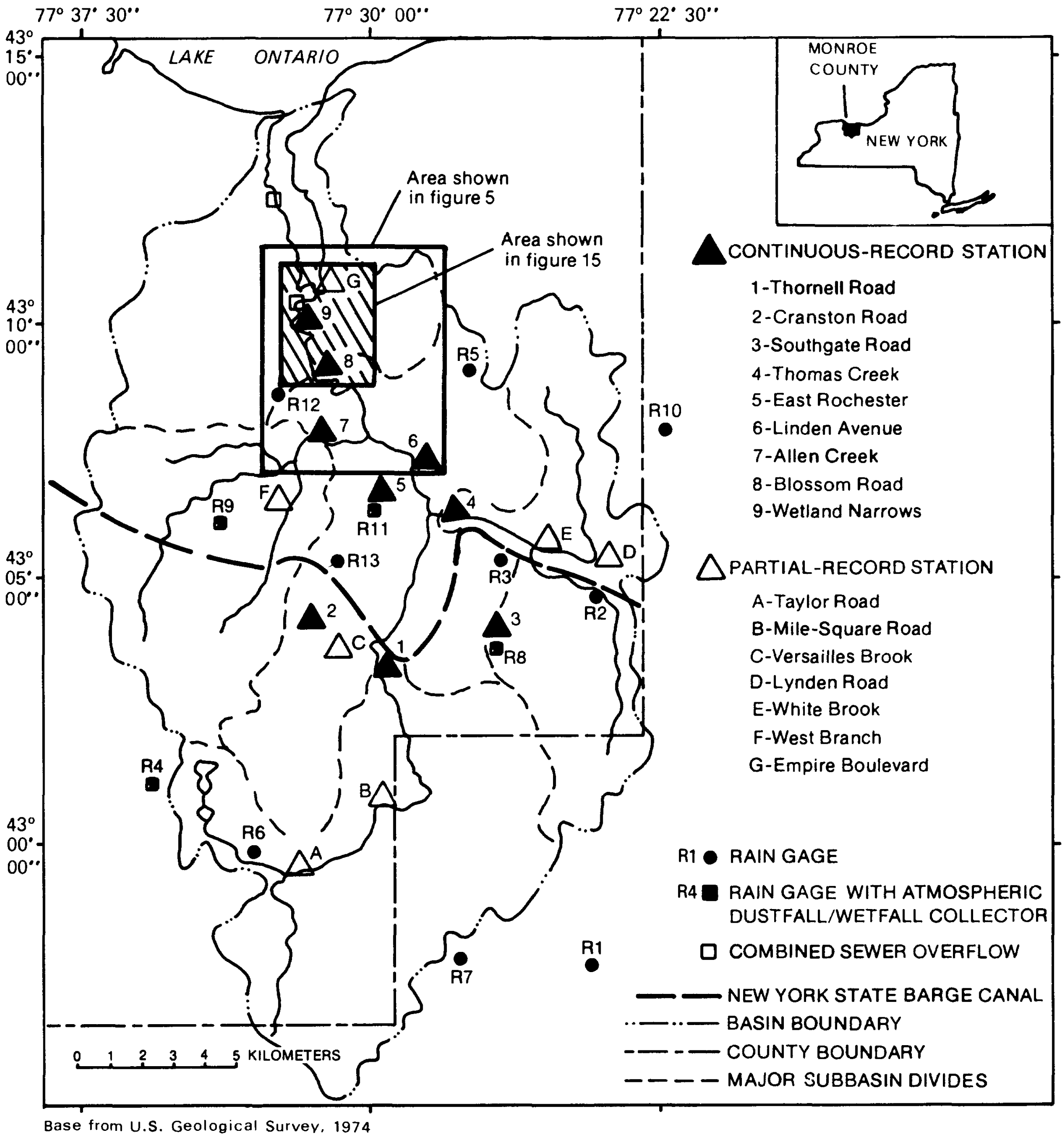


Figure 2.--Location of data-collection sites in Irondequoit Creek basin.

Climate

The climate in this part of New York State is humid continental. Precipitation, on the average, is evenly distributed throughout the year with approximately 66 mm/mo and 796 mm/yr (National Oceanic and Atmospheric Administration, 1980, 1981). The even temporal distribution of precipitation is attributed to Lakes Ontario and Erie, which affect local rain and snowfall patterns. These localized conditions also influence the average temperature extremes in the basin. The average daily temperatures range from -4.4°C in January to 21.6°C in July. Summers are generally warm and pleasant, and winters are long and cold with frequent periods of stormy, unsettled weather.

During the study, most of the sampled storms were produced by frontal systems moving northeastward during the fall and spring, and southeastward during the winter, which is typical for the region. Convective-type storms predominated in the summer, when the distribution of rainfall from individual storms was typically uneven over the basin and differences were as great as 50 mm among rain gages.

Analysis of the long-term precipitation record for the Rochester area indicated that the total amount of precipitation received during the 1980-81 study was above average. The timing of precipitation was also uneven, with above-normal precipitation in the summer and fall of 1980. Precipitation during 1981 was near normal in the winter but below normal during the summer. Even though the amounts and timing of rainfall were not considered normal, the patterns were representative of seasonal conditions within the Rochester area.

Subbasin and Site Descriptions

The Irondequoit basin was divided into six major subbasins on the basis of land use and stream configuration. In addition, four individual sites were chosen to represent the major land uses of the basin. Each subbasin and land-use site was monitored for quantity and chemical quality of storm runoff. (See glossary for definitions of site and subbasin.) Additional streamflow and water-quality data were obtained at six other subbasins within the Irondequoit basin. Physical characteristics of the subbasins and sites are summarized in table 1.

Two subbasins (Thomas Creek and Thornell Road) and three sites representing single land uses--Cranston Road (medium-density residential), Southgate Road (commercial/residential), and East Rochester (high-density residential), were designated as NURP monitoring stations (fig. 2), where detailed data on basin characteristics and land use were collected and analyzed as part of the urban-runoff study. Similar but less detailed land-cover data on the rest of the basin were collected through high-altitude spectral imagery.

Generalized descriptions of six subbasins and the four single-land-use sites follow. The common name of each monitoring station, as referred to in this report, is given in parentheses after the station name.

Irondequoit Creek near Pittsford (Thornell Road)

This National Urban Runoff Program (NURP) subbasin (no. 1 in fig. 2) has an area of 115 km^2, of which 89 percent is rural/agricultural and 11 percent is moderately developed. Approximately 3.7 percent is covered by effective impervious surfaces. Irondequoit Creek and its tributaries form the main drainage channels within the subbasin. The average gradient of Irondequoit Creek is 0.038 m/m (U.S. Army Corps of Engineers, 1975). The basin slope averages 0.013 m/m. Base flow in Irondequoit Creek consists of ground water that discharges primarily from the headwater areas. Most stormflow hydrographs are characterized by slowly rising peaks of long duration that reflect moderate soil-infiltration rates and the relatively gentle slope of the subbasin.

Thomas Creek at Fairport (Thomas Creek)

This NURP subbasin (no. 4 in fig. 2) has a total area of 73.8 km^2, of which 73 percent is rural/agricultural, 23 percent residential, and 4 percent commercial and light industrial. A 2.08-km^2 area of this subbasin drains directly to the New York State Barge Canal and does not contribute runoff to Thomas Creek and was therefore not considered in the modeling part of the study. Approximately 2 percent of the subbasin is covered by effective impervious surfaces and 7 percent by noneffective impervious surfaces.

The gradient of Thomas Creek ranges from 2.75 to 1.40 m/km (U.S. Army Corps of Engineers, 1981). The average basin slope is 0.013 m/m. Base flow in the subbasin consists of ground-water seepage from the headwaters and wetland areas. Stormflow hydrographs display an initial peak that reflects runoff from urban areas just upstream of the station, followed by a slow increase from runoff in the undeveloped areas upstream.

The Thomas Creek subbasin is divided by the New York State Barge Canal. Thomas Creek drains the area north of the canal; White Brook drains the area south of the canal and discharges to Thomas Creek through five 1.2-m-diameter inverted siphons under the canal near the village of Fairport (fig. 2). Thomas Creek, along the north side of the canal, loses approximately 0.10 m^3/s annually through ground-water infiltration. This area lies over an old outlet channel of glacial Lake Dawson reported by Fairchild (1928). Waller and others (1982) also report an extensive area of sorted sand and gravel along the east wall of the preglacial Irondogenesee Valley near this location.

Irondequoit Creek at East Rochester (Linden Avenue)

This NURP subbasin (no. 6 in fig. 2) has an area of 262 km^2, of which 29 percent is residential, and 71 percent rural and undeveloped. Within this area, 12.8 km^2 drains directly to the New York State Barge Canal. This subbasin includes the Thomas Creek and the Thornell Road subbasins and the intervening area from the Thornell Road station to the Linden Avenue station (fig. 2).

Storm runoff flows through natural channels except in urbanized areas. Effective impervious surfaces cover 8 percent of this subbasin, and noneffective impervious surfaces cover an additional 3 percent. The gradient of Irondequoit Creek is 2.1 m/km (U.S. Army Corps of Engineers, 1975). The basin slope averages 0.008 m/m. Base-flow contributions from the area along Irondequoit Creek downstream from the Barge Canal are small compared to that from the headwaters. The generalized storm hydrograph for Linden Avenue shows that storm-sewer discharges upstream create a sharp initial peak followed by an initial rapid recession, then a slower rise as the upstream contributions to Irondequoit Creek and Thomas Creek pass the Linden Avenue gage.

Allen Creek near Rochester (Allen Creek)

This subbasin (no. 7 in fig. 2) has an area of 78.0 km^2, of which 53 percent is rural-agricultural, 38 percent residential, and 9 percent commercial.

Table 1.--General descriptions of subbasin stations in the Irondequoit Creek basin.

[Station locations are shown in fig. 2.]

Number on fig.2 and station no.[1]	Station name (common name is in parentheses)	Drainage area (km^2)	Basin or site characteristics and principal land use
			Continuous-Record Sites and Subbasins
1† 04232040 430315077292800	Irondequoit Creek near Pittsford (Thornell Road)	115.0	Subbasin is agricultural, rural, undeveloped, with open-channel streams. Soils moderately well drained.
2† 430403077311500	Tributary to Barge Canal tributary near Pittsford (Cranston Road)	0.673	Medium-density residential site, storm sewers and concrete lined swales. Soils moderately well drained.
3† 430428077261100	White Brook tributary near Fairport (Southgate Road	.725	Shopping plaza site surrounded by residential development, storm sewers, and unlined ditches. Soils moderately well drained.
4† 04232046 430623077274300	Thomas Creek at Fairport (Thomas Creek)	73.8	Subbasin is rural with undeveloped headwaters, transitional urbanization downstream, generally open-channel streams, contiguous wetlands. Soils moderately to excessively well drained.
5† 430649077285500	Irondequoit Creek tributary (storm sewer) at East Rochester (East Rochester)	1.55	High-density residential site, storm sewered throughout. Soils excessively well drained.
6 04232047 430715077283800	Irondequoit Creek at East Rochester (Linden Avenue)	262*	Mixed residential/commercial subbasin, storm sewers with some open channels. Soils poorly to moderately well drained.
7 04232050 430749077310800	Allen Creek near Rochester (Allen Creek)	78.0	Subbasin is medium- to high-density residential, with some commercial areas, storm sewers, some open-channel streams. Soils poorly to moderately well drained.
8 0423205010 430850077304600	Irondequoit Creek at Blossom Road, Rochester (Blossom Road)	370	Subbasin includes characteritics of all preceding sites.
9 0423205023 430958077315600	Irondequoit Creek at Landfill Narrows (Wetland Narrows)	373	Subbasin includes characteristics of all sites as well as the Irondequoit wetland.

Table 1.--General descriptions of subbasin stations in the Irondequoit Creek basin (continued).

Number on fig.1 and station no.[1]	Station name (common name is in parentheses)	Drainage area (km^2)	Basin or site characteristics and principal land use
			Partial-Record Sites and Subbasins
A 425904077323100	Irondequoit Creek at Taylor Road near Mendon	30.0	Rural, agricultural.
B 430036077294000	Irondequoit Creek at Mile Square Road near Mendon	62.2	Rural, agricultural.
C 430311077301803	Versailles Brook near Pittsford (Versailles)	.906	Transitional with housing construction, approximately 2/3 developed, 1/3 undeveloped.
D 430528077241000	Thomas Creek at Lynden Road near Fairport	28.2	Rural, undeveloped, Thomas Creek subbasin north of New York State Barge Canal.
E 430528077251903	White Brook below Barge Canal at Fairport	37.3	Rural in headwaters, development in lower half of watershed, Thomas Creek subbasin south of New York State Barge Canal, agricultural, rural.
F 430654077314000	West Branch at Oak Hill Country Club near Brighton	31.6	Transitional and agricultural, rural in headwaters, moderate development elsewhere.
G 431034077313700	Irondequoit Creek at mouth near Rochester (Empire Blvd)	391	Irondequoit Creek at Irondequoit Bay including one combined sewer overflow from City of Rochester.

1 8-digit number is U.S. Geological Survey downstream-order station number; 15-digit number is latitude-longitude station number.

† Designated National Urban Runoff Program (NURP) monitoring site or subbasin.

* Intervening area between Linden Avenue site and the Thornell Road and Thomas Creek subbasins is 73.2 km^2.

Within this subbasin, 11.4 km^2 drains directly to the Barge Canal. Approximately 7 percent of the subbasin is covered by effective impervious surfaces and 11 percent by noneffective impervious surfaces. This urbanized subbasin contains both storm sewers and natural channels. The natural channel of Allen Creek has an average gradient of 5.49 m/km (U.S. Army Corps of Engineers, 1981). The basin slope averages 0.011 m/m. Flow in this creek is sustained by groundwater seepage and by variable discharges from the New York State Barge Canal. Storm hydrographs display a rapid rise in response to precipitation, then a short peak period, and a moderately rapid recession.

Irondequoit Creek at Blossom Road, Rochester (Blossom Road)

This subbasin (no. 8 in fig. 2) has an area of 370 km^2, of which 28.5 km^2 drains to the Barge Canal and does not contribute to Irondequoit Creek. Thirty-one percent of the basin is residential, 2 percent is commercial, and 67 percent is rural-agricultural. Effective impervious surfaces cover 8 percent of the subbasin, and noneffective impervious surfaces cover an additional 5 percent. The basin contains both stormwater and madmade channels, as in the Linden Avenue subbasin. The stream gradient is approximately 0.606 m/km. Basin slope averages 0.008 m/m.

Blossom Road is the last station before the Irondequoit wetlands and receives base flow from all above-mentioned subbasins. Storm hydrographs reflect two major sources of runoff--Allen Creek and mainstem Irondequoit Creek. Depending on a storm's direction of movement, duration, and intensity, the resultant Blossom Road hydrograph can display one or two peaks on moderately rapid rising and falling limbs. Variable backwater conditions affect the shape of the stage hydrograph; these conditions are caused by the low gradient and sinuous channel configuration of the creek near the station and by periodic high lake levels, which typically occur in June and July and cause seasonal changes in channel conveyance.

Irondequoit Creek at Landfill Narrows, Rochester (Wetland Narrows)

This subbasin (no. 9 in fig. 2) ends 4 stream-kilometers downstream from the Blossom Road station and includes the 370-km^2 Blossom Road subbasin and an intervening area of 4 km^2, of which 1.55 km^2 is wetland. The basin characteristics and base-flow conditions are similar to those of the Blossom Road basin. The stream gradient in the wetland is approximately 0.19 m/km. The variable backwater conditions that affect stormflows at Blossom Road affect flows at the Wetland Narrows to a much greater extent. A combined sewer overflow also empties into the wetland downstream from the Narrows, causing a temporary backwater in the creek.

Tributary to Barge Canal tributary near Pittsford (Cranston Road)

This NURP site (no. 2 in fig. 2) has an area of 0.673 km^2, all of which is a medium-density residential development. Approximately 15 percent is covered by effective impervious surfaces, and an additional 10 percent by noneffective impervious surfaces. Street gutters and concrete-lined ditches are the predominant form of drainage channels. The average basin slope is 0.011 m/m. Base flows originate from an old farm tile-drainage network draining to the stormwater system in parts of the housing development. Stormflow hydrographs show a direct response to rainfall intensity, with discrete high discharges of short duration. Even though flow from this subbasin discharges to the Barge Canal and not Irondequoit Creek, the subbasin is representative of medium-density residential land use in the Irondequoit basin.

White Brook tributary near Fairport (Southgate Road)

This site (no. 3 in fig. 2) encompasses 0.725 km^2, of which 37 percent is commercial, 28 percent low to medium-density residential, and 35 percent undeveloped. About 15 percent of the subbasin is covered by effective impervious surfaces and 5 percent by noneffective impervious surfaces. The main drainage systems are storm sewers and parking-lot drains in the commercial area and unlined swales and ditches in the outlying areas. The average basin slope is 0.013 m/m. Base flow consists of ground-water seepage from the lowlands north of the commercial area. Storm hydrographs show a rapid rise in response to runoff from the commercial area. The recession hydrograph broadens in response to runoff arriving from the outlying residential and undeveloped parts of the watershed.

Irondequoit Creek tributary at East Rochester (East Rochester)

This site (no. 5 in fig. 2) has a 1.55-km^2 area, of which 88 percent is high-density residential and the remaining 12 percent commercial. Approximately 17 percent is covered by effective impervious surfaces and 15 percent is covered by noneffective impervious surfaces. The drainage system consists of street gutters and storm sewers. The gradient of the storm-sewer system is 2.59 m/km. The average basin slope is 0.005 m/m. Base flow in the storm sewer consists of a small amount of ground-water seepage and an unknown amount of septic discharge. Storm runoff is responsive to rainfall intensity, as indicated by large discharges of short duration.

During the study, a 0.16-km^2 area was found to drain to a grassy retention/infiltration basin. This water could be pumped to the storm-drainage system but never was during the 14-month study (East Rochester Department of Public Works, oral commun., 1981). This area was considered to be non-contributing to the creek and was not used in the computation of flows nor in subsequent modeling.

Versailles Brook near Pittsford (Versailles)

The removal of a basinwide ban on new sewer tie-ins in 1980 prompted sizeable housing construction within the basin, mostly south of the Barge Canal. The new construction was expected to cause a substantial increase in sediment and nutrient loads to the Irondequoit Creek system. This site (site C in fig. 2) was added to the study in April 1981 to evaluate the sediment and nutrient loads from a housing-construction site. The data-collection period was May through August 1981.

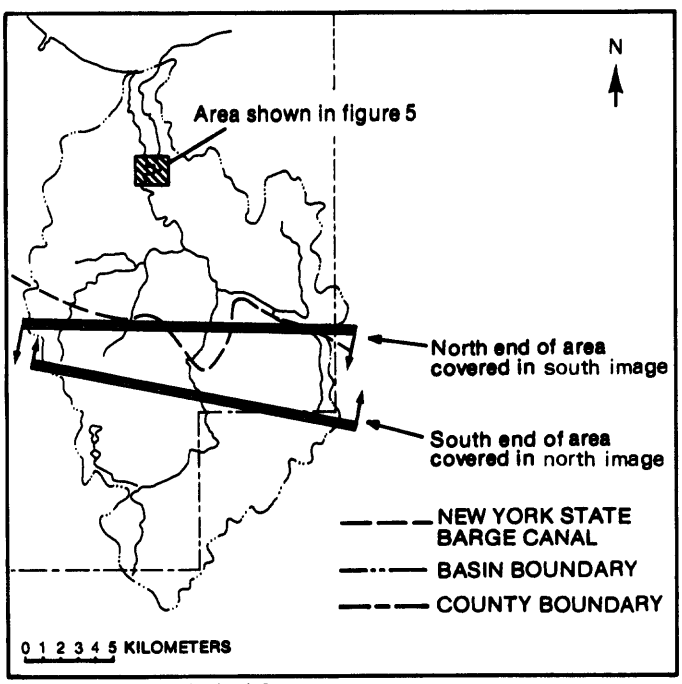
This site has an area of 0.906 km^2, and during the study, 17 percent was under construction, 52 percent was completed medium-density residential, and 31 percent was undeveloped. The average slope of the site is 0.012 m/m.

Impervious surface area of this site was not computed because the site was in transition. The main stormwater channels are street gutters and storm sewers in developed areas and natural channels elsewhere. Base flow is minor because the site is in the headwater region and the soil's infiltration rate is low. Storm runoff is highly responsive to rainfall intensity despite a 0.2-ha detention pond in the central part of the drainage basin upstream from the measurement station. No evidence of stormflow detention was found during the study, however.

LAND COVER AND LAND-USE ANALYSIS

An assessment of land cover in the large subbasins and detailed land-use information for the smaller land-use sites was critical to the development of rainfall-runoff models for the Irondequoit basin. Land-cover information was compiled through digital analysis of two high-altitude multispectral images. The image of the northern two-thirds of the basin was taken in August 1973; that of the southern third was taken in May 1973 (fig. 3). These images provided the most recent and complete delineation of land use available when the study began.

The land-cover classification developed for the basin used the spectral reflectance characteristics of the two remote-sensing images. The basin and subbasin boundaries were digitized, and land-surface features as small as 6.5 m^2 were compiled to form the initial basinwide data set. The initial analysis relied on spectral-intensity information only. Land-classification identifiers or "training sets" were used to separate similar spectral signals. For



Base from U.S. Geological Survey, 1974

Figure 3.

Area covered by the two high-level multispectral images. (Photos from Earth Resource Observation Satellite [EROS] Data Center, Sioux Falls, S.D.)

example, signals from bare ground were similar to those from impervious surfaces. Once training sets were selected and verified, the computer reclassified all elements in the data set. A summary of the land-cover data, by subbasin, is provided in table 2.

When land-cover information was being compiled, land-use maps of the smaller watersheds were obtained from the Monroe County Planning Department for each discrete land-use site. Each single land-use site was surveyed for (1) street, catchment-basin, and storm-sewer layouts, (2) roof-drainage systems, and (3) individual household practices such as pesticide and herbicide use. The latter group of data was obtained by house-to-house inventory. These data were required by the USEPA for the national program and were used in the modeling effort for these basins. Compilation of these data was a joint effort of O'Brien and Gere Engineers, Inc., and the U.S. Geological Survey. The data are available from USEPA and are presented in O'Brien and Gere (1981).

Table 2.--Remote-sensing classification of land cover in Irondequoit basin.

[Values are percentage of basin occupied by specified land cover; image areas are shown in fig. 3.]

Basin	Water	Wet-lands	Vege-tation (Mixed)	Agricultural fields and other vegetation	Trees	Barren area	Impervious/transi-tional area	Unclass-ified area
North basin image								
Lake Road (Bay mouth)	4.35	0.29	16.66	32.90	23.80	1.27	15.80	4.93
Blossom Road	.73	.29	17.33	36.18	26.17	1.07	13.68	4.55
Wetland Narrows	.66	.29	17.43	36.19	26.41	1.02	13.36	4.64
E. Rochester (storm-sewer)	.86	.10	14.14	35.28	7.58	.71	38.12	3.21
Thomas Creek	.22	.08	24.80	38.41	19.99	.88	10.52	5.10
Cranston Road	.0	.0	36.83	12.87	3.12	2.01	43.85	1.32
Southgate Road	.0	.20	13.78	44.41	24.48	.61	13.95	2.57
Allen Creek	3.1	.60	19.20	41.10	16.50	1.30	15.30	2.90
South basin image								
White Brook	.17	.12	18.43	36.27	30.19	.64	7.98	6.20
Thornell Road	1.70	.50	17.60	57.10	3.60	13.30	6.20	2.50

PRECIPITATION AND EVAPORATION MEASUREMENTS

Precipitation was recorded from July 1980 through September 1981 at 18 locations within the basin. At the five NURP subbasins (Cranston Road, East Rochester, Southgate Road, Thornell Road, and Thomas Creek), the data were recorded at 5-minute intervals to the nearest 0.25 mm by float-actuated analog-digital recorders. At the Mendon Ponds Park meteorologic monitoring site (fig. 2, R4), a weighing-bucket rain gage recorded precipitation on a weekly graphic chart. Daily precipitation data were collected by volunteers using cylindrical plastic rain gages at 12 other locations. During the winter, snowfall depth and water-equivalent data were collected at nine of these volunteer stations and at six recording stations. Analyses of the winter data revealed that the five float recorders did not collect representative snowfall data; therefore the winter data from these stations were not used in the modeling analysis. Daily evaporation was recorded in an evaporation pan at Mendon Ponds. Precipitation data for all stations are summarized by Zarriello and others (1984). Annual precipitation at the Rochester airport during the 1980 and 1981 water years[1] was 837 mm and 900 mm, respectively, both above the 796-mm average for the 150-year record of the Rochester area.

STREAMFLOW MEASUREMENTS

Continuous streamflow data were collected at seven stations from July 1980 through September 1981. Two other streamflow stations were added to the study in March 1981 for study of the upper Irondequoit Creek wetland as a detention area for stormflow, as described further on. Seven partial-record stations were established to provide supplemental discharge and water-quality data at additional locations within the basin. Locations of all data-collection sites are shown in figure 2.

The five NURP gaging stations (Thornell Road, Thomas Creek, Cranston Road, Southgate Road, and East Rochester) and the two downstream stations (Blossom Road and Wetland Narrows) had graphic and analog-digital stage recorders; the Allen Creek and Linden Avenue stations had analog-digital stage recorders only. The East Rochester and Wetland Narrows stations used a combination of velocity-sensor and pressure-balancing stage recorder (manometer) to determine discharge. The East Rochester station was located at a 1.35-m tiled storm sewer and used a Marsh-McBirney Model 250[2] recording flow meter with a digital recording option for discharge. Recorded discharges at East Rochester were verified by current-meter measurements at low discharges (less than 0.5 m^3/s) and dye-dilution measurements at high discharges.

Flow at the Wetland Narrows was determined from velocity and cross-sectional-area rating curves because the wetland has variable backwater conditions. The Narrows station was equipped with a Marsh-McBirney Model 201 velocity probe in conjunction with a U.S. Geological Survey velocity-stage interface unit to obtain point velocity and stage data. At all other stations,

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[1] Water year 1981 is October 1, 1980 to September 30, 1981.

[2] Use of brand names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

discharge was computed from stage-discharge relationships that were either derived from streamflow measurements made over a range of stages or based on theoretical rating verifed with streamflow measurements.

At the partial-record stations, staff and crest-stage gages were installed on the upstream side of the road culvert or bridge. Discharge measurements were made periodically throughout the study to establish a stage-discharge relationship or to verify a theoretical rating for each station.

At the Versailles (housing-construction) partial-record site, several stormflow hydrographs were developed from numerous staff-gage readings. A rainfall-runoff curve was derived from streamflow readings from three storms in late July and August 1981 and associated rainfall data from the Thornell and Cranston Road sites. These data were used to calculate storm loads and yields for comparison with similar data from continuous-record stations.

WATER SAMPLING AND CHEMICAL ANALYSIS

Precipitation and streamwater samples were collected during 23 storms between July 1980 and August 1981; these totaled 162 "station storms" for the five subbasins and three land-use sites. Of the 23 storms, 15 (106 station storms) had total precipitation amounts exceeding 12.5 mm and a maximum instantaneous rainfall intensity exceeding 5.00 mm/h. The remaining eight storms (56 station storms) had lesser intensities or total storm precipitation less than 12.5 mm and were not used in the rainfall-runoff modeling. Base-flow samples were also collected monthly during the study.

The water samples from the three single-land-use stations (Cranston Road, Southgate Road, and East Rochester) and the six subbasin stations (Thornell Road, Thomas Creek, Linden Avenue, Allen Creek, Blossom Road, and Wetland Narrows) were collected by automatic water samplers that were activated during storms when the stream reached a predetermined flow. The types of equipment and the mode of operation at each station are summarized in table 3. At the partial-record stations, discrete samples were obtained with hand-held samplers, and instantaneous discharges were obtained from staff-gage readings and stage-discharge relationships.

The National Weather Service radar at Buffalo, N.Y., was used to estimate the potential rainfall intensity and direction of storm movement. As a storm approached the basin, Monroe County Environmental Health Laboratory (EHL) monitored all stations to ensure that all equipment functioned correctly. In addition to the usual collection procedures, both the Geological Survey and EHL periodically collected cross-sectional stream samples to verify the representativeness of samples obtained by each automatic collector.

During the first 3 months of data collection, the water samples were taken to the EHL, where they were logged in and split into predetermined aliquots by a Geological Survey "cone-splitter"[1]. Some aliquots were measured or analyzed by

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[1] A gravity-fed sample-splitting device developed by the Geological Survey to split samples into 10 equal aliquots.

Table 3.--Types of sampling equipment and mode of operation of automatic data-collection stations in the Irondequoit Creek basin.

[Site locations are shown in fig. 2.]

Site and station no.	Sampler type[1]	Mode of operation	Sampler-intake characteristics
Thornell Road (04232040)	Manning Model S-4040 sequential	Stage-activated/time mode: Activation switch connected to sampler power supply, allowing time-mode samples to be collected 0.137 m above base flow. (Sampler was initially activated on a flow-proportional basis after 2,100 m^3 had passed. Sampler set at 500-mL sample (2 per bottle) on 15-, 30- or 60-min intervals, depending on flow.	6 m of line with a 1.2-m vertical lift
Thomas Creek (04232046)	Manning Model S-4040 sequential	Flow-proportional sampler activated after every 512 m^3 by a Manning model F-3000A flow meter. Sampler set at 500-mL samples (2 per bottle), and interval was changed or sampler switched to a time mode, depending on flow conditions.	0.6 m of line with a 3.6-m vertical lift
Linden Avenue (04232047)	Manning Model S-4040 sequential	Stage-activated/time mode: Sampler set for 500-mL samples (2 per bottle) at intervals of 30 or 60 min, depending on flow conditions.	6 m of line with a 3-m vertical lift
Allen Creek (04232050)	Manning Model S-4040 sequential	Stage-activated/time mode: Sampler set for 500-mL samples (2 per bottle) at intervals of 30 or 60 min, depending on flow conditions.	7.6 m of line with a 3-m vertical lift
Blossom Road (430850077304600)	Manning Model S-4040	Time mode: Sampler set for 500-mL sample (2 per bottle) at intervals of 30 or 60 min, depending on flow conditions.	24 m of line with a 3-m vertical lift
Wetland Narrows (430958077315600)	ISCO Model 1680	Time mode: Sampler set for 500-mL sample (2 per bottle) at intervals of 30 or 60 min, depending on flow conditions.	18 m of line with a 1.6-m vertical lift
Cranston Road (430403077311500)	Manning Model S-4040 sequential	Flow-proportional sampler activated primarily by a Manning model F-3000A flow meter. A 500-mL sample (2 per bottle) was initiated every 44.0 m^3 when the stage reached 0.122 m above base flow. Sample interval was changed depending on flow conditions.	45 m of line with a 1.5-m vertical lift
Southgate Road (430428077261100)	Manning Model S-4040 sequential	Flow-proportional sampler activated primarily by a Manning model F-3000A flow meter. A 500-mL sample (2 per bottle) was initiated every 170 m^3 after the stage-activation switch closed at 0.122 m above base flow. Sample times were recorded as an offset on the flow meter.	6 m of line with a 1.5-m vertical lift
East Rochester (430649077285500)	Manning Model S-4040 sequential	Flow-proportional sampler activated after every 49 m^3 by a Marsh-McBirney model 250 velocity modified flow meter. Sampler set at 500-mL sample (2 per bottle). Sample times were recorded on a 4/20 M-amp Rustrak recorder wired to the power supply of the vacuum pump. Sample interval varied depending on flow conditions.	6 m of line with a 4.8-m vertical lift

[1] Use of brand names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

EHL; the rest were preserved and shipped to the U.S. Geological Survey Central laboratory in Atlanta, Ga. Beginning in December 1980, the EHL assumed responsibility for all constituent analyses except total and suspended organic carbon and suspended sediments. (The organic carbon analyses were performed by the O'Brien and Gere Laboratory in Syracuse, N.Y., and suspended-sediment and particle-size analyses by the Geological Survey's sediment laboratory in Columbus, Ohio.) Data verification was performed by both EHL and the Geological Survey.

ATMOSPHERIC-DEPOSITION SAMPLING AND ANALYSIS

Samples of rainfall (wetfall) and of atmospheric particulate matter deposited as dustfall between storms provided data for estimation of atmospheric loads of selected constituents. Three Aero-Chemetric Model 301 wetfall/dryfall samplers were maintained within the basin. One was placed at the Mendon Ponds Park in the southwestern part of the basin (site R4 in fig. 2) to represent wetfall and dustfall unaffected by urban influences. The second collector was placed on the roof of the Perinton Square Shopping Center (Site R8 in fig. 2) in the Southgate commercial/residential land-use site. The third sampler was placed in the the high-density residential site in East Rochester. It had been initially placed on the top of the East Rochester High School but was moved in the spring of 1981 to a more secure location on the roof of the East Rochester Middle School (site R11). Bulk deposition (wetfall and dustfall) was collected near the village of Pittsford (site R9 in fig. 2) to supplement other atmospheric data during the nonwinter period.

General field-collection and data-processing procedures for atmospheric deposition samples followed U.S. Geological Survey guidelines (U.S. Geological Survey, Water Quality Branch, written commun. 1981). Dustfall and bulk containers were removed by observers on the first Tuesday of every month. Wetfall containers were removed after a storm of 12.5 mm or more. If a storm of this magnitude did not occur within a month, the wetfall containers were removed with the other containers on the first Tuesday of the month.

During June 1980 through March 1981, atmospheric samples except those from the Mendon Ponds subbasin were mailed to the U.S. Geological Survey office in Ithaca, N.Y., for measurement of pH and specific conductance. They were then treated and sent to the U.S. Geological Survey Central Laboratory in Atlanta, Ga., for analyses for other physical and chemical characteristics (table 4). The analytical techniques used during the project are given by Brown and others (1970), Skougstad and others (1979), and Friedman and Erdmann (1983).

In March 1981, responsibility for the collection and analysis of atmospheric samples from all subbasins except the Mendon Ponds station was transferred to the Monroe County Environmental Health Department laboratory in Rochester. Methods used by the laboratory were consistent with those used by the U.S. Geological Survey for the constituents analyzed. Conductance and pH measurements of samples from the Mendon Ponds subbasin were made in the U.S. Geological Survey laboratory in Albany, N.Y.; all other chemical analyses for this site were performed by the Geological Survey's Central Laboratory in Atlanta, Ga.

Table 4.--Water-quality constituents and properties measured in Irondequoit Creek runoff program.

Sediment indicators	Organic indicators
Particle-size analysis	Dissolved organic carbon (DOC)
Suspended sediment	Suspended organic carbon (SOC)
	Chemical oxygen demand (COD)
Inorganic indicators	*Ultimate biochemical oxygen demand (BOD)
	*5- and 20-day BOD
*Specific conductance	Organic contaminants such as pesticides, PCB's, oil, and grease
*pH	
Dissolved solids	
Dissolved $NO_2 + NO_3$ as N	**Bacteriological indicators**
Dissolved NH_3 as N	
Dissolved kjeldahl nitrogen as N	*Fecal coliform bacteria
Dissolved phosphorus as P	
Total phosphorus as P	
Total lead	
Major cations and anions	
Trace metals	

* Analyses by U.S. Geological Survey Central Laboratory in Atlanta, Ga. from July through November 1980 and by Monroe County Environmental Health Laboratory, Rochester, N.Y. from December 1980 through September 1981. Asterisk indicates analysis by Monroe County Laboratory throughout study.

QUALITY ASSURANCE/QUALITY CONTROL

An integral part of the data-collection effort was the Quality Assurance/Quality Control (QA/QC) program to ensure that the water-quality data were accurate and precise. The program was divided into three parts--streamflow accuracy, representativeness of samples, and laboratory proficiency. The procedures and guidelines are given in detail in Zarriello and others (1984) and summarized briefly below.

Accuracy of Streamflow Measurements

Stage-discharge relationships (ratings) were defined by direct and indirect streamflow measurements through standard U.S. Geological Survey techniques (Carter and Davidian, 1968; Buchanan and Somers, 1968). At the 1.35-m storm sewer in East Rochester, dye-dilution techniques (Rantz and others, 1982) were used to verify discharge values recorded by a flow meter.

Representativeness of samples

The second part of the QA/QC program was to determine whether the automatic water-quality samplers were collecting representative streamflow samples. Periodic depth-integrated cross-sectional samples were collected concurrently with the automatic samplers. Initially the data from the two groups were plotted and compared. Later in the program, statistical analyses were done for the same purpose. Results of these analyses indicated that the two sampling methods were not statistically different at the 0.95 significance level (Zarriello and others, 1984).

Laboratory Accuracy

The third aspect of the QA/QC program concerned the accuracy of water-quality analyses. Both the U.S. Geological Survey Central Laboratory in Atlanta, Ga., and the Monroe County Environmental Health Laboratory followed analytical procedures by Skougstad and others (1979) and Friedman and Erdmann (1983) and conducted their own internal quality-assurance/quality-control program. Samples were analyzed by the Central Laboratory in Atlanta between July and November 1980 and thereafter by the Monroe County Environmental Health laboratory. Results of the Atlanta QA/QC program are available from the U.S. Geological Survey Quality of Water Branch in Reston, Va., and from the Geological Survey Central Laboratory in Atlanta. Results from the Monroe County Environmental Health Laboratory are given in Zarriello and others (1984).

DATA-MANAGEMENT SYSTEM

Streamflow data, meteorologic data, and water-quality data were entered into the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE). This system maintains data in several computer files. The daily mean discharge and precipitation data were entered into the daily-values (DV) file. Data from the 106 station-storms selected for rainfall-runoff modeling consisted of instantaneous discharge and accumulated precipitation over short time intervals; these were entered into the unit-values (UV) file. Time intervals for the UV data were typically 5 minutes for the smaller land-use sites and 15 minutes for the larger subbasins. Water-quality analyses from the various laboratories were entered into the water-quality (QW) file.

Upon verification, these data were transferred into the Data Management System (DMS) developed by Doyle and Lorens (1982). The DMS was developed by the Geological Survey to manage and interface data with established computer programs and statistical procedures.

DETERMINATION OF RUNOFF QUALITY

Although this study focused primarily on storm runoff and its chemical quality, periodic base-flow sampling throughout the study provided sufficient data for an estimate of the annual load of eight constituents to Irondequoit Bay from sources upstream from Blossom Road. The estimates of annual loads of these constituents were based on samples collected during August 5, 1980 through August 13, 1981. The data were grouped into five sampling periods--the 1980 growing season, 1980-81 winter, 1981 snowmelt period, 1981 spring, and 1981 growing season. A representation of the five sampling periods and frequency of sampling during the study is given in figure 4.

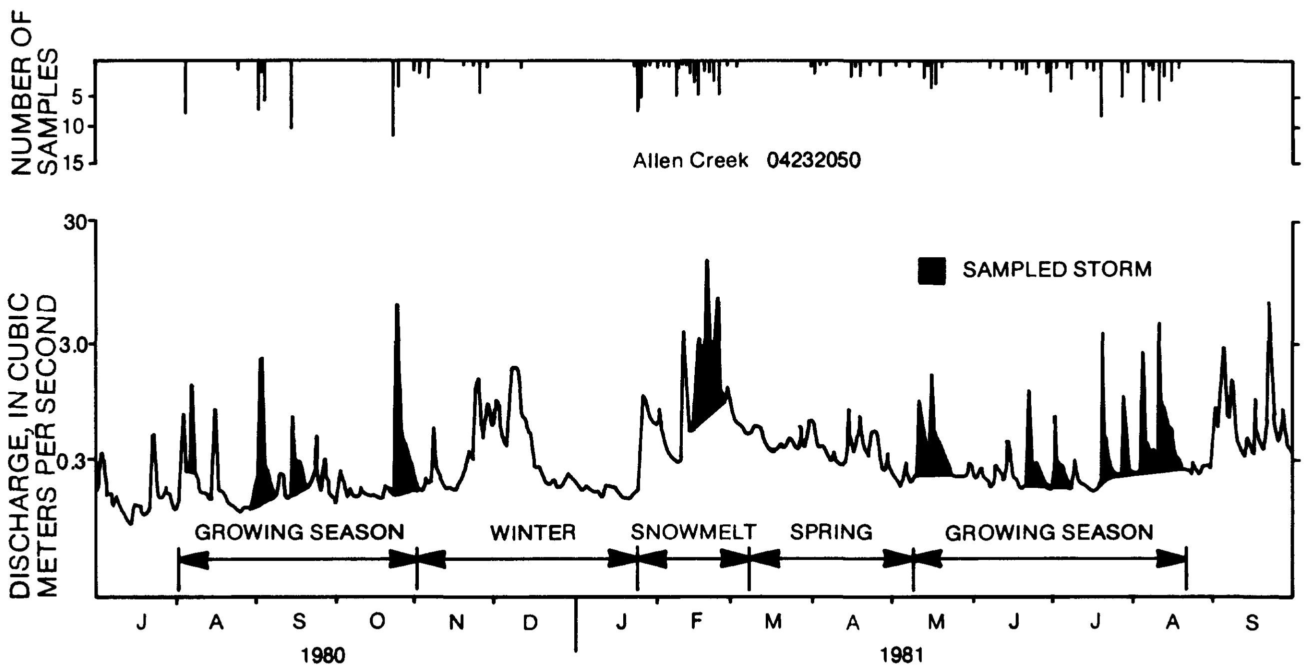

Figure 4.--Hydrographs of representative subbasins showing the five sampling periods and sampling intensity.

One objective of the data-collection effort was to support the calibration of a storm-runoff model. The model chosen for this study, the Distributed Rainfall Runoff Routing Model (DR3M) of Alley and Smith (1982a,b), does not include the option to simulate snowmelt runoff; therefore, modeling was generally limited to the growing season, and the data-collection effort was most intense during August through October 1980 and May through August 1981.

Selection of Modeled Chemical Constituents

The large amount of data collected necessitated that computer analysis and modeling be limited to runoff constituents that were most important in the creek and(or) bay. In the spring of 1981, the data obtained from this study as well as previous studies of the basin were reviewed, and the decision was made to limit the model analyses to eight constituents--total phosphorus, total kjeldahl nitrogen, chemical oxygen demand, suspended sediment, total chloride, total lead, total cadmium, and total zinc, for the reasons described below.

Total phosphorus.--Total phosphorus was the most important constituent because it is the key factor in the eutrophication of Irondequoit Bay--a major public concern.

Total kjeldahl nitrogen.--Total kjeldahl nitrogen was used to indicate the nature of organic nitrogen species available to wetland plants and bay algae.

Chemical oxygen demand.--Chemical oxygen demand was measured to determine the organic-matter content of the water and the oxygen demand created by its presence, and to obtain a measure of nutrient availability.

Suspended sediment.--Suspended sediment is important because it is visible. Also, because it is correlated directly with the concentration of other constituents, it would influence the choice of potential sedimentation-control techniques to be considered within the basin.

Dissolved chloride.--Although the use of deicing salt within the Irondequoit basin has been high in the past, it has been reduced substantially since 1974. This study provided a means to assess the effects of salt reduction through comparison of present chloride concentrations with those measured a decade before.

Heavy metals.--The three heavy metals--total lead, cadmium, and zinc--were deemed important because of their potential toxic effect on aquatic life in the creek and bay.

Runoff Characteristics

Growing-season loads

Runoff loads resulting from individual storms during the growing season were computed separately. Because water-quality sampling typically did not extend through the entire storm, the flow-weighted mean concentration of each constituent was computed for the sampled part of the storm. Storm loads were calculated only if sampling covered at least 60 percent of the storm and if at least five samples were analyzed. This mean concentration was then applied to the total runoff recorded for the storm to obtain the storm load. The estimated load carried by runoff during base-flow periods between storms was calculated from the same flow-weighted mean concentration method discussed previously. The total load produced during a given period was then calculated by summing the contributions from base-flow periods and storms.

Winter and spring loads

Runoff loads for the winter and spring periods were estimated from the flow-weighted mean concentration computed for each constituent during the period. This mean concentration was then multiplied by the volume of streamflow measured during the period to obtain the runoff load.

Snowmelt loads

Although the simulation of snowmelt runoff was not attempted in this study, it was assumed that runoff loads during this period would contribute a large percentage of the total annual load. Frequent sampling was therefore done during the snowmelt period of February 1981, which contained two major rainstorms. The estimated loads carried by the snowmelt runoff were calculated by the flow-weighted mean-concentration method.

Analysis of potential of wetlands to retain suspended sediments and nutrients

The Irondequoit wetland between Browncroft Boulevard and Irondequoit Bay (fig. 5) has been considered as a potential site for stormflow detention by temporary impoundment of storm runoff within the upper wetland to promote the settling of suspended sediment and nutrients from Irondequoit Creek. Several

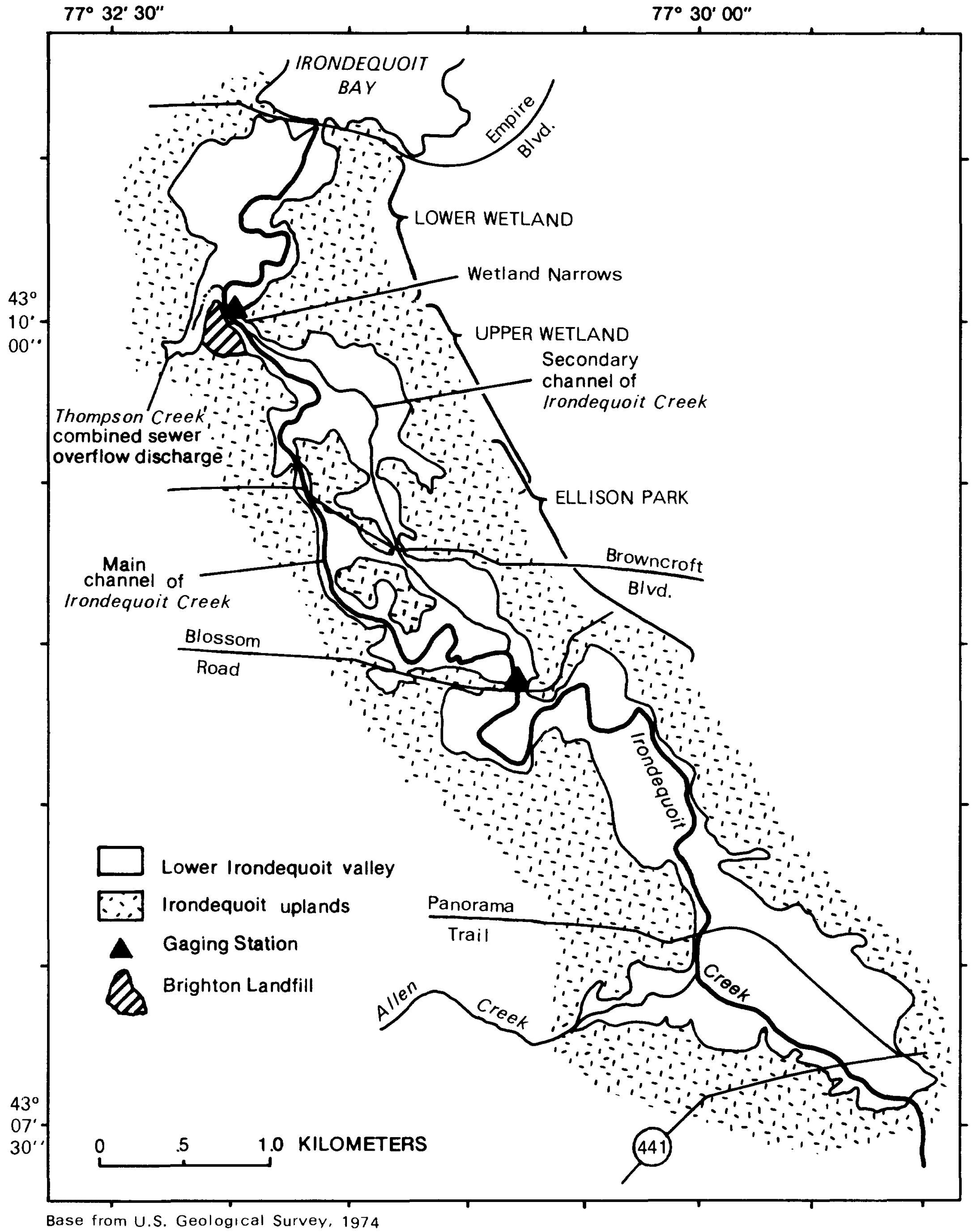

Figure 5.--Major features of lower Irondequoit Creek valley from State Route 441 north to Irondequoit Bay.

studies have indicated that these wetlands could act as nutrient- and sediment-retention areas (Hickok, 1980; Pratt and others, 1980; Brinson and others, 1981). The location of the wetlands would seem to provide an ideal setting for sediment retention, but managing the wetlands as a large detention basin will first require an evaluation of the present flow patterns and water-quality conditions as well as the potential for flooding and changes in the wetland ecosystem.

During the early part of the wetland investigation, it became apparent that not all of the wetland could be evaluated because its lower wetland unit was periodically affected by a large combined-sewer overflow. Just downstream from the Brighton landfill (fig. 5), which divides the wetland into a northern and a southern unit, a large 2.4-m-diameter combined sewer overflow for the City of Rochester discharges to Irondequoit Creek during storms. The septic discharge with peak flows of 12.7 m^3/s or more (Drehwing and others, 1981) alters the hydrologic and water-quality characteristics of the lower part of the wetlands. Therefore, the wetland-monitoring station was located at the Brighton landfill, just upstream from the CSO, where all streamflow is confined to a narrow channel known as the Narrows between the landfill and a steep hillside. A monitoring site upstream from the wetlands was located at Blossom Road in Ellison Park (fig. 5).

To define the present flow patterns of the wetland required flow analyses and water-quality data. The amount, timing, and duration of flood-plain inundation, subsequent flow to the secondary channel of Irondequoit Creek (fig. 5), and the dispersion of flows to the wetland were measured by direct discharge measurements and dye-tracing tests in the two stream channels and within the wetland. The wetland's ability to function as a large detention pond was evaluated by a computer reservoir-routing simulation to determine depth and duration of flooding behind theoretical control structures at the Narrows.

A requirement for the control structure under a high-flow and high lake-level condition was that the lowland flooding be comparable to present flooding conditions. Areas found to be vulnerable to flooding include Ellison Park and the relatively low-lying flood-plain highway crossings at Browncroft Boulevard and Blossom Road (fig. 5).

CHEMICAL QUALITY OF STORMWATER

Loads and Yields

The estimated loads of the eight runoff constituents measured at eight stations are presented in table 20 (at end of report). The table includes the runoff measured during each of the five seasonal sampling periods, and the flow-weighted mean concentration and load computed for each of the eight constituents. Loads contributed during base-flow periods within the growing season are reported separately from those contributed during storms.

Estimates of annual loads are based on the total loads for the storms and base-flow periods sampled. The daily average yield of each constituent was calculated by dividing the total sampled load by the drainage area upstream of the station and the number of days in the sampling period. In the computation of annual runoff loads, these daily yields were assumed to remain constant throughout the year. A detailed explanation of load and yield calculations is given in Zarriello and others (1984). Annual loads for the five larger subbasins are presented in table 5 along with the annual loads entering Irondequoit Bay. The latter were calculated by multiplying the annual loads at Blossom Road by a drainage-area factor of 1.17 to take into account the remaining 36 km^2 of area draining directly into the bay downstream from Blossom Road. (Land uses in this additional drainage area were considered similar to those upstream from Blossom Road.) The estimates do not include loads from the two Rochester combined sewer overflows because these are variable and were diverted out of the basin in 1985.

Constituent loads were highest in subbasins that produced the greatest volumes of storm runoff, which are the urban basins. Thus, even though the concentrations may at times have been higher in rural subbasins, the urbanized subbasins gave larger constituent yields.

Table 5.--Estimated annual loads of selected constituents (August 1980-August 1981) from each of the five larger subbasins of Irondequoit Creek[1] and estimated total annual loads to Irondequoit Bay[2].

[Site locations are shown in fig. 2.]

	Constituent[3]							
Site	TSS (Mg)	P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
Thornell Road	3,410	3,400	29,000	280	1,440	252	14,800	294
Thomas Creek	377	1,540	14,700	147	1,150	184	12,700	157
Linden Avenue	5,840	7,790	68,900	823	5,450	727	38,700	636
Allen Creek	2,170	3,560	33,400	355	3,660	1,190	15,300	374
Blossom Road	14,800	15,700	166,000	1,990	12,700	2,780	68,600	1,110
Annual load to Irondequoit Bay	17,300	18,400	194,000	2,300	14,900	3,250	80,300	1,300

[1] Value is product of daily yield (table 11 value x 365 days)
[2] Value is annual load at Blossom Road increased by 17.4 percent
[3] TSS, total suspended sediment; P, total phosphorus; TKN, total kjeldahl nitrogen; COD, chemical oxygen demand; Cl, dissolved chloride; Pb, total lead; Zn, total zinc; Cd, total cadmium.

Concentration Ranges

Measured concentrations of each constituent were highly variable during the study and typically ranged over three orders of magnitude. The maximum and minimum concentrations of the eight constituents at each station are plotted by constituent in figure 6. These plots indicate the range in mean concentration during 13 storms as well as the mean and flow-weighted mean for all samples analyzed. Also included for reference in figures 6E-6H are water-quality standards, where applicable, and drinking-water standards (U.S. Environmental Protection Agency, 1975) for four constituents--dissolved chloride, total lead, zinc, and cadmium. The Great Lakes Nearshore Index (GLNI) (Schierow and others, 1981) was selected as a standard for suspended sediment, phosphorus, dissolved chloride, and total lead, zinc, and cadmium.

Temporal and Spatial trends

Suspended sediment

The snowmelt period between late January and early March 1981 accounted for more than 50 percent of the annual suspended-sediment load at all sites sampled; the sampled storms contributed another 20 percent. The estimated annual yields in megagrams per square kilometer (Mg/km^2) from each subbasin and site were as follows:

Subbasin	Yield (Mg/km^2)	Site	Yield (Mg/km^2)
Thornell Road	29.6	Cranston Road	24.6
Thomas Creek	5.1	Southgate Road	57.3
Linden Avenue	23.4	East Rochester (storm period)	187
Allen Creek	32.6		
Blossom Road	43.3		

The estimated annual yield was 23 to 57 Mg/km^2 for all subbasins except Thomas Creek, which yielded 5.15 Mg/km^2. Thomas Creek is a rural subbasin that contains large wetland areas and has low stream gradients. The mean concentration computed for each sampling period was greater than the Great Lakes Nearshore Index except in the spring runoff period. The average flow-weighted mean concentration at the most downstream station, Blossom Road, was six times the Great Lakes standard (fig. 6A). The highest yield among the three land-use sites during storms was East Rochester--the high-density residential site.

Total phosphorus

Total phosphorus loads from all subbasins showed a seasonal pattern, in which the 3-month snowmelt/spring runoff period accounted for nearly 50 percent of the annual load, and the sampled storms contributed an additional 20 percent. The estimated annual yields from each subbasin and site were as follows:

Subbasin	Yield (kg/km^2)	Site	Yield (kg/km^2)
Thornell Road	29.6	Cranston Road	68.6
Thomas Creek	20.9	Southgate Road	75.6
Linden Avenue	31.3	East Rochester (storm period)	405
Allen Creek	53.4		
Blossom Road	46.0		

Annual yields were highest in the urbanized subbasins (Allen Creek, Linden Avenue, and Blossom Road) and averaged 42 kg/km^2--nearly twice the yield of the rural/agricultural subbasins (Thornell Road and Thomas Creek). As indicated in figure 6B, computed flow-weighted mean concentrations and mean storm concentrations were all above the level of total phosphorus associated with the mesotrophic/eutrophic boundary for freshwater lakes, and the flow-weighted mean concentration at Blossom Road was eight times this reported value (Schierow and others, 1981). The high-density-residential site (East Rochester) was the major contributing site during storms.

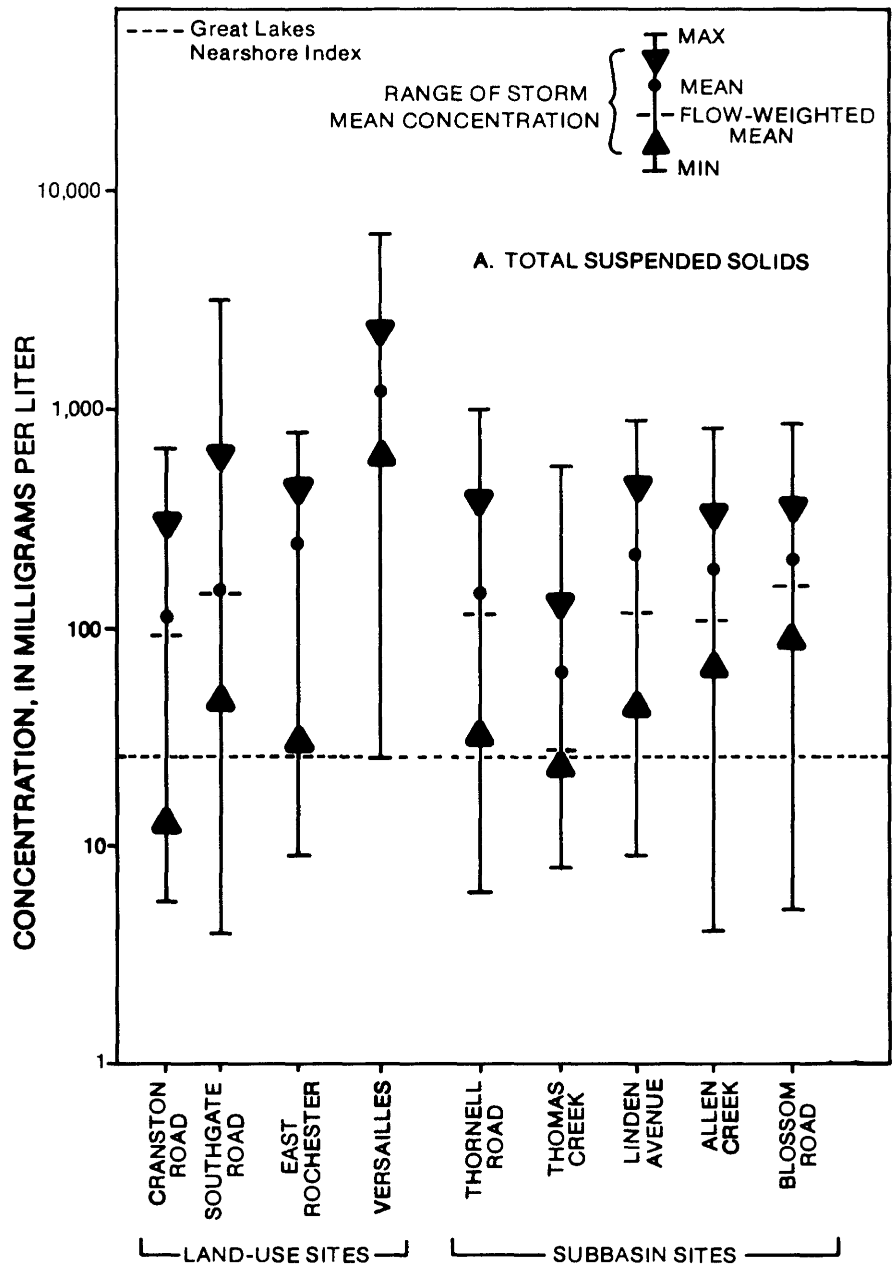

Figure 6A.--Range of total suspended-sediment concentrations in stormwater samples.

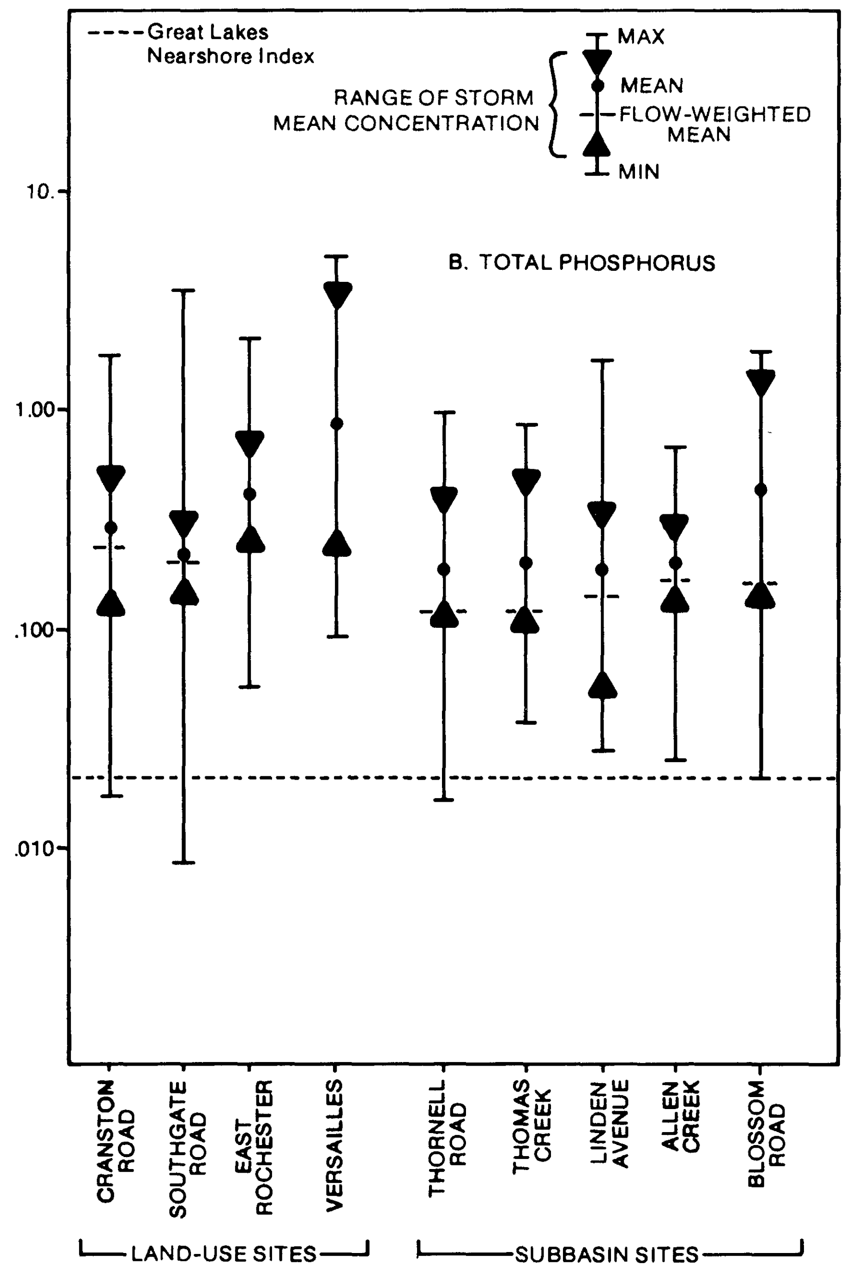

Figure 6B.--Range of total phosphorus concentrations in stormwater samples.

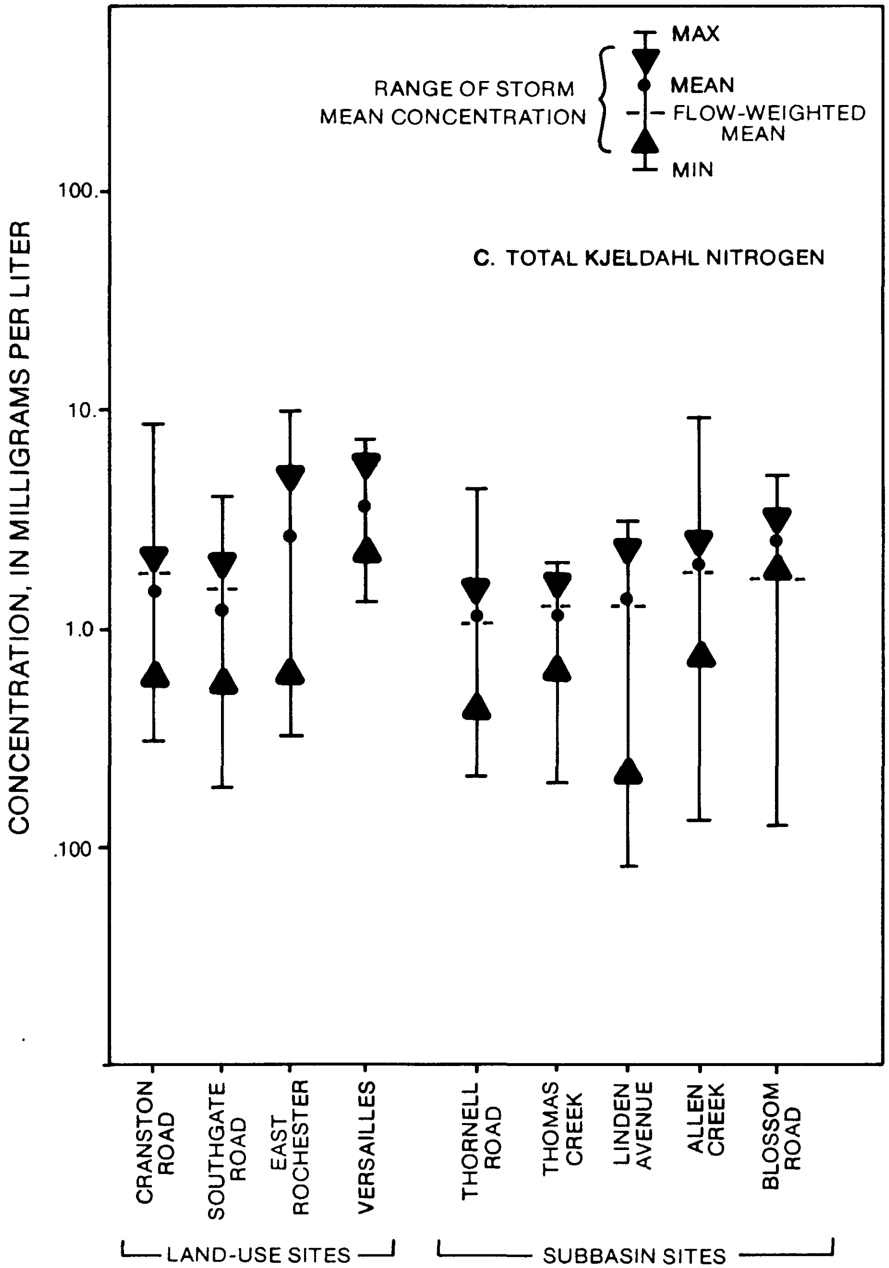

Figure 6C.--Range of total kjeldahl nitrogen concentrations in stormwater samples.

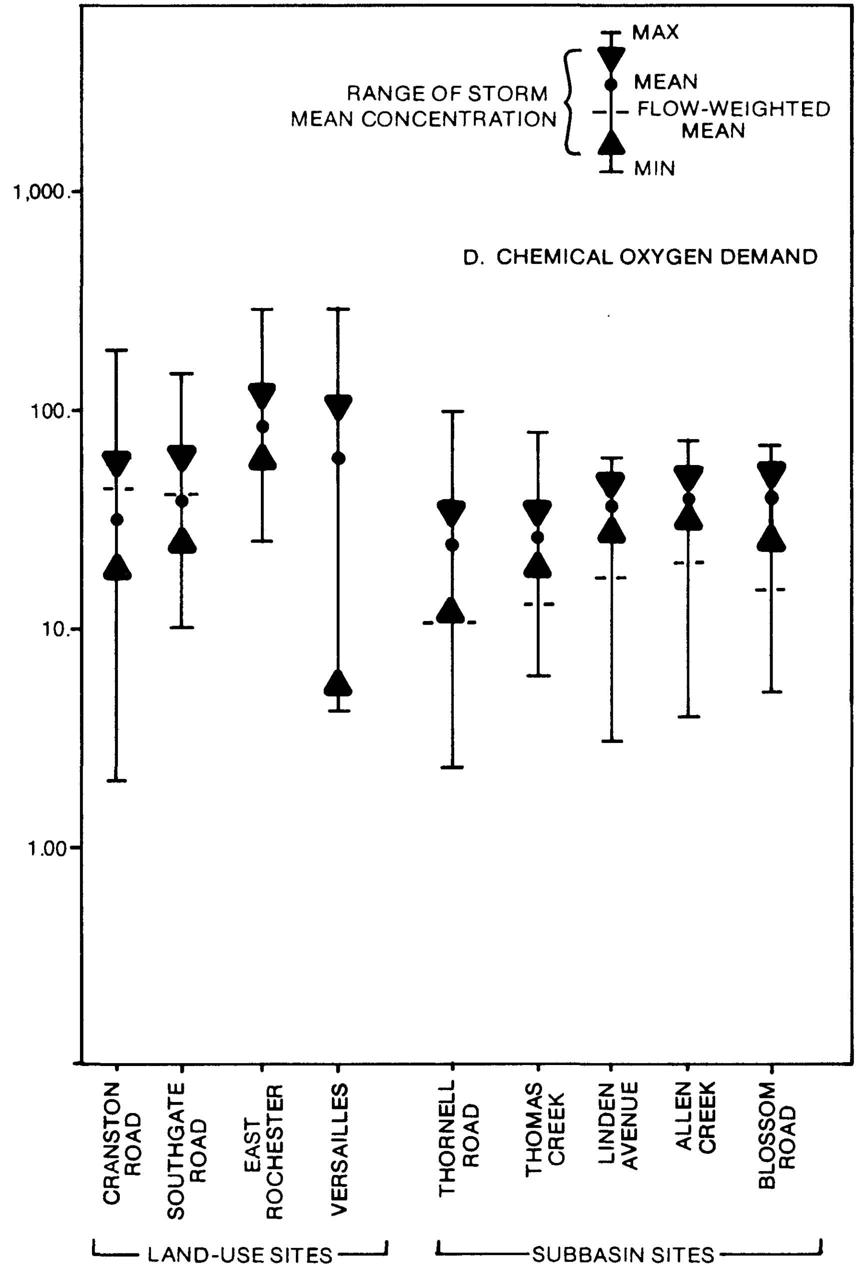

Figure 6D.--Range of chemical oxygen demand in stormwater samples.

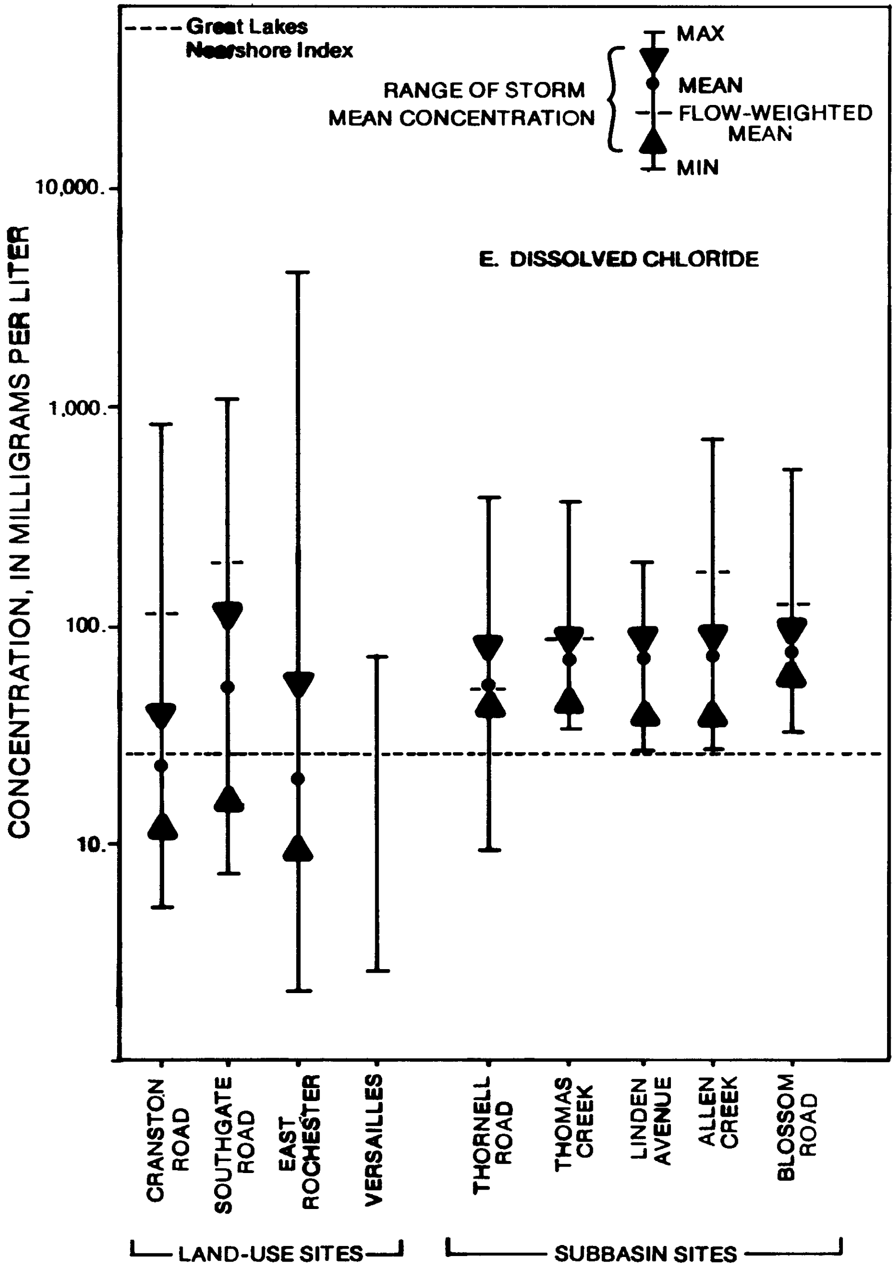

Figure 6E.--Range of dissolved chloride in stormwater samples.

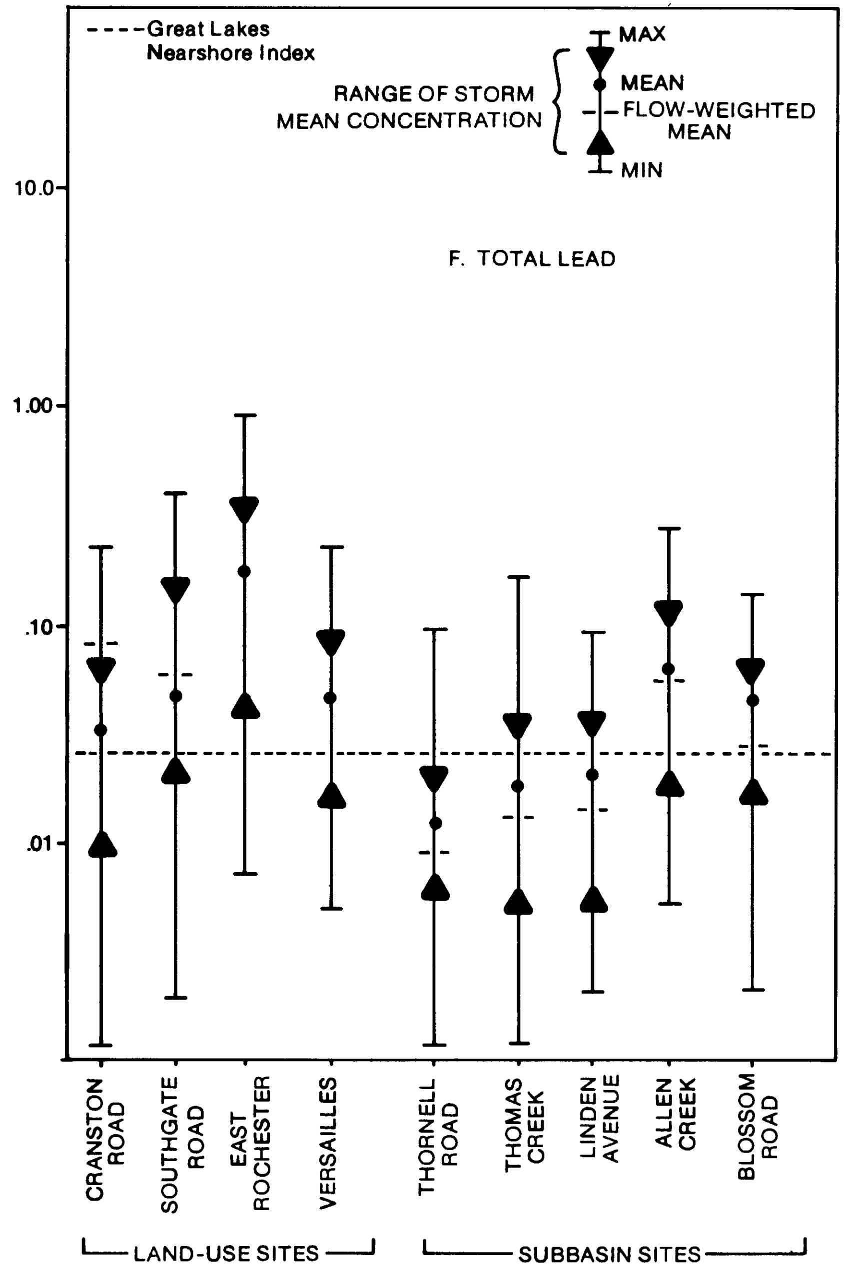

Figure 6F.--Range of total lead concentrations in stormwater samples.

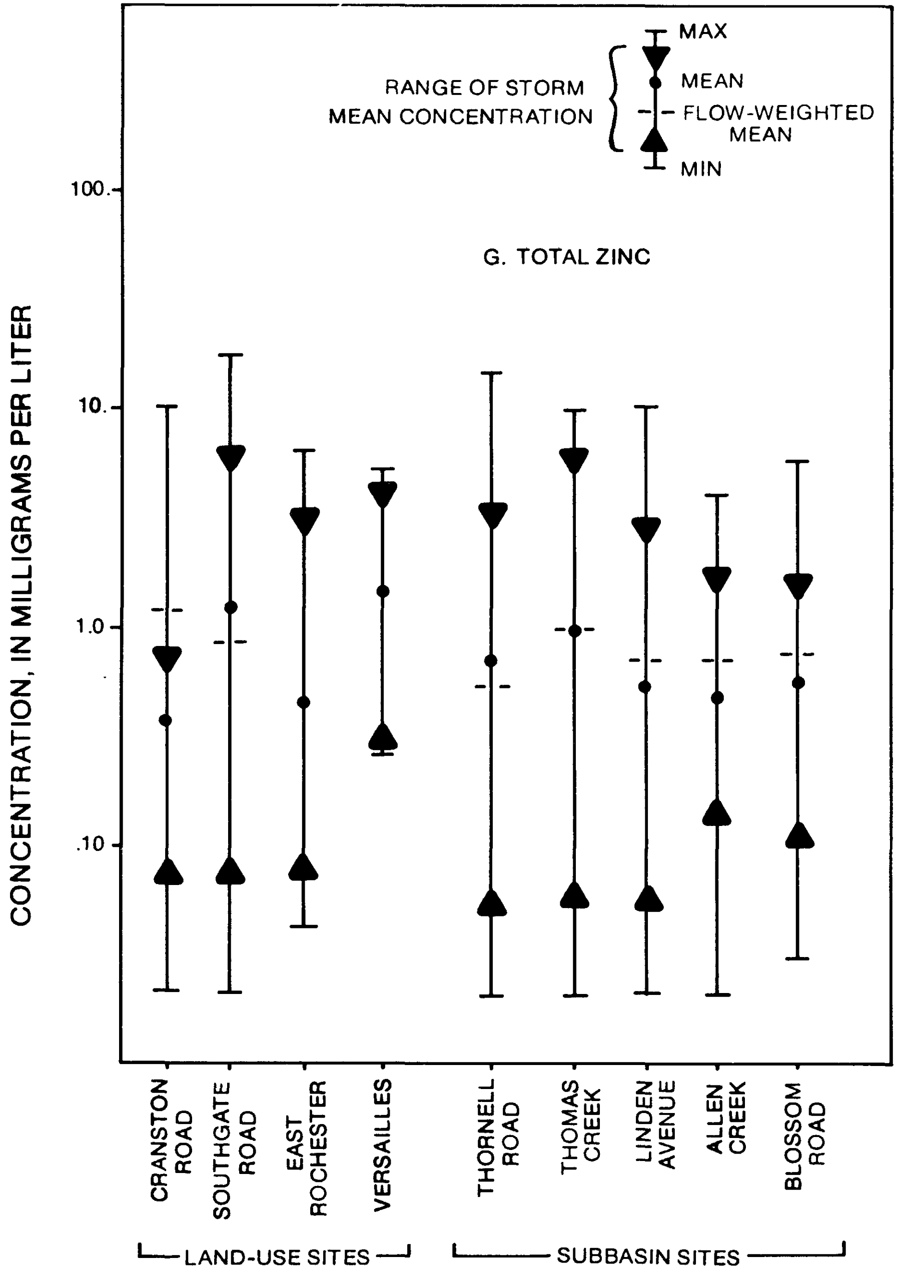

Figure 6G.--Range of total zinc concentrations in stormwater samples.

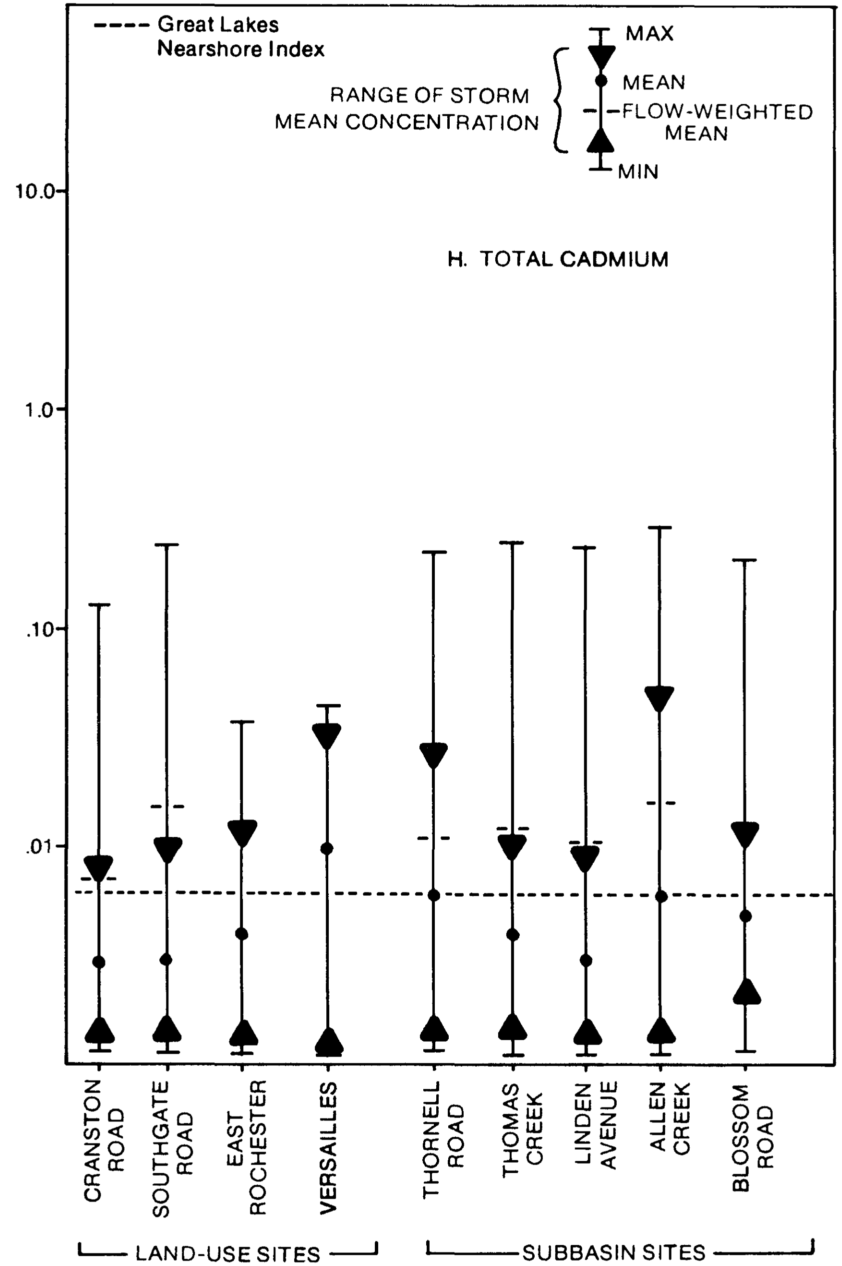

Figure 6H.--Range of total cadmium concentrations in stormwater samples.

Total kjeldahl nitrogen

The seasonal distribution of the TKN load from all basins followed the pattern of total phosphorus. The snowmelt and spring runoff periods accounted for 40 percent of the annual load, and the storms provided an additional 15 percent. Estimated annual yields were as follows:

Subbasin	Yield (kg/km^2)	Site	Yield (kg/km^2)
Thornell Road	252.	Cranston Road	500.
Thomas Creek	199.	Southgate Road	551.
Linden Avenue	276.	East Rochester (storm period)	2380.
Allen Creek	501.		
Blossom Road	486.		

The urbanized subbasins (Allen Creek, Linden Avenue, and Blossom Road) produced the highest annual yields, approximately 412 kg/km^2, which was twice the yield from the large rural subbasins (Thornell Road and Thomas Creek). The average mean storm concentration at all subbasins was in the range of 1 to 3 mg/L (fig. 6C). No USEPA or State water-quality standards have been established for total kjeldahl nitrogen. The high-density residential site (East Rochester) was the major contributor during storms.

Chemical oxygen demand

The annual load of chemical oxygen demand (COD) from all basins was more equally distributed among the sampling periods than total kjeldahl or phosphorus. The largest percentage of the load was during the snowmelt and spring runoff periods. Annual yields were as follows:

Subbasin	Yield (Mg/km^2)	Site	Yield (Mg/km^2)
Thornell Road	2.43	Cranston Road	9.09
Thomas Creek	1.99	Southgate Road	22.4
Linden Avenue	3.30	East Rochester (storm period)	63.5
Allen Creek	5.33		
Blossom Road	5.83		

Annual yields from most subbasins were from 2 to 6 Mg/km^2. The high yield from the Southgate Road site (commercial/medium-density residential) may be due, in part, to the lowland area between the shopping center and the measurement site. The flow-weighted mean COD concentration computed for Blossom Road was 15 mg/L; well below the 20- to 30-mg/L BOD concentration typically found in secondary-treatment effluent. However, the average of all mean storm concentrations is roughly equal to this secondary effluent value. Because the COD analysis measures a greater percentage of organic material than the BOD analysis, the COD loads reported for Blossom Road could be less than those associated with treatment-plant effluent. East Rochester, the high-density residential site, was again the major contributing site during storms, possibly because the storm-water drainage system receives a small amount of continual septic flow.

Dissolved chloridide

Annual dissolved chloride loads were typically highest at most sites during the snowmelt period. The sampled storms accounted for 10 percent of the annual load from all sites. Annual yields were as follows:

Subbasin	Yield (Mg/km^2)	Site	Yield (Mg/km^2)
Thornell Road	12.5	Cranston Road	32.9
Thomas Creek	15.6	Southgate Road	71.9
Linden Avenue	21.9	East Rochester (storm period)	22.3
Allen Creek	54.9		
Blossom Road	37.2		

Computed annual yields from the urbanized subbasins were as much as four times greater than those from rural/agricultural subbasins. The average mean storm concentrations of chloride computed for nearly all sampling periods were above the Great Lakes Nearshore Index for chloride (fig. 6D), and the average flow-weighted mean chloride concentration at Blossom Road was five times greater than the standard. The commercial land-use site (Southgate Road) was the major contributor during storms, presumably because of road salt used on the major roads leading to the commercial area and the large number of cars depositing road-salt residue in the parking lots.

During the winter of 1980-81, approximately 29,000 Mg of deicing salts were applied within the Irondequoit basin. This value was calculated from the quantity reported by each Town and the percentage of total road miles in the basin represented by that Town. The 1980-81 estimate represents a 60-percent decrease in use of road-deicing salts within a decade; Diment and others (1974) reported the application of road salts in the basin to have been 76,600 Mg in 1969-70 and 73,500 Mg in 1970-71.

The 12,700 Mg of dissolved chloride calculated at Blossom Road during 1980-81, compared to the reported annual loads of 28,500 Mg for 1970-71 and 39,100 Mg for 1971-72 at Browncroft Boulevard (Diment and others, 1974), represents a 60-percent reduction in chloride loads to Irondequoit Bay. The slight difference in drainage area between Blossom Road and Browncroft Boulevard is not significant to this calculation.

Expressed in terms of sodium chloride ($NaCl$), which is the most common road-deicing salt, the 12,700 Mg of chloride measured at Blossom Road is equivalent to 20,900 Mg of deicing salt. This suggests that 16 percent of the chloride applied to roads as $NaCl$ during the 1980-81 study was retained within the soils, and the rest was washed into Irondequoit Creek and Bay. The ratio of the road-deicing salt quantity to the annual chloride loads in Irondequoit Creek (2:1) is consistent with Diment's findings in his study of deicing salts in 1971.

Total lead

The snowmelt and spring runoff periods accounted for nearly 70 percent of the annual lead load at all sites, and storms contributed another 20 percent. Annual yields of total lead were:

Subbasin	Yield (kg/km^2)	Site	Yield (kg/km^2)
Thornell Road	2.19	Cranston Road	24.8
Thomas Creek	2.49	Southgate Road	25.2
Linden Avenue	2.92	East Rochester (storm period)	153
Allen Creek	17.9		
Blossom Road	8.1		

The urbanized Allen Creek subbasin produced the highest annual subbasin yield of 17.5 kg/km^2, six times the yield of the other urbanized basin (Linden Avenue) and eight times the yield from the Thornell Road and Thomas Creek subbasins. The Cranston Road and Southgate Road yields were approximately equal and nearly 1.5 times the Allen Creek yield. Mean storm concentrations of total lead were slightly above the Great Lakes Nearshore Index at most stations throughout the year. The flow-weighted mean concentration at Blossom Road was approximately equal to the level reported as the standard (fig. 6F). The high-density residential site at East Rochester was the major contributor during storms.

Total zinc

The snowmelt period accounted for 60 percent of the annual load of total zinc at all sites; storms provided an additional 10 percent. Annual yields of total zinc were:

Subbasin	Yield (kg/km^2)	Site	Yield (kg/km^2)
Thornell Road	129.	Cranston Road	363.
Thomas Creek	172.	Southgate Road	301.
Linden Avenue	155.	East Rochester (storm period)	363.
Allen Creek	230.		
Blossom Road	201.		

The average mean storm concentrations of total zinc were high compared with recent published values for storm runoff (U.S. Environmental Protection Agency, 1982). A possible source of the zinc may be the mineral sphalerite (zinc sulfide), which occurs in the Silurian Lockport Dolomite that underlies the central part of the basin and is also within the drift and soils derived from it. The mean flow-weighted concentration at Blossom Road was 0.74 mg/L (fig. 6G).

Total cadmium

The spring runoff accounted for nearly 75 percent of the annual cadmium load at most sites; only 5 percent was recorded during storms. Annual estimated yields of cadmium were:

Subbasin	Yield (kg/km^2)	Site	Yield (kg/km^2)
Thornell Road	2.56	Cranston Road	2.19
Thomas Creek	2.13	Southgate Road	6.20
Linden Avenue	2.55	East Rochester (storm period)	2.92
Allen Creek	5.62		
Blossom Road	3.25		

The highest annual yield (6.2 kg/km^2) was produced in the commercial subbasin (Southgate Road); this value is slightly higher than that for Allen Creek basin and nearly three times the yield of the other subbasins.

Although constituent concentrations differed among the sites and subbasins, the greater loads and yields were found in the more urbanized basins. The highest loads of all constituents except cadmium were from the high-density residential site at East Rochester. Among the six large mixed land-use subbasins, the highest loading rates were from the two most highly urbanized (Allen Creek and Linden Avenue). The high yields noted at Blossom Road may be attributed to (1) deposition during non-storm periods and resuspension during storm periods, and (2) the estimation of flow and water quality during the first 4 months of the sampling period (August through November 1980).

Runoff Quality at a Housing-Construction Site

Mean concentrations of total phosphorus, total kjeldahl nitrogen, suspended sediment, total lead, total cadmium, total zinc, and chemical oxygen demand at the Versailles housing-construction area (site C, fig. 2) were calculated from water samples collected during seven storms from June through August 1981. Stormflow hydrographs were developed from rated staff-gage readings, and total storm loads for eight constituents (table 6) were then calculated for each storm as the product of total runoff volume and the mean storm concentration.

The mean storm-concentration data were compared with data from the five NURP land-use areas to assess the differences in chemical concentrations. The

Table 6.--Runoff concentrations and runoff loads during selected storms at Versailles housing-construction site (0.91 km^2).

[Location is shown in fig. 2.]

Date	Rainfall (cm)	Runoff (cm)	Mean concentrations (mg/L)							
			TSS	Total P	Ortho P	TKN	COD	Pb	Zn	Cd
06-21-81	9.65	7.54	640	0.303	0.209	2.86	5.2	0.015	0.267	0.002
06-22-81	16.2	2.09	989	.239	.102	3.03	36.7	.034	.357	.035
07-02-81	14.0	1.60	2043	3.68	.095	6.24	110.	.093	2.20	.004
07-20-81	42.2	14.5	855	.384	.106	2.42	49.0	.024	2.90	.001
07-28-81	21.6	3.56	588	--	--	--	--	.042	.320	.022
08-04-81	21.6	3.43	2535	.556	.067	5.28	103.	.092	.606	.002
08-11-81	43.2	17.4	809	.216	.128	2.76	56.9	.031	4.40	.005
			Loads (kg)							
			TSS	Total-P	Ortho P	TKN	COD	Pb	Zn	Cd
06-21-81	9.65	7.54	1160	0.549	0.526	5.17	93.9	0.026	0.481	0.004
06-22-81	16.2	2.09	2970	.717	.306	9.07	110.	.103	1.07	.106
07-02-81	14.0	1.60	5380	9.71	.250	16.5	289.	.244	5.81	.013
07-20-81	42.2	14.5	6890	3.08	.826	19.4	399.	.190	21.4	.010
07-28-81	21.6	3.56	2230	--	--	--	--	.159	1.22	.008
08-04-81	21.6	3.43	9340	2.04	.247	19.4	379.	.339	2.23	.009
08-11-81	43.2	17.4	7470	1.95	1.18	25.5	526.	.287	40.3	.036

SAS (Statistical Analysis System) ANOVA (Analysis of Variance) procedure (SAS, 1982) with the Duncan option was chosen for this analysis because the mean concentration value was assumed to be representative of a flow-weighted mean concentration that approximated a normal distribution (Daniel, 1974).

The Duncan test ranked, by constituent, sites that had mean storm concentrations statistically similar to those measured at the Versailles site; results are given in table 7. The table shows only the sites with highest concentration of each constituent. Within each constituent group, the sites are listed in order of highest to lowest concentration. The Versailles site had significantly higher suspended sediment than all other sites, but the Thornell Road site had the highest mean storm concentration of cadmium. Mean storm concentrations at the other sites were lower than, but statistically similar to, those measured at Versailles.

Table 7.--Basins with constituent concentrations statistically similar to those at Versailles housing-construction site, as determined by analysis-of-variance Duncan test.

[Sites are listed in order of decreasing mean storm concentration.]

Suspended sediment	Total phosphorus	Total kjeldahl nitrogen	Chemical oxygen demand	Total lead	Total zinc	Total cadmium
--	East Rochester	East Rochester	East Rochester	Southgate Rd.	Southgate Rd.	Thornell Rd.
				Cranston Rd.	Thornell Rd.	Southgate Rd.
				Thornell Rd.	Cranston Rd.	Cranston Rd.
					E. Rochester	E. Rochester

The results of this analysis indicate that areas in which extensive soil excavation has recently occurred produce high suspended-sediment loads even when detention ponds, straw-bale check dams, and other erosion-control measures are in place. Total phosphorus, total kjeldahl nitrogen, and chemical oxygen demand measured at the Versailles site were also larger than average mean concentrations in agricultural and moderately urbanized areas but were similar to concentrations at the East Rochester high-density residential area. The concentrations of the heavy metals (total lead, zinc, and cadmium) measured at the Versailles site are similar to those at both the rural and urbanized parts of the Irondequoit watershed, but Versailles showed the highest mean storm concentration of all heavy metals except cadmium.

Relation of Particle-Size Distribution of Suspended Sediment to Phosphorous Concentration

One of Monroe County's concerns in the Irondequoit Creek basin study is the reduction of nonpoint-source loads of phosphorus and suspended sediment to Irondequoit Bay. The county and their consultants reviewed previous water-quality data and initial results of this study to determine which methods would be considered. The reduction of phosphorus load, the reduction of erosion from agricultural and developing parts of the basin, and the reduction of suspended-sediment yields from the streams draining the basin were considered to be the most important criteria for evaluation of methods (O'Brien and Gere, 1983).

Particle-size distribution

Evaluation of the load-reduction methods required an understanding of the relationship between the particle-size distribution of suspended sediment and the concentration of dissolved and total phosphorus. A summary of particle-size distribution at nine sites is shown in table 8.

Table 8.--Average particle-size distribution of suspended sediment at five subbasins and four land-use sites within the Irondequoit Creek basin.

[Locations are shown in fig. 2.]

Station	Number of samples	Clay %	Silt %	Sand %
Thornell Road	5	34	60	6
Thomas Creek	3	37	55	8
Linden Avenue	4	23	67.5	9.5
Allen Creek	3	31.5	61	7.5
Blossom Road	4	24	71	5
Cranston Road	2	30	58	12
East Rochester	3	24	53	23
Southgate Road	5	21	62	17
Versailles	5	32	65	3
Mean		28.5	61.4	10.1
Standard deviation		5.62	5.78	6.34

The basinwide average particle-size distribution was 29 percent clay, 61 percent silt, and 10 percent sand. Two factors influencing the particle-size distribution in suspended sediments are the glacial origin of the soils and type of stormwater-drainage system. Within the high-density residential area at East Rochester, the soils are derived from sandy and gravelly glacial deposits, and the stormwater drainage systems are highly efficient street drains and storm sewers. Suspended sediments from this area therefore contain more sand than the other single-land-use sites, which drain till soils and have both storm sewers and natural channels (table 8). In the larger subbasins, which have a higher degree of urbanization and more efficient stormwater systems, the particle-size distribution is shifted toward the larger particles.

Suspended-sediment concentrations

The average suspended-sediment concentration at all sites except the housing-construction site at Versailles was 136 mg/L. The Thomas Creek subbasin had the lowest average concentrations (89 mg/L) owing to the high proportion of undeveloped land, the low stream gradient, and the presence of contiguous wetlands along most of the stream channel. The Thornell Road site had a higher sediment concentration (129 mg/L), probably because it represents more agricultural land, and the soil is derived from clayey lacustrine deposits. The Allen Creek and Cranston Road basins, which contain soils derived from till, yielded intermediate concentrations (102 mg/L and 104 mg/L, respectively). These latter values are attributed to the greater degree of urbanization and the more efficient stormwater-drainage systems than at the Thomas Creek site. The

East Rochester and Southgate Road land-use basins yielded high concentrations (197 mg/L and 194 mg/L, respectively) that are attributed to the highly efficient stormwater-drainage systems, which transported more suspended material than the natural stream courses of the other urbanized basins. The Linden Avenue and Blossom Road stations also yielded high concentrations (164 mg/L and 158 mg/L, respectively) because of the mixing of sediment from the several subbasins upstream. The Versailles housing-construction site yielded the highest average concentration (1,943 mg/L) as a result of the recent earth-moving operations, which disturbed the vegetation and exposed the soils which are derived from lake deposits of silt and very fine sand. This led to a high rate of erosion, as reflected by the high suspended-sediment concentrations.

Phosphorus-to-sediment relationship

The relationship of phosphorus to sediment was investigated through SAS STEPWISE (Statistical Analysis System, 1982), a multiple-linear-regression program, from data that were first log-transformed to obtain a near-normal distribution. Correlations were also drawn between phosphorus and total discharge and between phosphorus and total rainfall to discern which would best explain the variance in the phosphorus data. Most analyses showed that sediment was the variable most closely correlated to phosphorous. The addition of discharge or precipitation variables gave little or no improvement. The coefficient of determination[1] (r^2) of sediment on phosphorous were:

Subbasin	r^2	Site	r^2
Thornell Road	0.44	Cranston Road	0.54
Thomas Creek	.47	Southgate Road	.58
Linden Avenue	.43	East Rochester (storm period)	.20
Allen Creek	.82		
Blossom Road	.45		

The low r^2 value for East Rochester suggests that the septic wastes observed in the storm sewer greatly influenced phosphorus values within this basin.

The results of the STEPWISE regression models explained about half the phosphorus variance at the 0.95 significance level and would not be useful as a predictive tool for most sites examined. In a similar study, Zison (1980) found the variance in several constituents, including phosphorus, to be largely a function of land use. The results of the regression analysis mentioned above indicated linear correlation between phosphorus and sediment, but the data obtained in this study were insufficient to show which size range is associated with the phosphorus.

The relationship between phosphorus and sediment was also examined by Sartor and Boyd (1972) in a study of contaminants derived from street surfaces. Their findings indicated a higher fraction of phosphorus with decreasing particle size, but their study examined only fine-sand-sized particles of 43 µm and larger in diameter.

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[1] These r^2 values represent the variation as determined by the regression equation--a value of 0.70 is considered significant in regression analysis.

The relationship of sediment to phosphorus was also tested in the present Irondequoit basin study through the SAS CORR (correlation) and GLM (General Linear Model) procedures of Statistical Analysis Systems (1982). Neither one indicated a significant relationship between phosphorus and sand, silt, or clay-size fractions.

Reduction of phosphorus by sediment removal

A comparison of total phosphorus to dissolved phosphorus concentrations revealed that 60 to 85 percent of the total measured phosphorus is in particulate form. A similar percentage of the suspended sediment is silt and sand-sized particles that could be removed by settling. The data suggest that methods designed to reduce phosphorus by removing the sediment to which it is adsorbed would need to remove particles as small as the silt fraction to be effective.

Potential removal efficiencies are difficult to estimate because they depend upon the configuration of the detention basin and type of materials that enter them. However, results of the wetland study, described further on, suggest that the potential for reducing sediment and the associated phosphorus loads in the wetland is great enough to warrant further investigation of detention-pond designs.

CHEMICAL QUALITY OF ATMOSPHERIC DEPOSITION

Yields

Yields of total phosphorus, total kjeldahl nitrogen, dissolved chloride, and total lead in wetfall and dustfall at three sites within the Irondequoit basin--Mendon Ponds Park (124-km^2 drainage area), East Rochester Middle School (128-km^2 drainage area), and Perinton Square Mall (90-km^2 drainage area) (gages R4, R11, and R8, in fig. 2)--were computed from measurements of dustfall and wetfall samples. The area represented by each atmospheric-quality collector was determined by the Theissen Polygon method, by which bisecting lines are drawn between stations to geometrically divide a basin. The yields for each collector were summed to provide the total atmospheric yields to the Irondequoit Creek basin upstream from Blossom Road. Results are given in table 9.

Loads

Total phosphorus

The annual atmospheric load of total phosphorus was about 65 percent of the stream load; 66 percent of the atmospheric load occurred as dustfall.

Total kjeldahl nitrogen

The total kjeldahl nitrogen (TKN) atmospheric load exceeded the amount transported out of the basin in runoff by about 25 percent, indicating that approximately 60 Mg was retained in the Irondequoit basin during the data-collection period. Similar retention of nitrogen has been observed in other studies (Pearson and Fisher, 1971: Betson, 1978; and Peters and Bonelli, 1982). Approximately two-thirds of the total atmospheric TKN was in the wetfall.

Table 9.--Yields of phosphorus, nitrogen, chloride, and lead in wetfall and dustfall at three sit and ratio of atmospheric load to estimated streamflow load at Blossom Road.

Constituent	Estimated annual wetfall plus dustfall yields (kg/km^2)			Estimated basin loads (kg)		Ratio of total atmospheric load to total streamflow load (percent)
	Perinton Square Mall (90 km^2)	E. Rochester Middle School (128 km^2)	Mendon Ponds Park (124 km^2)	Atmospheric	Streamflow at Blossom Road	
WETFALL						
Total phosphorus	21.1	15.2	11.0	5.21×10^3	23.7×10^3	22
Total kjeldahl nitrogen	544.	444.	384.	$153. \times 10^3$	$166. \times 10^3$	92
Dissolved chloride	1620.	4210.	582.	$757. \times 10^3$	$12,700. \times 10^3$	6
Total lead	29.1	2.24	13.3	4.56×10^3	2.78×10^3	164
DUSTFALL						
Total phosphorus	13.3	22.5	49.2	10.2×10^3	23.7×10^3	43
Total kjeldahl nitrogen	140.	175.	290.	71.0×10^3	$166. \times 10^3$	43
Dissolved chloride	511.	1330.	231.	$245. \times 10^3$	$12,700. \times 10^3$	2
Total lead	49.4	46.5	24.2	13.4×10^3	2.78×10^3	482
TOTAL COMBINED (wetfall + dustfall)						
Total phosphorus	34.4	37.7	60.2	15.4×10^3	23.7×10^3	65
Total kjeldahl nitrogen	684.	619.	674.	$224. \times 10^3$	$166. \times 10^3$	135
Dissolved chloride	2130.	5540.	813.	$1000. \times 10^3$	$12,700. \times 10^3$	8
Total lead	78.5	48.7	37.5	18.0×10^3	2.78×10^3	647

Dissolved chloride

Atmospheric deposition of chloride accounted for only 8 percent of the observed stream load. The most likely other source of chloride is road-deicing salts. An estimated 29,000 Mg was used during the winter of 1980-81. If this was in the form of sodium chloride, the most commonly used form, 16 percent of the chloride in the deicing salts would be retained within the basin; some of these salts would be resuspended by wind and traffic and would settle as dustfall.[1]

Total lead

Approximately three-fourths of the total atmospheric contribution of lead was in dustfall, and nearly 85 percent of the atmospheric lead load was retained in the basin (table 9). The ratio of annual atmospheric load to annual stream load was the same as that observed by Troutman and Peters (1982) in a remote location in the Adirondack Mountains of New York State. The ratio of annual atmospheric lead contribution to stream load for the Irondequoit basin as measured at Blossom Road was 6.5. Betson (1978) reported ratios ranging from 0.54 in rural areas of Tennessee to 17.0 in urbanized parts of Knoxville, Tenn. Combining the rural land-use percentages for the Blossom Road subbasin with the lead ratios reported from the Knoxville study (Betson, 1978) as follows:

$$\text{Ratio} = \begin{array}{c}\text{rural}\\ \text{Tenn.}\\ \text{ratio}\end{array} \times \begin{array}{l}\text{\% of Blossom}\\ \text{Road basin}\\ \text{that is rural}\end{array} + \begin{array}{c}\text{urban}\\ \text{Tenn.}\\ \text{ratio}\end{array} \times \begin{array}{l}\text{\% of Blossom}\\ \text{Road basin}\\ \text{that is urban}\end{array} \qquad (1)$$

and substituting the values given above and the rural and urbanized percentages as computed for Blossom Road (67 and 33 percent, respectively) yields a value of 6.0--close to the 6.5 ratio measured at Blossom Road.

Considerations in Interpreting Atmospheric Contributions

In general, results of the Irondequoit Creek atmospheric-monitoring program are comparable to those obtained by Peters and Bonelli (1982), Betson (1978), Troutman and Peters (1982), and Pearson and Fisher (1971). Thus, atmospheric deposition contributes a substantital percentage of the chemical load of Irondequoit Creek except for chloride.

The interactions of phosphorus, nitrogen, lead, and chloride from the time of deposition through stream assimilation and transport are not well understood, and many uncertainties are associated with atmospheric sampling as well. For example, Galloway and Likens (1976) cited sample contamination by birds and insects, areal variability in precipitation, and transport mechanisms--particularly those pertaining to dustfall particles--as contributing to the uncertainty of atmospheric sampling. Another major concern is to determine the appropriate number of samples and representative locations for samplers. Thus, results of the atmospheric-deposition sampling indicate only the magnitude of chemical contributions from atmospheric sources and should be used with extreme caution in calculating seasonal values of deposition, accumulation, or washoff to streams.

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[1] See discussion of dissolved chlorides in runoff in "Temporal and Spatial Trends" section, p. 27.

RAINFALL-RUNOFF-QUALITY MODELING

One objective of the Irondequoit study was to examine the usefulness of simulation models to predict chemical concentrations in storm runoff from various land-use areas. The stormwater yields predicted by the rainfall-runoff routing quality model (DR3M-QUAL) were compared with the yields observed at the outlets of several watersheds. A major aspect of this effort was to test the accuracy of discrete land-use-site models that had been calibrated for watersheds smaller than 2 km^2 in simulating runoff quality in mixed land-use subbasins larger than 65 km^2.

Description of Model

The model selected for this analysis was the Distributed Routing Rainfall-Runoff Quality Model developed by the U.S. Geological Survey. The model consists of two parts--a rainfall-runoff model, DR3M (Alley and Smith, 1982a), and a runoff-quality model, DR3M-QUAL (Alley and Smith, 1982b). The water-quality algorithms in DR3M-QUAL are based upon formulations incorporated in other models, such as STORM (U.S. Army Corps of Engineers, 1976) and SWMM (Metcalf and Eddy, Inc., and others, 1971). The models are part of a program package that includes a data-management system that is compatible with the U.S. Geological Survey WATSTORE system, which contains precipitation, streamflow, and water-quality data.

The DR3M (rainfall-runoff component) is an event-based model for routing storm runoff through a system of pipes and (or) channels with rainfall quantity as input. The storm runoff is routed by an algorithm based on kinematic wave theory. The DR3M-QUAL (runoff-quality component) can be used to compute storm-runoff loads and can plot concentrations of up to four constituents in relation to time during a storm. Together these components provide detailed simulation of selected storms and a daily accounting of soil moisture and surface load between storms. Each component can be run in either a "lumped parameter" mode or a "distributed-parameter" mode.

Lumped-parameter mode

In the lumped-parameter mode, average hydrologic values are used for the entire watershed. After calibration in the lumped-parameter mode, the watershed can be represented as a system of overland flow planes linked by channel segments to the outlet. Each of these planes and channel segments is characterized by a set of parameters.

The watershed is conceptualized as a set of pervious and impervious surfaces linked to the basin outlet by a series of channels. In the lumped-parameter mode, the model computes the total runoff volume generated by a storm for the defined physical configuration of the basin. A simplifying assumption is that all rainfall on effective impervious surfaces (for example, streets and driveways) is discharged as runoff once depression storage has been filled, and rainfall on noneffective impervious surfaces (for example, rooftops draining onto lawns) is transferred to pervious surfaces. Pervious-area runoff is computed by subtracting stormwater infiltration to the soil from total rainfall plus runoff from noneffective impervious surfaces. The infiltration capacity of the soil is calculated from soil characteristics and antecedent moisture conditions. Storm runoff from pervious areas is calculated by the model through a variation of the Green-Ampt equation (Alley and Smith, 1982). This estimate can be calibrated to approximate the measured value by adjusting the soil-moisture factors, the infiltration factors, and the percentage of basin overlain by impervious cover. The soil-moisture and infiltration terms are listed and explained in table 10.

Table 10.--Definition of soil-moisture and infiltration terms used in Irondequoit rainfall-runoff (DR3M) model.

[Modified from Alley and Smith, 1982.]

SOIL MOISTURE

EVC--A pan coefficient for converting measured pan evaporation to potential evapotranspiration

RR --The percentage of daily rainfall that infiltrates the soil for the period of simulation excluding storms

BMSN--Available soil water at field capacity, in inches

INFILTRATION

KSAT--Effective hydraulic conductivity at saturated conditions, in inches per hour

RGF--Ratio of suction at the wetting front at wilting point to that at field capacity

PSP--Suction at wetting front at field capacity, in inches

Distributed-parameter mode

In the distributed-parameter mode, the pervious and impervious surface areas characterized in the lumped-parameter mode are apportioned among a set of overland flow segments representing the watershed surface. The model calculates the runoff from each of these segments over a series of time steps corresponding to a given storm. The runoff is then routed through the channel network to the watershed outlet. The timing of the runoff contribution from each overland flow or channel segment may be varied by adjusting the length, slope, and roughness coefficients associated with the segment.

Water-quality prediction

Chemical quality of storm runoff is calculated by summing the chemical contributions from impervious areas, pervious areas, and precipitation. Runoff loads from impervious areas are calculated by constituent accumulation and washoff equations shown in table 11. The model assumes that the rate of accumulation is nonlinear and that the amount of a constituent that can accumulate between storms is finite. Washoff of the constituent is assumed to occur at a rate proportional to the amount of the constituent remaining on the land surface and is represented by an exponential decay equation. The dissolved phase of constituents in precipitation is represented as a constant concentration during a storm but may be varied to reflect seasonal changes.

Runoff load from pervious areas could be simulated by adding the dissolved concentration to the suspended fraction attached to sediment, but because few storms during the study produced significant runoff from pervious areas, no attempt was made to quantify these loads in the runoff-quality modeling.

In the lumped-parameter mode, the model assumes that the constituents originate from precipitation and from impervious areas. The total load at the watershed outlet is computed from measured volumes of storm runoff, and the values of K1, K2, and K3 (table 11) are adjusted until the calculated load approximates the measured loads. A parameter-estimation method is described in Alley and Smith (1982b).

Simulation of chemical loads for storms in which contributions from pervious areas are significant requires the use of DR3M-QUAL in the distributed mode. In this application, simulated runoff data generated by a previous DR3M run are used to estimate constituent contributions from each segment. This allows the specification of accumulation and washoff values for each individual segment and enables prediction of runoff loads from as many as four different types of land use.

Table 11.--Constituent-accumulation and washoff functions for the Irondequoit rainfall-runoff (DR3M) model.

CONSTITUENT ACCUMULATION

$$L = K_1 \left[1-e^{(-K_2 T)}\right] \tag{2}$$

where: L = amount of constituent on impervious area, in kg
T = accumulation time, in days
K_1 = maximum surface accumulation, in kg
K_2 = rate constant for constituent removal, in days $^{-1}$

CONSTITUENT WASHOFF

$$W = L \left[1-e^{(-K_3 R \Delta t)}\right] \tag{3}$$

where: W = amount of constituent removed during time step, Δt
R = runoff rate, in cm/h
K_3 = washoff coefficient, in cm^{-1}
Δt = time step, in hours

Model Calibration

Flow models

The data set for each site or subbasin was randomly divided to provide independent data for calibration and verification of the simulation models. A flow model was developed for each watershed, and the hydrologic coefficients were calibrated to match the observed runoff volumes and peak discharges of the calibration data set. Lumped-parameter estimation was done by an optimization algorithm provided as part of the DR3M. The effective impervious area (EIA) factor was first adjusted by considering the smaller storms in the calibration data set, in which runoff was derived principally from impervious surfaces. The percentage of EIA obtained with these storms approximated the mean runoff coefficient, which expresses the volume of storm runoff as a percentage of precipitation. Factors that control the amount of runoff from pervious areas were then optimized for the larger storms in the calibration data set. (An example is given in table 18.)

Once the predicted storm-runoff values from the lumped-parameter models were as accurate as possible, distributed-parameter flow models were calibrated to optimize the prediction of peak storm discharges. Because no automatic technique is provided for this part of the calibration, stream-segment values were adjusted manually to vary the timing and magnitude of flows routed through the drainage network.

Water-quality models

Water-quality models developed for the watersheds were then applied in the lumped-parameter mode to predict stormwater loads. Parameter estimation for these models was also a manual procedure done with the aid of model output and by procedures outlined by Alley and Smith (1982b). The constituent-washoff parameter, K_3, was chosen to best approximate the shape of storm curves expressing the cumulative constituent load as a function of cumulative storm runoff. Predictions of constituent accumulation were optimized by adjusting the values for K_1 and K_2, described in table 11. The maximum surface-accumulation value, K_1, is directly proportional to the constituent loads generated by the DR3M-QUAL and is relatively simple to estimate. The rate constant, K_2, was more difficult to adjust, and a range of values was tested before the value was selected for each constituent. Lumped-parameter applications of DR3M-QUAL assume that all constituent loads originate from impervious surfaces; this means that the predictions will be less accurate for storms of long duration, in which a significant part of the constituent load is contributed from pervious areas or channel erosion.

Model Verification

After calibration, the flow and water-quality models were applied to the remaining storm data for verification of model predictions. The mean absolute error and the root-mean-square (RMS) error[1], and also the Spearman correlation coefficient (Daniel, 1974), were computed for the observed and predicted values for each watershed to measure the the models' accuracy. The RMS errors reported in the following sections refer to RMS errors calculated for verification storms.

The two subbasins that were selected to test the application of DR3M to large areas were Allen Creek, which encompasses 78 km^2 of mixed land use, and

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[1] Absolute error = $\Sigma \frac{AE}{n}$, and RMS error = $\left[\Sigma \frac{(AE)^2}{n}\right]^{1/2}$

where: $AE = \frac{\text{observed value} - \text{predicted value}}{\text{observed value}}$ for each storm, and

n = number of storms

Thornell Road, which encompasses 115 km^2 of agricultural land. Flow models were calibrated for each of these subbasins and then run with the verification data to compile summary statistics as described above. A water-quality model for the Allen Creek subbasin was prepared by applying the values calculated previously through the application of DR3M-QUAL to the smaller land-use sites and to each of the corresponding land-use areas in the large subbasin. The transferability of these values was tested by applying this model directly, without calibration, to predict the loads measured for each storm sampled during the study.

Model of Rainfall-Runoff Component

As part of the distributed routing rainfall-runoff quality model, the rainfall-runoff relationship of each land-use site in the study area was modeled to determine site-specific soil moisture, soil infiltration, and impervious-surface parameters. The development of these models occurred in two phases; the first dealt with small watersheds with homogenous land use, and the second dealt with much larger mixed land-use watersheds.

Small watersheds

Optimized parameter values.--Optimized values used in the flow models representing the three small watersheds (Cranston Road, Southgate Road, and East Rochester) are presented in table 12. Values of the soil-moisture terms for the Cranston Road and Southgate Road watersheds are similar because both areas are covered by a till soil of low permeability; the East Rochester area, in contrast, contains well-drained sandy soils. Values for effective impervious area lie close to the mean runoff coefficient for each site, which indicates that most of the storm runoff during the study was derived from precipitation on

Table 12.--Optimized parameter values used in rainfall/runoff models for small land-use watersheds--Cranston Road, Southgate Road, and East Rochester.

Term	Cranston Road	Southgate Road	East Rochester
Land use	Low-density residential	Commercial	High-density residential
Area (km^2)	0.673	0.725	1.40
Effective impervious area (percent)	15.2	15.2	16.8
Retention in impervious areas (mm)	1.52	1.52	1.52
Infiltration terms[1]			
PSP (mm)	254.00	203.00	20.3
KSAT (mm/hr)	3.81	3.81	50.80
RGF	19.3	22.0	7.00
Soil-moisture terms[1]			
BMSN (mm)	107.0	94.0	119.00
EVC	.77	.75	.75
RR	.95	.95	.80

[1] Definitions given in table 10, p. 43.

impervious surfaces. Runoff from pervious areas in these smaller watersheds was significant only during storms of long duration, which were infrequent.

Storm-runoff volumes and peak discharges.--Storm-runoff modeling results for the three small watersheds are presented in tables 13A-13C. RMS error in runoff volume predictions of the verification storms ranged from 8 percent for Southgate Road (table 13B) to 24 percent for East Rochester (table 13C). RMS error in peak discharge of the verification storms was 30 percent for Southgate Road and 15 percent for Cranston Road (table 13A). Peak discharge from the East Rochester watershed was not simulated. The Spearman correlation statistics indicate no significant differences between the observed and predicted values of runoff volume and peak discharge at the 0.01 significance level. The correlations between observed and predicted runoff values are shown in figure 7 (p. 50), and runoff hydrographs for the storm of July 20, 1981 in the Cranston Road and Southgate Road sites are shown in figure 8 (p. 50).

Table 13.--Storm-runoff volumes, peak discharges, and model errors.

[Obs. = observed; Pred. = predicted]

Storm date[1]	Rainfall (mm)	Runoff coefficient (percent)	Runoff volume (mm) Obs.	Runoff volume (mm) Pred.	Peak discharge (m^3/s) Obs.	Peak discharge (m^3/s) Pred.
A. CRANSTON ROAD (drainage area 0.67 km^2)						
80-08-05 V	19.6	11.4	2.24	2.54	0.280	0.300
80-08-30 C	19.8	9.0	1.78	2.64	.340	.376
80-09-01 C	70.4	15.3	10.74	12.80	.733	.679
80-09-14 V	19.8	11.0	2.18	2.82	.337	.391
80-10-25 C	74.7	22.3	16.69	16.48	.368	.229
81-05-10 C	23.1	20.9	4.83	3.10	.280	.215
81-05-15 V	17.3	15.0	2.59	2.21	.181	.139
81-06-21 C	25.1	16.1	4.04	3.43	.311	.255
81-07-02 C	14.5	9.8	1.42	1.90	.591	.419
81-07-20 C	41.7	15.9	6.60	6.15	.424	.357
81-07-28 V	25.1	12.4	3.12	3.43	.243	.241
81-08-04 V	38.1	11.7	4.47	5.87	.422	.419
81-08-10 V	36.8	15.9	5.87	7.52	.422	.512
Total	426.		66.6	70.9	4.93	4.53
Mean		14.4				
Coefficient of variation		28.0				
Model error						
Verification storms:						
Absolute error (percent)			21		12	
RMS error			23		15	
All storms:						
Absolute error			22		16	
RMS error			20		20	
Spearman correlation coefficient			0.91		0.80	

[1] V = verification storm
C = calibration storm

Table 13.--Storm-runoff volumes, peak discharges, and model errors (cont.)

[Obs. = observed; Pred. = predicted]

Storm date[1]	Rainfall (mm)	Runoff coefficient (percent)	Runoff volume (mm)		Peak discharge (m^3/s)	
			Obs.	Pred.	Obs.	Pred.
B. SOUTHGATE ROAD (drainage area 0.73 km^2)						
80-08-05 V	36.3	16.8	6.10	6.02	0.665	0.521
80-08-30 C	14.5	12.5	1.80	2.01	.068	.110
80-09-01 C	71.1	16.7	11.86	13.87	1.01	.934
80-10-25 C	78.2	21.9	17.17	13.87	.396	.323
81-05-10 C	22.9	17.6	4.01	3.25	.062	.062
81-06-21 C	30.5	14.8	4.52	4.52	.229	.328
81-07-02 C	8.9	14.0	1.24	1.14	.079	.088
81-07-20 C	42.9	14.6	6.27	6.55	.249	.334
81-07-28 V	24.9	16.2	4.04	3.61	.156	.195
81-08-04 V	26.4	16.8	4.44	3.94	.175	.266
81-08-10 V	40.6	16.1	6.55	6.96	.277	.291
Total	397.		68.0	65.7	3.37	3.45
Mean		16.2				
Coefficient of variation		14.0				
Model error						
Verification storms:						
Absolute error (percent)			7		27	
RMS error			8		30	
All storms:						
Absolute error			9		26	
RMS error			11		32	
Spearman correlation coefficient			0.99		0.94	

[1] V = verification storm
C = calibration storm

Large watersheds

The same process used to develop the small land-use site flow and water-quality models was used to establish site-specific soil moisture, soil infiltration, and impervious surface characteristics for the large mixed land-use subbasins.

Optimized parameter values.--Optimized parameter values used in the two subbasin models are presented in table 14. Soil-parameter values generally agree with those presented earlier for the two sites containing soils of moderate permeability--Cranston Road and Southgate Road (table 12). The Thornell Road subbasin also contains areas covered by clays of low permeability represented by soil type I. The retention value for impervious areas at Allen Creek was set higher than for the other sites to reflect storage effects of large parking lots and small detention basins within the watershed. As expected, the percentage of basin area covered by impervious surface was smaller in the two larger watersheds than in the smaller watersheds.

Table 13.--Storm-runoff volumes, peak discharges, and model errors (cont.)

[Obs. = observed; Pred. = predicted]

Storm date[1]	Rainfall (mm)	Runoff coefficient (percent)	Runoff volume (mm)	
			Obs.	Pred.
C. EAST ROCHESTER (drainage area 1.40 km^2)				
80-10-25 C	77.7	16.4	12.75	14.50
81-05-10 C	22.1	23.0	5.08	3.48
81-05-15 V	20.8	16.7	3.48	3.28
81-06-21 C	26.7	13.7	3.66	4.29
81-07-02 C	15.2	11.5	1.75	2.46
81-07-20 C	41.4	20.6	8.51	7.26
81-07-28 V	29.7	11.2	3.33	4.85
81-08-04 V	20.1	17.8	3.58	3.43
81-08-10 V	28.7	16.8	4.83	5.54
Total	282.		47.0	49.1
Mean		16.4		
Coefficient of variation		24.0		
Model error				
Verification storms:				
Absolute error (percent)		18	--	
RMS error		24	--	
All storms:				
Absolute error		21	--	
RMS error		25	--	
Spearman correlation coefficient		0.77		

[1] V = verification storm
C = calibration storm

Table 14.--Values used in rainfall/runoff models for large watersheds.

Term	Thornell Road		Allen Creek
Land use	Agricultural		Mixed
Area (km^2)	115.		66.6
Effective impervious area (percent)	1.7		6.9
Retention of impervious areas (mm)	1.52		3.81
Infiltration term[1]	Soil I	Soil II	
PSP (mm)	465.0	190.0	279.0
KSAT (mm/hr)	5.08	35.6	5.08
RGF	32.1	37.5	5.0
Soil moisture term[1]			
BMSN (mm)	76.2	76.2	76.2
EVC	0.80	0.64	0.77
RR	.95	.89	.92

[1] Definitions given in table 10, p. 43.

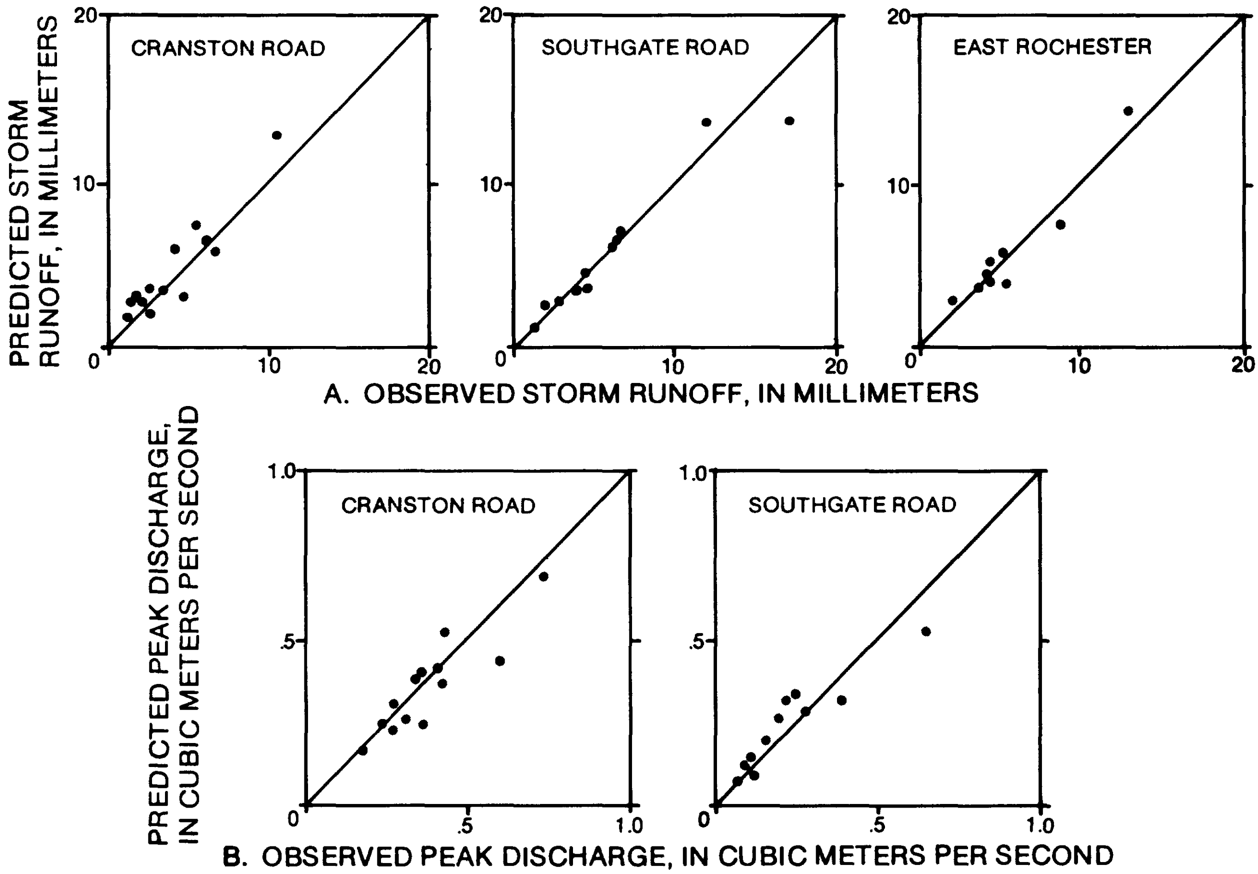


Figure 7.--Predicted streamflow values plotted against observed values for selected small land-use sites: A. Storm-runoff volume. B. Peak discharge.

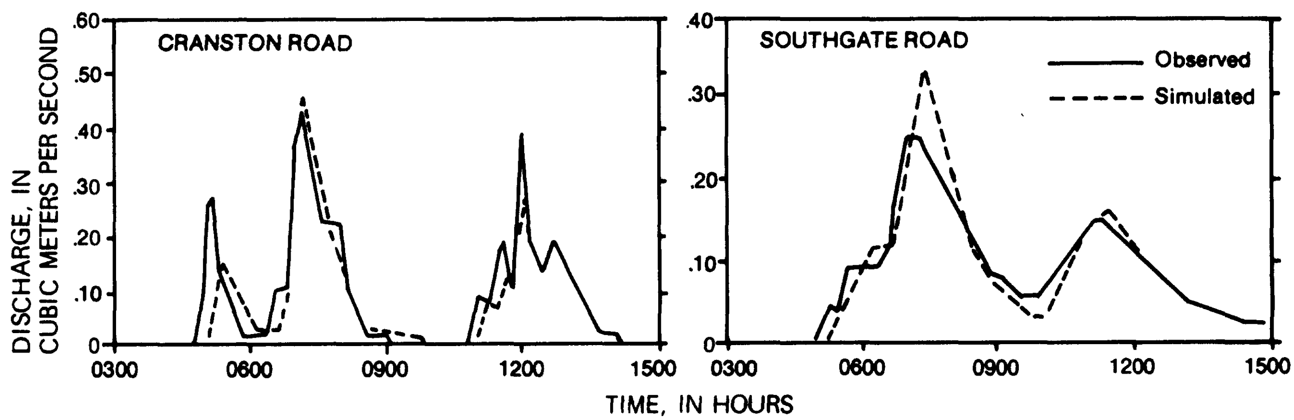


Figure 8.--Observed and simulated peak discharge of July 20, 1981 storm at two small land-use sites.

Storm-runoff volumes and peak discharges.--Storm-runoff modeling results for Allen Creek and Thornell Road are summarized in tables 15A and 15B, and the correlation between observed and predicted values at these sites is plotted in figure 9. The RMS error in the runoff-volume prediction of the verification storms was 31 percent for Allen Creek and 70 percent for Thornell Road; the RMS error in the prediction of peak discharge was 23 percent for Allen Creek (table 15B). Attempts to calibrate distributed-parameter runs of the Thornell Road model were unsuccessful, and little correlation was found between the observed and predicted peak discharges. Problems in calibrating the Thornell Road model were caused by variability in rainfall, topography, and soils in the watershed, discussed later in the text. Despite concerns for applying the model to larger watersheds, the model performed nearly as well for the 78.0-km^2 Allen Creek subbasin as for two of the smaller watersheds. Predictions for the 115-km^2 Thornell Road subbasin were less accurate, however (table 15A).

Table 15.--Storm-runoff volumes and peak discharges in large watersheds.

[Site locations are shown in fig. 2. Obs. = observed; Pred. = predicted]

Storm date[1]	Rainfall (mm) Gage 1	Gage 2	Gage 3	Runoff coefficient (percent)	Runoff volume (mm) Obs.	Pred.
			A. THORNELL ROAD (drainage area 115 km^2)			
80-08-05 V	1.5	6.4	38.9	2.2	0.33	0.28
80-08-30 C	1.3	3.3	18.3	1.0	.08	.10
80-09-01 C	48.3	59.7	58.9	2.6	1.09	1.02
80-09-14 V	21.6	22.9	33.0	1.7	.23	.53
80-10-25 C	71.1	87.6	67.3	5.6	3.10	2.18
81-05-10 C	22.9	20.3	20.6	4.6	.76	.33
81-05-10 C	22.9	20.3	20.6	4.6	.76	.33
81-05-15 V	24.1	20.3	15.5	8.8	.84	.33
81-06-21 C	24.1	23.4	26.4	3.9	.41	.41
81-07-20 C	30.5	43.2	47.8	2.0	.43	.71
81-07-28 V	19.8	25.4	27.2	1.7	.30	.41
81-08-04 V	45.7	26.7	27.2	2.0	.38	.69
81-08-10 V	41.1	48.3	48.3	3.3	1.14	.91
Total	375.	408.	450.	3.4	9.85	8.23
Model error						
Verification storms:						
Absolute error (percent)				57	--	
RMS error				70	--	
All storms:						
Absolute error				44	--	
RMS error				57	--	
Spearman correlation coefficient				.65	--	

[1] V = verification storm
C = calibration storm

Table 15.--Storm-runoff volumes, peak discharges, and model errors (cont.)

[Site locations are shown in fig. 2. Obs. = observed; Pred. = predicted]

Storm date[1]	Rainfall (mm)	Runoff coefficient (percent)	Runoff volume (mm)		Peak discharge (m^3/s)	
			Obs.	Pred.	Obs.	Pred.
B. ALLEN CREEK (drainage area 66.6 km^2)						
80-08-05 V	35.6	4.3	1.52	2.36	5.207	4.471
80-08-30 C	7.1	2.1	0.15	0.23	0.566	0.453
80-09-01 C	41.7	8.4	3.48	4.11	6.962	11.32
80-09-14 V	23.1	4.6	1.07	1.45	2.632	3.085
80-10-25 C	80.8	17.5	14.17	8.10	18.79	15.2
81-05-10 C	24.9	7.2	1.80	1.35	1.472	1.160
81-05-15 V	24.3	7.5	1.80	1.47	3.085	3.679
81-06-21 C	32.5	6.7	2.18	2.08	4.330	4.952
81-07-02 C	18.5	5.2	.97	1.17	5.066	4.415
81-07-20 C	52.8	9.4	4.98	4.29	11.72	10.64
81-07-28 V	32.0	5.5	1.75	2.16	4.217	5.632
81-08-04 V	46.2	11.3	5.21	4.72	8.943	11.97
81-08-10 V	38.1	16.9	6.43	7.95	11.57	10.95
Total	458.		45.51	41.4	84.6	87.9
Mean		8.2				
Coefficient of variation		56.0				
Model error						
Verification storms:						
Absolute error (percent)			28		21	
RMS error			31		23	
All storms:						
Absolute error			26		22	
RMS error			3		26	
Spearman correlation coefficient			.89		.90	

[1] V = verification storm; C = calibration storm

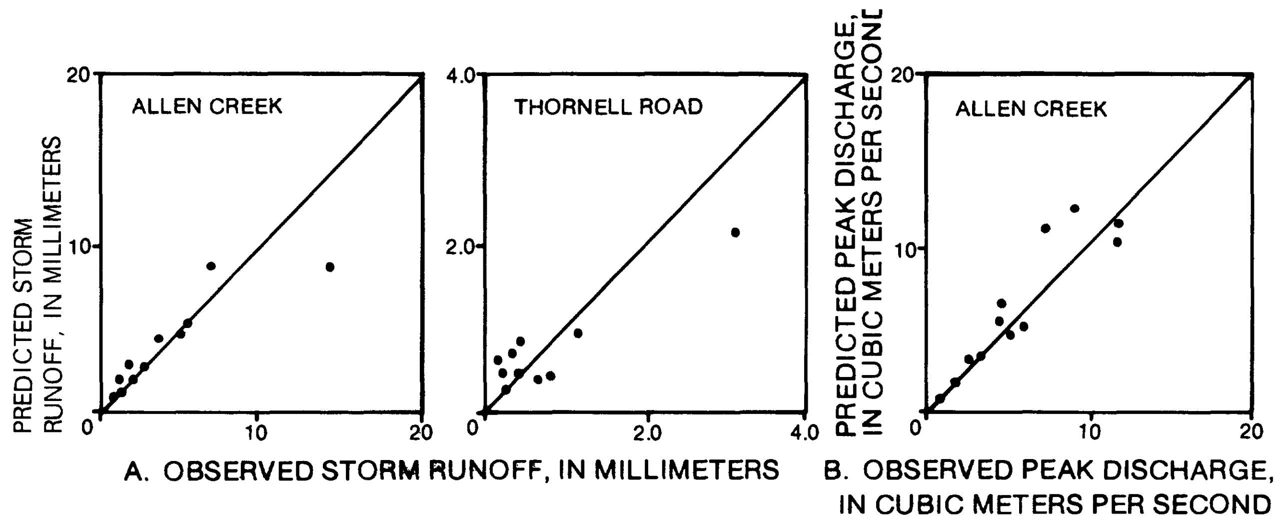


Figure 9.--Predicted streamflow values plotted against observed values for two large mixed land-use watersheds: A. Storm-runoff volume. B. Peak discharge.

Rainfall variability.--The most important difference between small and large watersheds is the areal variability in rainfall received during a storm. The DR3M can accept data from as many as three rain gages as input from which the storm-runoff volumes are derived. Even though one gage may be sufficient to model a watershed smaller than 3 km^2, three gages may not be enough to accurately depict the amount of precipitation on a watershed larger than 100 km^2. In addition, the weight given to each rain gage is the same in DR3M for every storm, while in reality it may vary depending upon the type and direction of the storm.

Rainfall intensity, the most influential factor in the rainfall-excess computation, can also vary widely over a large watershed. For example, rainfall rates for the storm of August 30, 1980 at Thornell Road ranged from 4.57 mm/hr to 0.176 mm/hr among the three rain gages in the subbasin. This variability occurred during several storms and could not be consistently accounted for in the model by weighting one gage more than the others. In contrast, a single rain gage at the center of the Allen Creek subbasin usually accounted for the observed runoff from each storm. Rainfall in the Allen Creek subbasin may be more evenly distributed, and this in turn could be related to its relatively uniform topography in this watershed. Simulated and observed discharges at the Allen Creek gage for the storm of July 20, 1981 are plotted in figure 10.

The sensitivity of predicted flows to variation in rainfall intensity was evaluated during calibration of the Allen Creek flow model. Peak discharges had been matched for all but the storm of August 4, 1981, in which the rainfall was particularly intense. The exact magnitude of the peak intensity was uncertain, so a range of values was considered. Changing the rainfall during one 15-minute interval from 15.7 mm to 12.7 mm decreased the predicted peak discharge from 17.6 m^3/s to 12.0 m^3/s, indicating a high sensitivity to precipitation amounts and timing.

The lack of detailed rainfall data during storms is a serious limitation in the application of the DR3M or other runoff models to large watersheds in the Irondequoit basin.

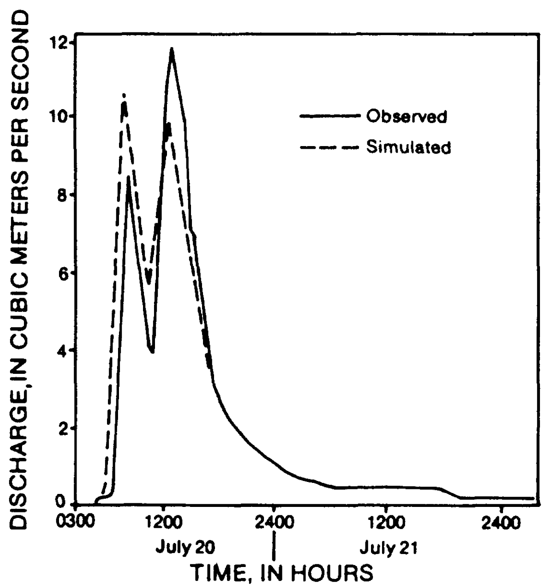


Figure 10.

Observed and simulated discharges during storm of July 20-21, 1981 in Allen Creek (large mixed-land use) subbasin.

Seasonal sensitivity.--Another finding of the modeling effort indicates that seasonal variations in basin characteristics may alter storm-runoff processes in pervious areas and affect the accuracy of model prediction. Runoff volumes predicted by the DR_3M for the October and May storms were lower than the observed volumes at all sites modeled. This is apparent in the runoff plot for Allen Creek in figure 9, which shows that the largest storm, with over 10 mm of runoff, was underpredicted by 40 percent. This storm, on October 25-26, 1980, exhibited a rainfall of long duration and steady intensity, which is unusual for this region.

This underprediction could also be due to increased runoff from pervious areas at the beginning and end of the growing season. Increased soil moisture and the lack of foliage to intercept rainfall would tend to enhance runoff from pervious areas. This conclusion is supported by results noted by Lumia (1981), who applied the U.S. Army Corps of Engineers HEC-1 Flow Hydrograph Package to 10 small watersheds in Rockland County, N.Y., and found that adjustment of soil-infiltration parameters for growing-season and nongrowing-season conditions increased the accuracy of model predictions.

Degree of urbanization.--Another important difference between small and large watersheds is that the effects of urbanization are less significant with increasing watershed size (Pilgrim and others, 1981). The influence of stream-channel developments, which may be significant in a small watershed, is likely to be attenuated or masked by other conditions in a large watershed. In general, the contribution of impervious areas to the total runoff volume is far less in large basins than in small ones, and the percentage of runoff from pervious areas in large basins is greater.

Variation in pervious-area runoff.--The process used to account for the generation of rainfall excess from pervious areas in the DR_3M model is known as Hortonian flow, which assumes that runoff is produced when rainfall intensity exceeds the infiltration capacity of the soil. Because infiltration capacity is assumed to be uniform throughout the watershed, the calculated rainfall excess is also uniform; therefore the entire surface of the modeled watershed contributes storm runoff to the outlet channel. The DR_3M allows parameter specification for two different soil types to account for variability in infiltration capacity.

The assumption of Hortonian flow processes affects the prediction of both the volume and timing of storm runoff by the model. Because the entire watershed is assumed to contribute runoff during a storm, surface runoff from all parts of the watershed must be routed to stream channels. Practical considerations of reducing time and expense in the simulation of large areas dictate the use of fewer and larger overland flow planes to represent the watershed surface. The resulting overland flow paths are therefore unrealistically long and necessitate the use of much smaller roughness coefficients than those reported in the literature.

Recent investigations have suggested some modifications to this theory for the generation of storm runoff. In some areas, soils overlying a zone of low hydraulic conductivity may become saturated during a storm and function as impervious surfaces, causing further rainfall to become surface runoff. This process probably occurs in low-lying parts of any watershed and varies in areal extent during a storm. Thus, the area contributing to storm runoff is not fixed, as in Hortonian flow, but varies during the storms (Miller, 1984).

Some of the rainfall that infiltrates the soil surface near stream channels may percolate laterally through macropores and reach the stream channel, where it reappears as storm runoff. This type of subsurface flow probably occurs mainly in agricultural and forested watersheds (Freeze and Cherry, 1979). The indirect path the water must follow through the soil causes a delay, however. This type of flow can be plotted as a separate component of the storm hydrograph, lagging behind the direct surface runoff but preceding storm-related ground-water flow.

The character of storm runoff is the result of individual processes that vary within the watershed, and some of this variation may be seasonally related. It is therefore unlikely that use of Hortonian flow in simulation of storm runoff in a large watershed could accurately portray the pervious-area component of runoff. For example, the varied topography and soils in the Thornell Road subbasin may require a larger number of overland flow planes to represent the watershed surface than were used in the Allen Creek flow model.

Although the seasonal variation in evaporation and soil moisture may influence the runoff from pervious areas to a considerable degree, the DR_3M model cannot accommodate seasonal variability in the soil-moisture or infiltration parameters. Also, the data collected from storms outside the growing season were insuffient for calibration of separate soil parameters for the growing season and nongrowing seasons. Therefore, the calibrated-model values presented in tables 12 and 14 are not adjusted for seasonal variation.

Variation in ground-water interflow.--Before calibration of the Allen Creek and Thornell Road subbasin models, the measured storm runoff volumes input to the DR_3M were corrected to account for rising ground water during the storm. Analyses of streamflow hydrographs indicated that subsurface flow to stream channels was derived from ground-water storage and could be treated as flow from a linear reservoir. The recession curves of the streamflow hydrograhs were fitted to an equation of the form:

$$Q = Q_0K \qquad (4)$$

where Q is the discharge at time t, in days after a given discharge, and Q_0 and K are recession constants related to the hydrogeology of the basin (Todd, 1980, p. 155.). A value of K was determined for each storm from the slope of a straight line fitted to the recession part of the streamflow hydrograph. The recession curve was extrapolated back to the beginning of the storm to determine the contribution of subsurface flow to total streamflow. An example of the method presented in Chow (1964) is given in figure 11. This method could overestimate the subsurface flow component of storm runoff because it is generally believed that subsurface flow does not increase during a storm until after the peak in surface runoff occurs.

Modeling results indicated that source areas of storm runoff in the two large subbasins were more variable than those in the three smaller discrete land-use sites. The coefficients of variation in runoff coefficients for the small sites (tables 13A-13C) ranged from 14 to 28 percent, which suggests that storm runoff represented a relatively constant percentage of the total precipitation. The coefficient of variation in the runoff coefficient for Allen Creek was larger than 50 percent, however, which suggests that pervious areas contribute significant volumes of runoff during large storms but little runoff in

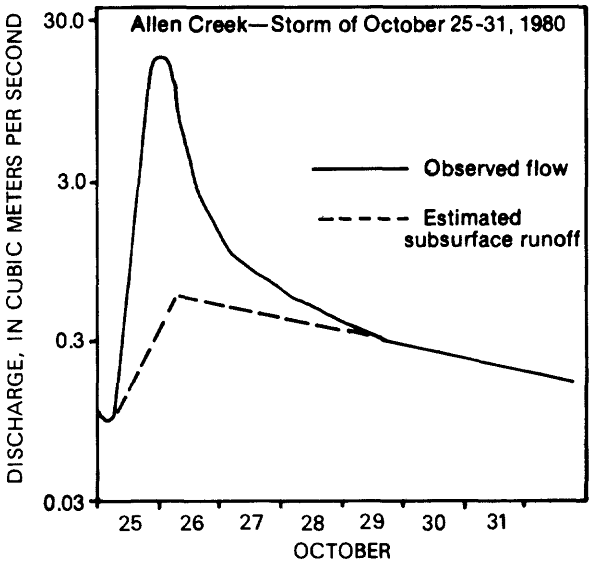


Figure 11.

Method of estimating subsurface-runoff contribution to streams from a stormflow hydrograph.

smaller storms. This result was also supported by the flow model for Allen Creek, which predicted a much smaller effective impervious area coefficient than the mean runoff coefficient.

Model of Runoff-Quality Component

A water-quality model (DR3M-QUAL) was calibrated for each of three small watersheds representing single land uses; the parameters developed for these watersheds were then used to calibrate a model for Allen Creek, a large subbasin with several types of land use, as described below.

Small watersheds

The DR3M-QUAL models were applied in the lumped-parameter mode to generate predictions of storm runoff loads of the eight water-quality constituents mentioned previously for each of the three single-land-use areas. The prediction of runoff loads was limited to impervious areas because the data were insufficient to calibrate for pervious areas, as explained above.

Optimized buildup/washoff values.--Optimized parameter values for the water-quality models representing urban land-use sites are presented in table 16. The values obtained for K1, the accumulation parameter, suggest that surface accumulations of most constituents studied were greatest in the high-density residential area of East Rochester. Surface accumulations at the medium-density residential site (Cranston Road) and the commercial site (Southgate Road) were nearly equal. As expected, the constituent having the largest values at each site was suspended sediment, followed by COD, dissolved chloride, TKN, total phosphorus, and the heavy metals.

Runoff loads.--The observed runoff loads from the three small sites and the corresponding values predicted by the models are given in tables 17A-17C and figures 12A-12C. Runoff loads listed in the tables were calculated by the water-quality model from data collected during the sampled part of each storm.

Table 16.--Optimized parameter values for water-quality models for the small single-land-use sites.

[Locations are shown in fig. 2.]

Constituent	Parameter	East Rochester	Southgate	Cranston Road
Suspended sediment	K_1	600.	65.	150.
	K_2	.30	.20	.05
	K_3	.10	.50	.50
Total kjeldahl nitrogen	K_1	1.00	.30	.40
	K_2	.10	.10	.18
	K_3	3.00	1.0	1.0
Total phosphorus	K_1	.23	.07	.13
	K_2	.15	.60	.18
	K_3	.50	1.00	1.00
Chemical oxygen demand	K_1	30.0	22.0	18.0
	K_2	.20	.16	.33
	K_3	1.00	.50	.50
Dissolved chloride	K_1	8.00	30.0	20.0
	K_2	1.00	.60	.05
	K_3	.50	.50	.50
Total lead	K_1	.450	.025	.020
	K_2	.100	.080	.160
	K_3	.100	.500	.500
Total cadmium	K_1	.003	.01	.006
	K_2	.030	.04	.200
	K_3	1.00	.10	.10
Total zinc	K_1	.100	.136	.120
	K_2	.260	.160	.160
	K_3	3.00	1.00	1.00

K_1 = maximum surface constituent accumulation (kg)
K_2 = rate constant for constituent removal ($days^{-1}$)
K_3 = washoff coefficient (cm^{-1})

Although the error in model predictions differed considerably among the three sites, depending upon the constituent modeled, root mean square (RMS) errors for the verification storms were typically in the range of 30 to 75 percent except for lead and cadmium. Inspection of the Spearman correlation coefficients (tables 17A-17C) reveals that model predictions for TKN and total zinc at East Rochester and total zinc at the Southgate Road do not correlate with the observed values. Predicted values for the other constituents were all correlated at the 0.10 significance level.

Overall, the best model predictions were those for the high-density residential site (East Rochester). Figure 12A shows accurate predictions of suspended sediment, total phosphorus, dissolved chloride, and total cadmium. The predicted loads of suspended solids and phosphorus were biased slightly low, however, indicating that the accuracy could be improved by increasing the surface-accumulation parameters, K1. Results for lead and TKN were less consistent; the poor prediction of TKN loads could be due to septic wastes, which are discharged to the storm sewer that drains the area.

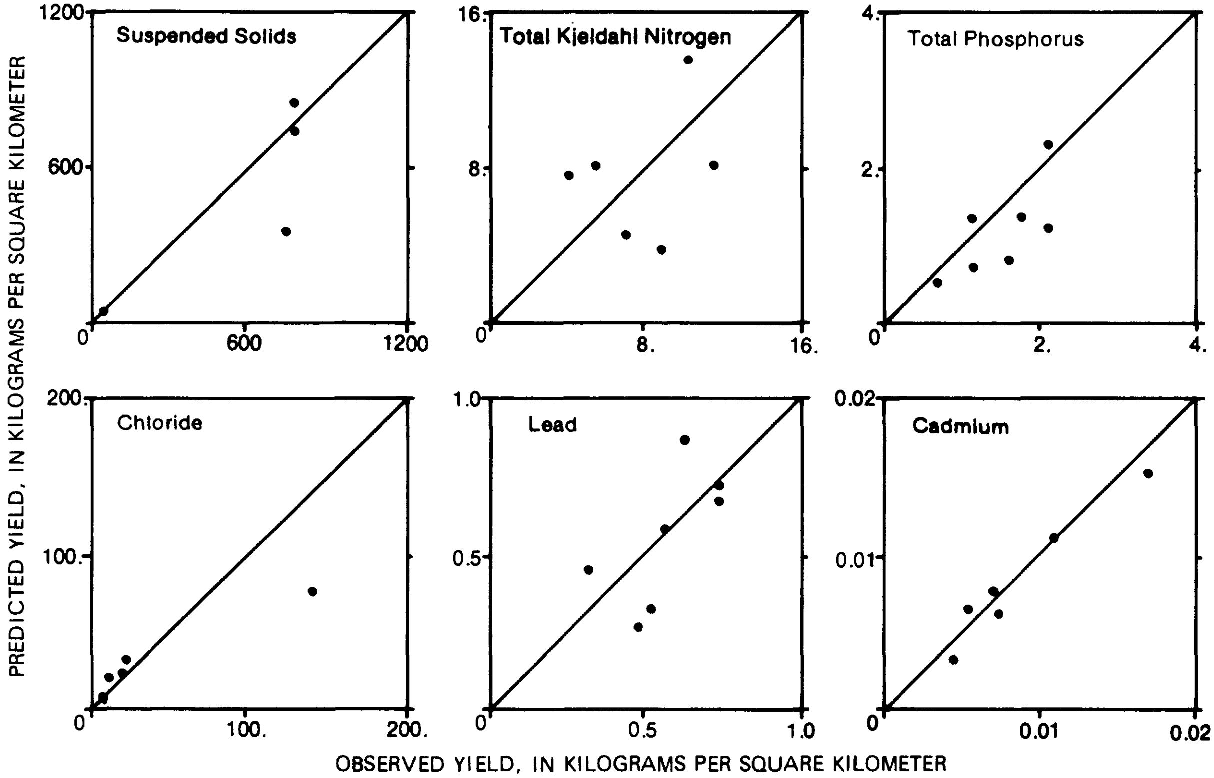


Figure 12A.--Predicted constituent yields plotted against observed yields from the East Rochester (high-density residential) site.

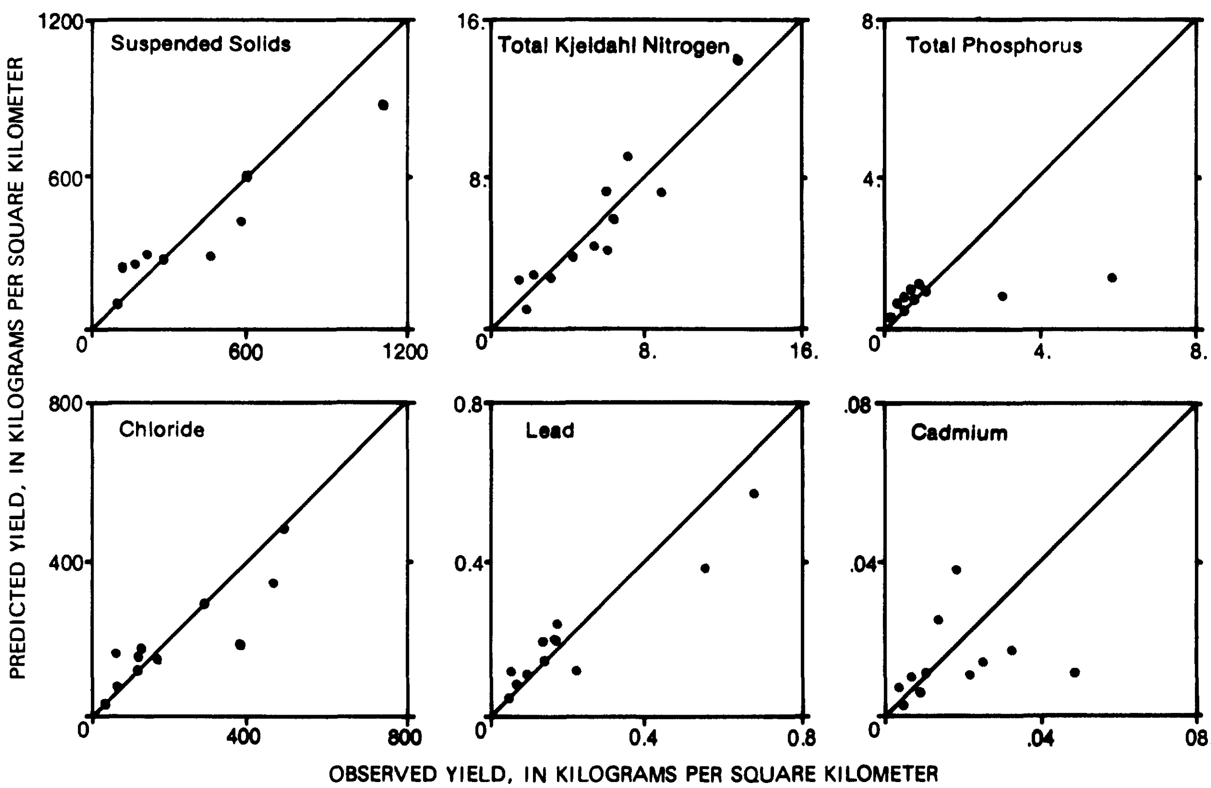


Figure 12B.--Predicted constituent yields plotted against observed yields from the Southgate Road (commercial/residential) site.

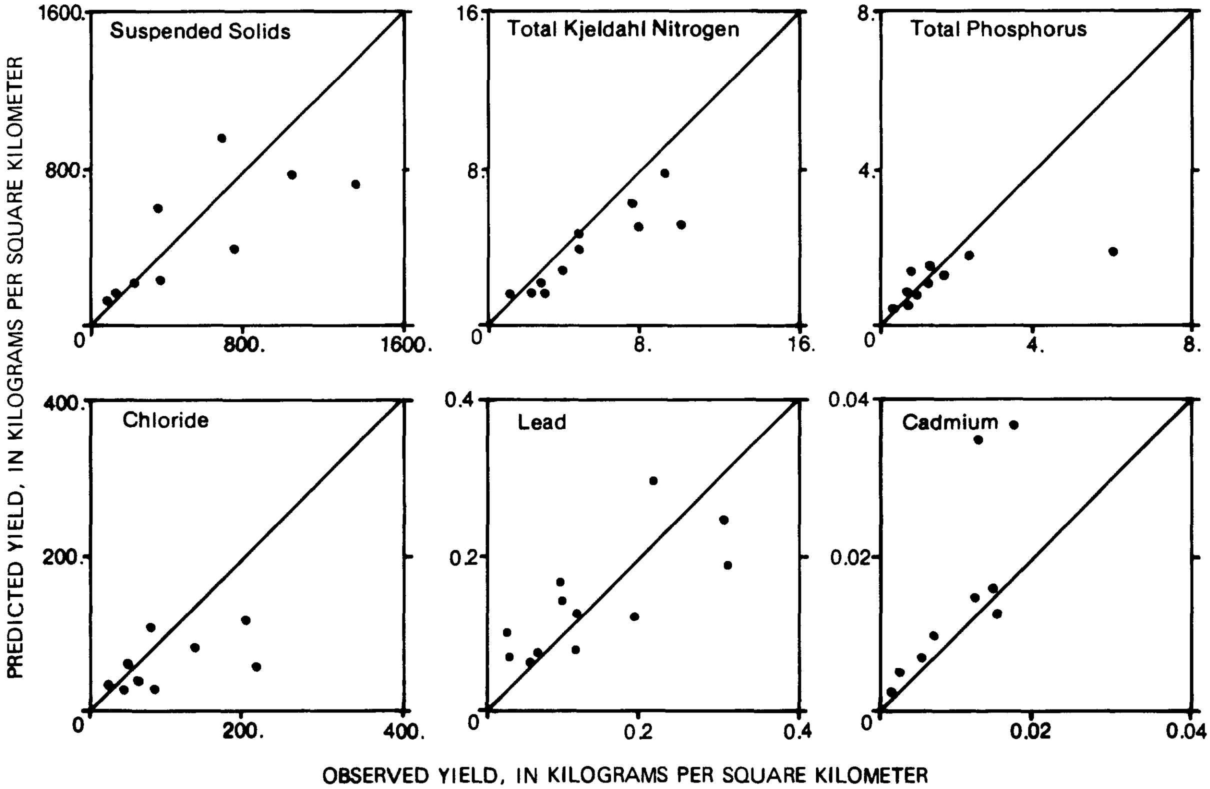


Figure 12C.--Predicted constituent yields plotted against observed yields from the Cranston Road (medium-density residential) site.

Model results for the commercial site at Southgate Road (fig. 12B) were good for suspended sediment, TKN, dissolved chloride, and total lead, and fair for total cadmium. Predictions of total phosphorus loadings were good for all but the two largest storms sampled, which suggests that a large percentage of the total phosphorus load was contributed from pervious areas or by channel erosion, mechanisms that are not accounted for by the lumped-parameter model. Runoff loads from pervious areas seem to be significant in only two sampled storms, and these were not adequate to calibrate washoff parameters for pervious areas.

The model results for the medium-density residential site at Cranston Road (fig. 12C) indicate good predictions of TKN loads and fair predictions of suspended solids, chloride, and lead loads. Slightly improved predictions for TKN and chloride loads could be obtained by increasing the surface-accumulation parameter, K1. Predictions of total phosphorus at the Southgate Road site were good for all but the largest storm.

Washoff-coefficient (K3) modifications

Although the pollutant accumulations and washoff equations used by the DR3M-QUAL model seemed to reflect the physical mechanisms actually occurring in the small watersheds, the model predictions could be improved by accounting for local variations in rainfall intensity. The following paragraphs discuss relationships among the constituent concentrations, loads, and stream discharge and relate these to rainfall intensity.

Table 17.--Observed and predicted constituent yields and model error analysis.
[Dashes indicate no data. Obs. = observed, pred. = predicted.]

A. EAST ROCHESTER SITE (drainage area 1.40 km^2)

Storm date†	Runoff (mm)	Suspended sediment		TKN		Total Phosphorous		COD		Dissolved chloride		Total lead		Total cadmium		Total zinc	
		obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.
YIELDS																	
10-25-80 C	12.8	--	--	5.5	8.5	2.2	2.3	--	--	140	81	--	--	--	--	0.65	0.81
06-21-81 C	3.7	782	880	10.4	14.0	1.2	1.4	205	254	55	52	0.75	0.68	0.0173	0.0153	1.30	1.76
07-02-81 C	1.8	336	342	6.8	7.8	1.2	.7	196	153	8	7	.52	.33	.0055	.0065	2.02	1.17
07-20-81 C	8.5	1239	1108	7.2	5.2	1.9	1.4	264	215	14	21	.62	.88	.0108	.0114	.91	.52
07-28-81 V	3.3	39	40	4.2	8.1	1.7	.8	160	189	20	24	.33	.46	.0075	.0062	.55	1.27
08-04-81 V	3.6	795	776	11.7	8.5	1.1	1.0	359	228	21	29	.59	.59	.0072	.0075	.81	1.21
08-10-81 V	4.8	749	352	9.1	4.2	.7	.5	155	106	--	--	.49	.26	.0046	.0032	1.25	.64
Total	38.5	3940	3500	54.9	56.3	10.0	8.1	1340	1140	258	214	3.30	3.20	.0529	.0501	7.49	7.38
MODEL ERROR																	
Verification storms:																	
Absolute error (percent)		19		61		30		29		33		31		17		77	
RMS error		44		49		46		36		35		35		17		79	
All storms:																	
Absolute error		6		41		25		24		30		26		11		54	
RMS error		7		49		31		25		33		31		13		64	
Spearman correlation coefficient		0.90		0.32		0.67		0.60		0.99		0.80		0.70		-0.03	

† C = Calibration storm
V = Verification storm

Table 17.--Observed and predicted constituent yields and model error analysis (continued).

[Dashes indicate no data. Obs. = observed, pred. = predicted.]

C. CRANSTON ROAD SITE (drainage area 0.67 km^2)

Storm	Runoff	Suspended sediment		TKN		Total Phosphorous		COD		Dissolved chloride		Total lead		Total cadmium		Total zinc	
date†	(mm)	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.	obs.	pred.
								YIELDS									
08-30-80 C	1.8	--	--	3.3	3.0	0.9	0.7	--	--	60	49	0.11	0.08	0.0020	0.0041	--	--
09-01-80 C	10.7	1080	880	5.8	4.6	--	--	--	--	203	62	.12	.14	.0129	.0122	--	--
09-14-80 V	2.2	95	190	1.2	2.3	.3	.4	--	--	37	26	.03	.07	.0027	.0047	--	--
10-25-80 C	6.7	--	--	15.6	14.2	6.7	1.7	--	--	420	190	.22	.30	--	--	1.35	1.35
05-10-81 C	14.8	1490	812	8.1	6.3	1.0	1.3	284	129	190	108	.32	.19	.0115	.0129	2.23	1.15
05-15-81 V	2.6	142	223	3.5	2.1	.4	.3	95	47	74	30	.06	.07	.0054	.0074	.58	.20
06-21-81 C	4.0	271	711	5.3	5.6	.6	1.2	108	108	122	81	.09	.17	.0102	.0366	.95	.47
07-02-81 C	1.4	237	230	2.8	2.3	.7	.5	33	45	20	31	.05	.06	.0034	.0047	1.02	.47
07-20-81 C	6.6	663	1015	9.5	8.1	2.2	1.6	210	162	68	108	.31	.25	.0156	.0372	--	--
07-28-81 V	3.1	--	--	4.9	3.5	.5	.8	57	88	26	32	.03	.10	.0068	.0095	.62	.63
08-04-81 V	4.5	426	298	8.8	5.5	1.6	1.1	203	122	42	56	.09	.15	.0108	.0135	1.02	.09
08-10-81 V	5.9	880	413	11.5	5.2	1.2	.9	102	115	--	--	.19	.12	.0115	.0135	3.11	.74
Total	64.3	5284	4772	80.3	62.7	16.1	10.5	1092	816	1262	773	1.62	1.70	0.0928	0.1563	10.88	5.10
								MODEL ERROR									
Verification storms:																	
Absolute error (percent)		70		53		42		39		37		120		43		47	
RMS error		73		58		49		43		41		160		47		58	
All storms:																	
Absolute error		58		29		42		34		44		64		68		48	
RMS error		74		37		51		39		47		100		99		57	
Spearman correlation coefficient		0.82		0.84		0.81		0.93		0.72		0.76		0.83		0.62	

† C - Calibration storm
V - Verification storm

The graph of total phosphorus during the storm of May 10, 1981 at Cranston Road (fig. 13, col. I, plot b) shows that the concentration was highest at the beginning of the storm and decreased sharply thereafter, indicating that an initial "first flush" greatly reduced the surface loading. The convex-upward shape of the load characteristic curve for this storm (fig. 13, col. I, plot c) is characteristic of a storm in which a first flush occurs. The washoff equation presented in table 11 (eq. 3) was designed to predict this type of storm (Alley

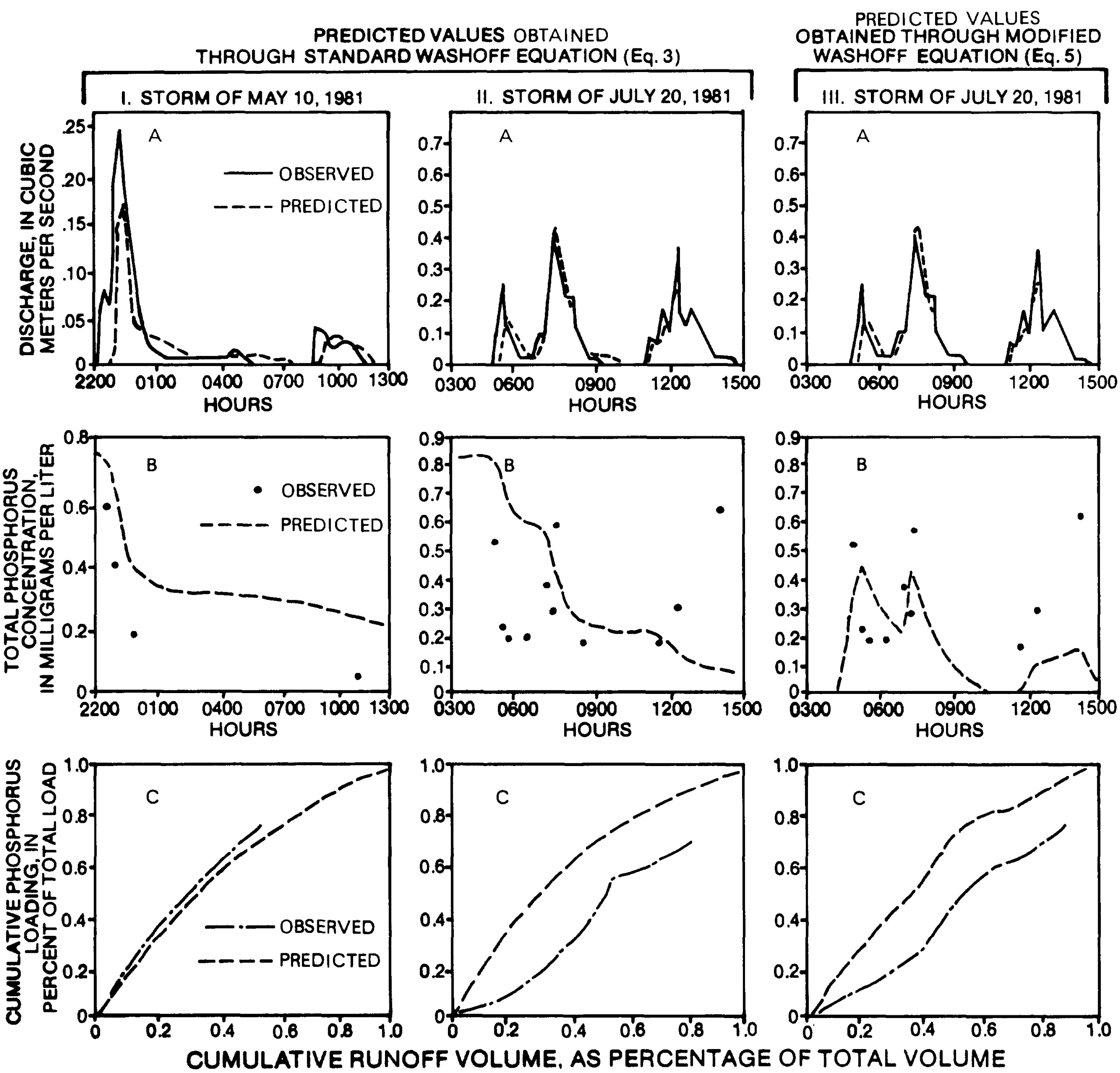


Figure 13.--Stormflow hydrograph (top row), phosphorus concentration (middle row), and cumulative phosphorus loading (bottom row) at the Cranston Road (medium-density residential) site during storms of May 10 and July 20, 1981.

Table 17.--Observed and predicted constituent yields and model error analysis (continued).

[Dashes indicate no data. Obs. = observed, pred. = predicted.]

B. SOUTHGATE ROAD SITE (drainage area 0.73 km^2)

Storm date†	Runoff (mm)	Suspended sediment obs.	Suspended sediment pred.	TKN obs.	TKN pred.	Total Phosphorous obs.	Total Phosphorous pred.	COD obs.	COD pred.	Dissolved chloride obs.	Dissolved chloride pred.	Total lead obs.	Total lead pred.	Total cadmium obs.	Total cadmium pred.	Total zinc obs.	Total zinc pred.
YIELDS																	
08-05-80 V	6.1	--	--	8.8	7.5	--	--	--	--	295	289	--	--	0.0314	0.0176	--	--
08-30-80 C	1.8	151	239	2.1	3.1	0.5	0.5	--	--	126	113	0.06	0.10	.0025	.0057	--	--
09-01-80 C	1.9	--	--	6.9	9.4	3.2	.9	--	--	471	346	.57	.39	.0145	.0258	--	--
09-14-80 V	2.9	270	277	1.4	2.9	.4	.6	--	--	126	145	.09	.10	.0025	.0075	--	--
10-25-80 C	17.2	131	880	12.6	14.5	6.1	1.4	--	--	503	490	.69	.58	.0195	.0390	1.32	3.08
05-10-81 C	4.0	207	390	6.0	4.3	.5	.7	157	132	396	182	.17	.18	.0069	.0101	1.26	1.38
06-21-81 C	4.5	585	421	6.0	7.5	.9	.8	207	138	170	151	.14	.19	.0509	.0126	.94	1.45
07-02-81 C	1.2	101	107	1.8	1.1	.2	.2	42	33	25	26	.05	.04	.0031	.0025	1.63	.38
07-20-81 C	6.3	616	597	6.3	5.9	1.1	.9	126	176	--	--	.18	.23	.0264	.0145	10.69	1.76
07-28-81 V	4.0	113	251	3.1	2.8	.5	.6	72	82	63	72	.06	.10	.0094	.0075	1.07	.88
08-04-81 V	4.4	--	--	4.4	4.1	.8	.8	132	101	113	145	.14	.13	.0101	.0101	1.01	.10
08-10-81 V	6.6	459	295	5.5	4.5	.7	.6	163	88	69	170	.23	.11	.0233	.0113	27.66	.69
Total	70.9	3633	3457	64.9	67.6	14.9	8.0	899	750	2357	2129	2.38	2.15	.2005	.1642	45.58	9.72
MODEL ERROR																	
Verification storms:																	
Absolute error (percent)		53		36		32		30		44		45		79		58	
RMS error		74		52		34		34		74		54		106		70	
All storms:																	
Absolute error		41		29		29		28		29		32		67		70	
RMS error		56		38		38		30		49		40		85		80	
Spearman correlation coefficient		0.93		0.92		0.88		0.54		0.88		0.88		0.76		0.07	

† C - Calibration storm
V - Verification storm

and Smith, 1982). An opposite pattern would result from storms in which the constituent concentration increases steadily.

Most storms during the study period were more complex than the type illustrated in figure 13, column I. For example, the storm of July 20, 1981 at Cranston Road (fig. 13, column II) had several peaks in contrast to the single-peaked storm of May 10, 1981 (column I). The concentration plot for the July 20, 1981 storm indicates a series of flushes in response to each peak in discharge. The load-characteristic curve for this storm reflects both sudden and sustained increases.

The mixed-type concentration curve illustrated in figure 13, column II, can be approximated by a linear curve to estimate the total runoff load. The large number of multipeak storms observed during the study thus explains the low value for the K_3 parameter obtained by model calibration. Values of K_3 that are less than unity plot as a nearly linear load-characteristics curve when applied to the washoff equation (eq. 3) presented in table 11.

Although the DR3M-QUAL model can be made to predict runoff loads for the multipeak storms typical of the Irondequoit area, predictions of constituent concentration frequently are considerably in error, as seen in figure 13, column II. The close relationship between peak concentration and peak discharge for this storm indicates that rainfall intensity is an important factor in the washoff of constituents from impervious surfaces. To incorporate this relationship, a modified washoff equation incorporating rainfall intensity can be applied to the DR3M-QUAL model in place of the equation given in table 11. The modified equation is:

$$W = L\ [1-e^{(-K_3 R^2 \Delta t)}] \qquad (5)$$

where: W = amount of constituent removed in time step, Δt
L = amount of constituent on impervious area, in kg
K_3 = washoff coefficient, in cm^{-1}
R = runoff rate, in cm/h
Δt = time step, in hours

The concentration and load-characteristic curves for the storm of July 20, 1981, as computed from the modified washoff equation are shown in figure 13, column III. The predicted concentrations correspond more closely to observed values than those generated by the standard washoff equation (column II). Although the load-characteristic curve is improved, it still shows a significant disparity between the predicted and observed data.

Large watersheds

Water-quality modeling results for Allen Creek (mixed land-use subbasin) are presented in table 18 and figure 14. Because the model was applied directly without calibration, average errors for all the sampled storms were calculated. The predicted loadings in table 18 were generated by applying the DR3M-QUAL in the distributed mode and using simulated flow data from the DR3M model. Impervious surfaces in the watershed were apportioned among three types of land uses, each with a set of parameter values corresponding to those obtained from the three land-use areas (table 12). As in the water-quality models discussed earlier, all runoff loads were assumed to originate from impervious surfaces.

Table 18.--Observed and predicted constituent yields (kg/km²) and model error analysis for Allen Creek (mixed land-use) subbasin (modeled drainage area 66.6 km²).

[Dashes indicate no data. Obs. = observed, pred. = predicted.]

Storm date	Runoff (mm)	Suspended sediment obs.	Suspended sediment pred.	TKN obs.	TKN pred.	Total phosphorous obs.	Total phosphorous pred.	COD obs.	COD pred.	Dissolved chloride obs.	Dissolved chloride pred.	Total lead obs.	Total lead pred.	Total cadmium obs.	Total cadmium pred.	Total zinc obs.	Total zinc pred.
								YIELDS									
09-01-80	3.5	822	685	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10-25-80	14.2	--	--	12.3	10.3	3.4	1.4	--	--	1230	205	0.30	0.75	0.0123	0.0281	--	--
05-10-81	1.8	--	--	3.6	4.3	0.2	0.6	58	103	247	62	--	--	--	--	--	--
05-15-81	1.8	500	329	8.9	2.7	.7	.5	130	89	342	62	.14	.18	.0103	.0068	1.03	0.55
06-21-81	2.2	--	--	5.5	5.4	.6	.8	--	--	--	--	.23	.27	--	--	.82	1.03
07-02-81	1.0	226	260	1.7	3.2	--	--	--	--	47	50	--	--	--	--	--	--
07-20-81	5.0	822	822	11.0	7.5	1.7	1.2	--	--	--	--	.42	.47	.0075	.0171	1.10	1.37
07-28-81	1.8	301	397	4.8	3.7	.5	.6	103	116	--	--	.10	.23	.0041	.0075	.23	0.75
08-04-81	5.2	1230	685	10.3	5.5	1.8	.9	294	164	89	123	.38	.40	.0137	.0130	1.23	.96
08-10-81	6.4	1780	411	13.7	3.4	1.4	.5	294	96	130	82	.29	.27	--	--	2.81	.62
Total	42.9	5680	3590	71.8	46.0	10.3	6.5	879	568	2080	584	1.86	2.57	0.0479	0.0726	7.22	5.28
								MODEL ERROR									
Verification storms:																	
Absolute error (percent)		48		56		34		37		59		62		58		120	
RMS error		52		60		39		44		64		85		63		145	
All storms:																	
Absolute error		31		41		53		47		54		40		75		72	
RMS error		39		50		65		52		61		61		90		104	
Spearman correlation coefficient		0.66		0.42		0.62		0.05		0.46		0.82		0.30		-0.09	

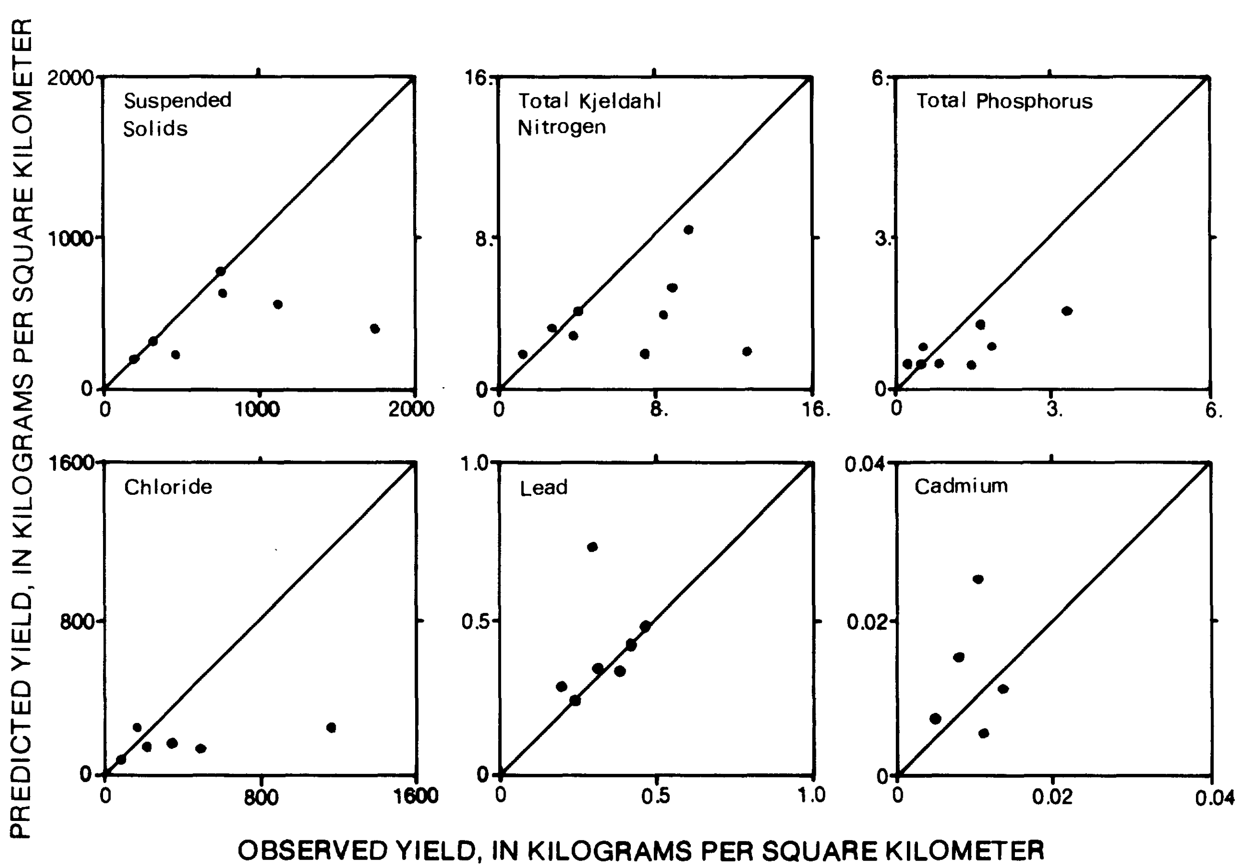


Figure 14.--Predicted constituent yields plotted against observed yields from Allen Creek (large mixed land-use) subbasin.

Predicted and observed loads were correlated at the 0.10 level of significance for suspended solids, total phosphorus, and lead. Root-mean-square errors in the prediction of these constituent loadings for verification storms ranged from 39 to 85 percent and are of the same magnitude as the errors associated with the smaller watershed models. However, the effects of neglecting runoff from pervious areas in the larger storms are apparent in the results for suspended solids and phosphorus loads for larger storms, in which model predictions were below the observed loads (fig. 14). Resuspension of sediment in natural channels may also have contributed to the high loads during these storms.

Failure of the model to accurately predict loads of TKN and chloride may be related to the watershed size. Significant concentrations of TKN were observed in the precipitation at several stations in the basin and were found to vary throughout the year. This precipitation-caused variability could have adversely affected the model results. Dissolved chloride loads also do not fit the pattern predicted by the model simulation; they consist mainly of a slug load during the early spring, presumably from road salt applied during the winter. The model for Allen Creek greatly underpredicted chloride load during the spring. This slug load is followed by decreasing loads through the summer.

Applications and limitations

The accuracy of runoff predictions by the DR3M flow model indicate that this model can be used in the design of instream settling basins to limit the chemical and sediment loads entering Irondequoit Creek and Bay, specifically suspended solids, phosphorus, and lead. The inability of the DR_3M model to incorporate the contributions from snowmelt and spring runoff to annual constituent loads is the one major limitation of this model in the Irondequoit basin. Runoff during the snowmelt and spring runoff periods transported at least half the annual load of the constituents discussed in this report. However, as indicated earlier, the DR_3M may be adapted to simulate large runoff events outside the growing season if a separate set of soil-infiltration parameters is calibrated to account for rainstorms when snow is present.

POTENTIAL OF WETLANDS TO RETAIN SEDIMENT AND NUTRIENTS IN RUNOFF

Present Flow Patterns

Flows in the upper Irondequoit wetland (fig. 15) were monitored from March 1981 through September 1982. During this 19-month period, natural flow patterns and flow dispersion within the wetland were studied through a range of lake stages and flow magnitudes. These measurements show distinct changes in both the quantity of water and velocity characteristics during high-flow periods.

The factors that determine whether water will be stored in the wetland are (1) Lake Ontario stage, which affects wetland-channel-storage capacity, (2) the amount of vegetation, which alters channel conveyance, and (3) distribution of flow in the main and secondary channels (fig. 15). The stage of Lake Ontario determines the channel capacity of the creek in the wetland and is the prime factor in determining whether most of the stormflow will be routed directly along the creek or will be dispersed over the banks of the channel into the wetland. The amount of wetland vegetation and its position on the natural channel banks (or levees) and its position relative to wetland water level can further affect the passage of water in the channel and into the wetland. The flow distribution in the main and secondary Irondequoit channels is determined by channel storage and conveyance factors in Ellison Park, upstream from the wetland. The interaction of these factors is illustrated in the following comparison of two runoff periods that were monitored in the wetland.

Fall runoff

During a storm on September 8, 1981, streamflow was monitored at Blossom Road, at the Wetland Narrows, and at the mouth of the creek at Empire Boulevard to observe flow attentuation within the upper and lower wetland units. Storm hydrographs for these three stations are shown in figure 16.

The hydrograph for Blossom Road is typical for this site. No backwater conditions were observed near the gage, as would be expected from the low peak discharge (7.5 m^3/s), and no diversion to the secondary channel occurred. The discharge record for the Wetland Narrows displayed the typical initial decrease in flow when the large combined sewer overflow from the City of Rochester discharged directly to Irondequoit Creek, just downstream from the gaging station, and inhibited creek flow for a short period at the Narrows station. As the sewer discharge (and temporary backwater) diminished, flow in the creek

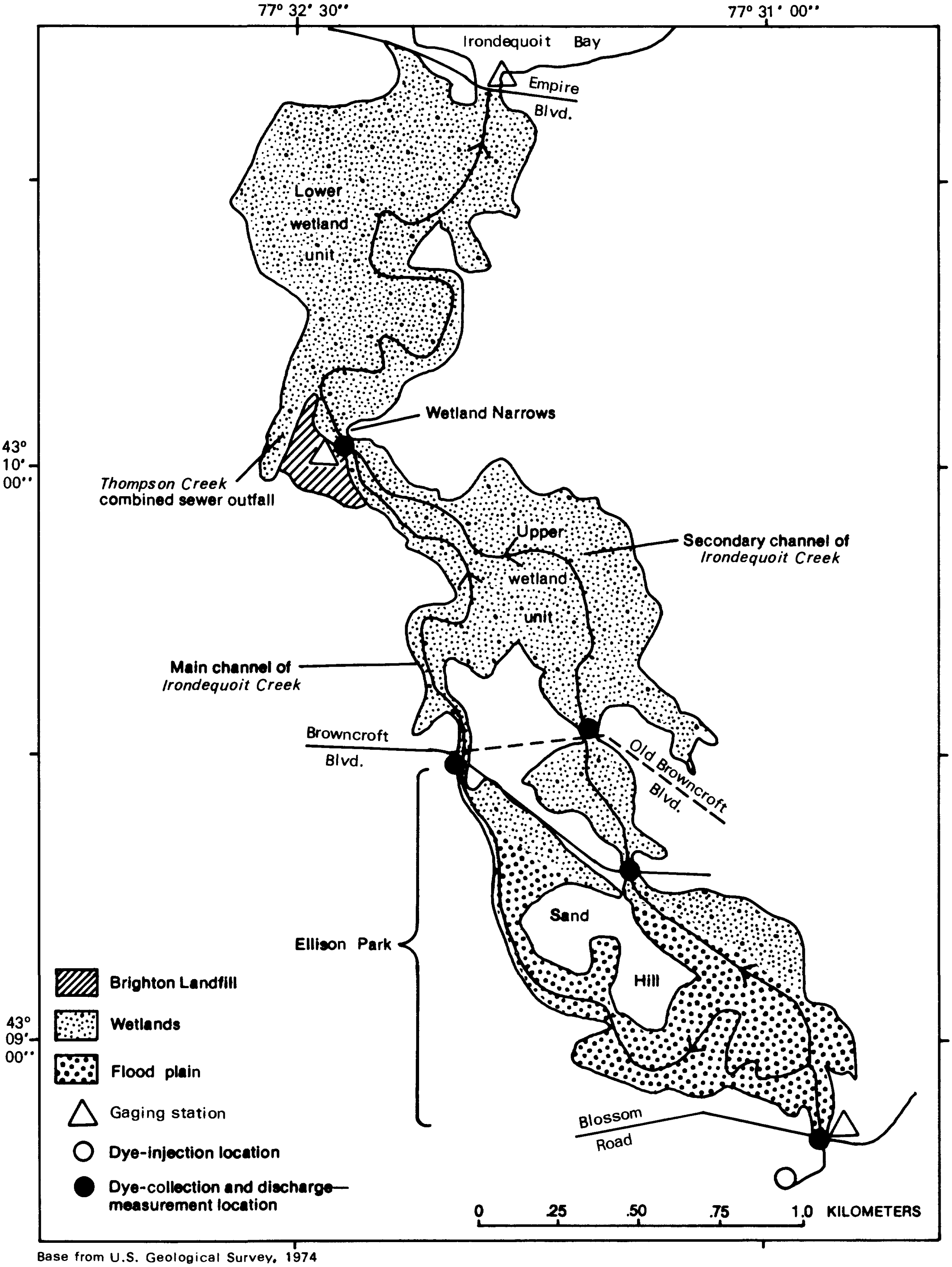


Figure 15.--Major features of the upper Irondequoit Creek wetland and flood plain.

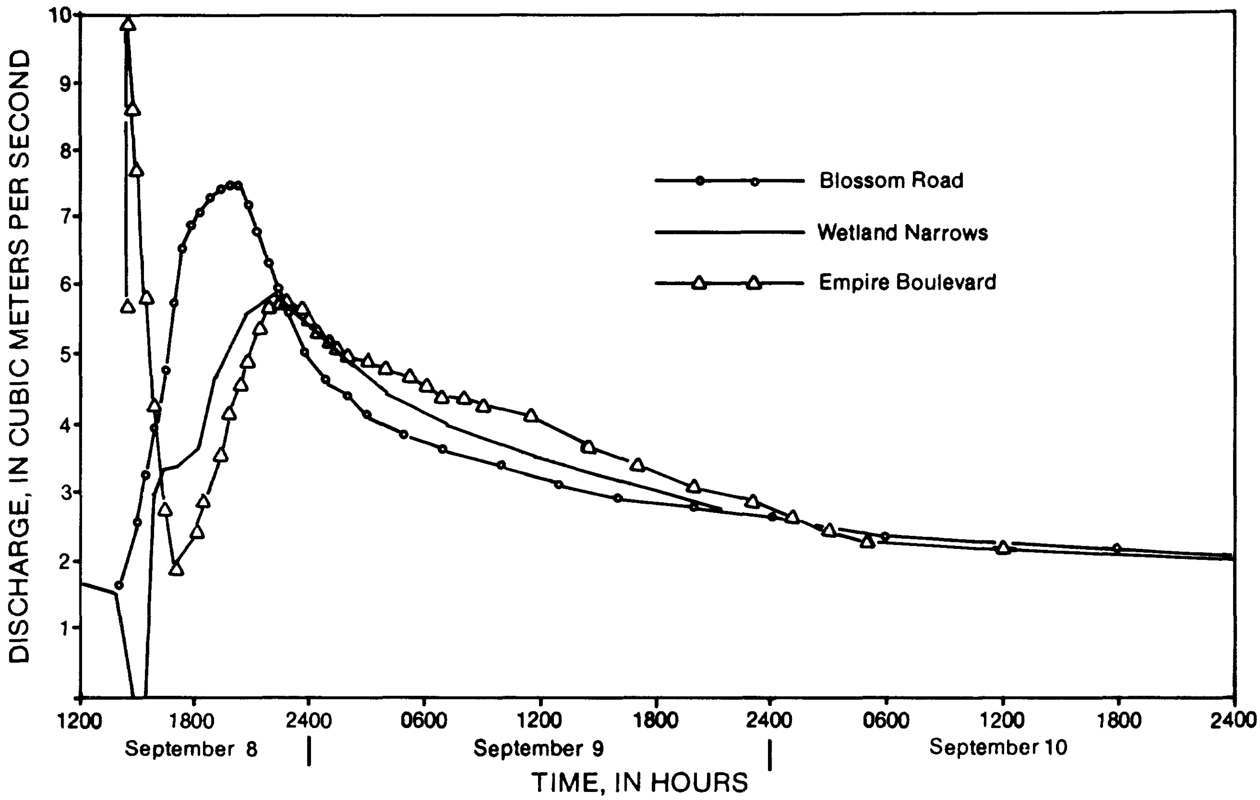


Figure 16.--Composite discharge hydrograph of Irondequoit Creek during storm of September 8-11, 1981 at Blossom Road, Wetland Narrows, and Empire Boulevard. (Locations are shown in fig. 15.)

rapidly increased with the release of water from channel storage and from localized runoff and also when flow from the rest of the basin began to pass through the wetland.

Peak discharge at the Narrows occurred approximately 2 hours later than at Blossom Road and was about 20 percent lower. The recession on the Narrows hydrograph (fig. 16) is much longer than the rising limb, which reflects the release of water from channel storage and some wetland storage. Also the thick growth of wetland vegetation reduced channel conveyance, which slowed the release of wetland and channel storage.

The Empire Boulevard hydrograph (fig. 16) shows a sharp peak discharge of 10.2 m^3/s from the combined sewer outfall, followed more than 8 hours later by a second peak representing the Irondequoit Creek flow. The Empire Boulevard recession displayed the same characteristics as the Narrows recession.

Spring runoff

During the spring rainfall and snowmelt period (March 9 through March 20, 1982), rhodamine WT dye was injected upstream of the Blossom Road station to monitor traveltime, flow separation between the two Irondequoit channels, and dye dispersion within the upper wetland. Discharge measurements were also taken at several locations on the two channels in the upper wetland unit (table 19).

Table 19.--Peak discharges and velocity in Irondequoit Creek wetland on March 17, 1982.

[Locations are shown in fig. 15. Dashes indicate no data.]

Site	Time of peak dye concentration	Travel time (min)	Distance (km)	Type of measurement: Dye tracer Velocity (m/s)	Current meter Velocity (m/s)	Current meter Discharge (m^3/s)	Current meter Time Mililtary
Service road bridge	1055	0	0.0	-	-	-	-
Blossom Road	1100	5	.233	0.78	0.81	21.0	1120-1155
New Browncroft Blvd. (secondary channel)	1140	45	1.79	.66	-	-	-
New Browncroft Blvd. (main channel)	1200	65	4.09	1.05	.91	19.7	1335-1420
Old Browncroft Blvd. (secondary channel)	1205	70	2.45	.58	.63	3.77	1245-1320
Wetland Narrows	1245	110	6.42	.97	.89	22.6	1302-1415

Channel conveyance and storage capacity were quickly filled by the sustained discharge that also caused the creek to overtop its banks at several locations and flood the lower part of Ellison Park (fig. 15). A natural swale on the south side of the "sand hill" allowed some flow from the main channel to enter the secondary channel. As the discharge at Blossom Road increased to a peak of approximately 23 m^3/s, greater amounts of water were diverted into the secondary channel.

The distribution of flow in the main and secondary channels at the Browncroft Boulevard bridges (table 19), near the peak discharge of this spring storm period, revealed that the main channel carried more than 80 percent of the total flow. Discharges in the main and secondary channels at Browncroft Road were 19.7 m^3/s (84 percent) and 3.77 m^3/s (16 percent), respectively. Concurrently, discharge at the Narrows was 22.6 m^3/s, which was near the peak discharge for this storm.

Influence of Lake Ontario

During March 9 through March 20, 1982, Lake Ontario was at the lowest level of the 1981-82 winter (fig. 17). Under this condition, the channel-storage capacity of both main and secondary channels was at its greatest. The wetland vegetation was covered by ice and snow and would thus provide little resistance to water movement (conveyance) once the channel capacity was exceeded. Although some main-channel overflow entered the secondary channel, the channel capacity of both wetland channels was not exceeded, and flow did not disperse into the wetland proper.

Comparison of the storm-runoff pattern of September 8, 1981 with that of March 9, 1982 reveals similar wetland responses despite dissimilar flow-channel capacity and channel-conveyance conditions. During September 1981, Lake Ontario was near its "high-average" stage for the year, and peak flow at Blossom Road was 7.5 m^3/s. The main channel storage was minimal, and conveyance factors were low. Once channel storage was filled, flow into the wetland was limited by the dense vegetation. As peak flow rapidly diminished, water from the channel slowly drained, as reflected in the extended recession limb of the Empire Boulevard hydrograph (fig. 16).

During the March 1982 runoff, Lake Ontario's stage was approximately 0.3 m lower than in September 1981, and the peak discharge was three times greater than the September peak flow rate (22.6 m^3/s). Because the Lake Ontario and wetland water levels were low, the Irondequoit Creek channel had a greater storage capacity to carry flow. The higher flow volume during this storm caused the main channel storage to be quickly filled in Ellison Park, and some of the storm runoff flowed onto the flood plain and into the secondary channel. Once these areas were inundated, some runoff flowed into the interior of the wetland, but this ceased as storm runoff diminished.

These factors, together with the physical configuration of the Irondequoit Creek channel along the western edge of the upper wetland unit (fig. 15), determine the extent of backwater conditions and the potential for flooding within the upper wetland unit. Under some conditions, the effects of these factors are additive and create short-term wetland flooding. Under other conditions, these factors negate one another, allowing direct through-flow of storm runoff without wetland flooding.

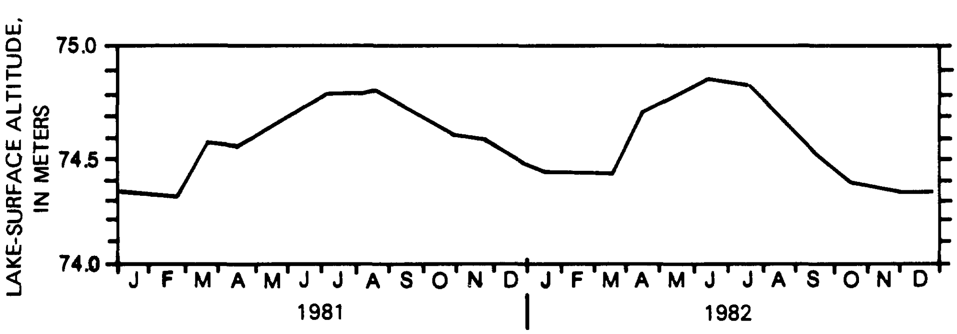


Figure 17.--Monthly mean Lake Ontario water level in 1981-82, as measured at Oswego, N.Y.

Computer Simulation of Water Levels and Wetland Inundation

Computer simulation of wetland water levels and inundation were used to evaluate the effects of wetland flooding during periods of high lake level and high runoff. The DR3M detention pond program was not used in this computer simulation owing to the complexity of the wetland drainage system and the seasonal nature of the wetlands' vegetation, which vastly altered internal wetland flow directions and velocities.

The step-backwater and floodway analysis program (Shearman, 1976) was used to develop water-surface profiles from the mouth of Irondequoit Creek upstream through the Irondequoit wetland and the Ellison Park area. Discharges ranging from 5.7 to 227 m^3/s were simulated as entering the wetland from Blossom Road for both high, average, and low Lake Ontario levels. The simulated profiles did indicate that the Narrows constricts flow leaving the upper wetland at higher flows and lake levels. The simulation also revealed that the main and secondary-channel bridges at Browncroft Boulevard constrict flow at higher peak discharges and may also cause flooding in the low-lying areas of Ellison Park. The profiles obtained were then used as the basis of the reservoir-routing program (Jennings, 1977) to determine depth and duration of flooding in the upper wetland unit.

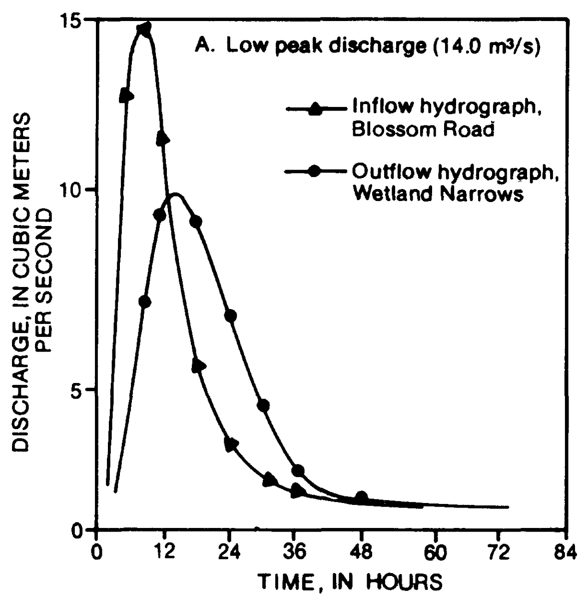
Reservoir-routing analysis

Three peak-flow ranges were chosen on the basis of the U.S. Army Corps of Engineers Flood Frequency Analyses (U.S. Army Corps of Engineers, 1982). Peak flows of 14.0, 42.5, and 113 m^3/s, respectively, represent events with recurrence intervals of 0.5, 2, and 20 years. Results of the reservoir-routing program (Jennings, 1977) for the 14.0 m^3/s peak discharge are shown in figure 18A as an inflow hydrograph at Blossom Road and the corresponding outflow hydrograph at the Wetland Narrows. To test the validity of the reservoir-routing analysis, the synthesized outflow hydrograph of this peak-flow event was compared with several measured storm hydrographs having a similar peak flow. The synthesized hydrograph matched the rises and the peaks fairly well, but the predicted recessions were shorter than the observed recessions. Differences in rainfall/runoff patterns, ground-water and streambank storage and release, and varying lake levels probably account for the differences between the simulated and observed values.

Synthesized inflow and outflow hydrographs for a medium and a high peak discharge at this site are presented in figures 18B and 18C (p. 73). The hydrographs for the two larger flows are similar throughout the runoff period except for a slight decrease in peak-flow volume and a small time offset. No storms occurred during the study that could be used for comparison with these simulated peak discharges.

Figure 18.

Runoff-routing simulation of upper wetland inflows at Blossom Road and outflows at Wetland Narrows:
A. At low peak discharges.
B. At medium peak discharges.
C. At high peak discharges.



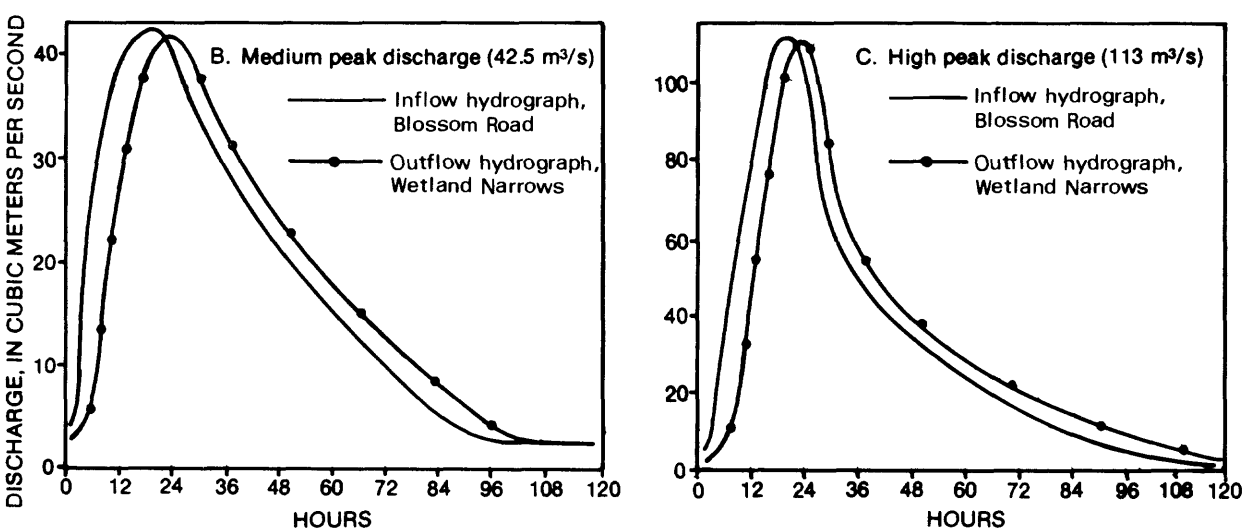
Computer analysis of control-structure alternatives for stormflow detention

To increase the dispersion of flow and detention of stormflows within the wetland, several theoretical flow-regulation configurations at the Narrows were tested. Computer analysis of the present flow configuration in the wetland indicated that detention of flow occurs only during higher flows and for short periods. If the wetland is to be managed for nutrient and sediment reduction, the present conditions will need to be modified to detain flows during a wider range of runoff conditions.

Control-structure simulation.--Several theoretical control-structure designs for the Narrows were simulated to determine the effects of the structure on wetland water levels. The purpose of the structure would be to allow wetland inundation during low to medium stormflows but not increase the depth of flooding at high stormflows. The structure would also allow for fish passage at any flow or lake level and could be used to develop an accurate record of stream discharge during all flow conditions.

Initial designs were tested to develop water-surface profiles along the entire reach from the Narrows through Ellison Park. Control-structure designs that did not meet the above criteria were discarded. Two weir designs, trapezoidal and rectangular (fig. 21), were then chosen for use in the reservoir-analysis computations. Resulting outflow hydrographs for the natural channel and the two theoretical structures, for flows having the low, medium, and high peak flows used previously, are shown in figure 19A-19C. To analyze the duration of flooding within the upper wetland unit, 75.8 m was chosen as the level of significant wetland inundation. This elevation was chosen through a review of topographic maps and inspection of the wetland during high-flow periods.

Results.--Results for the low peak discharge, 14.0 m^3/s (fig. 19A), indicate that both structures decrease peak flows and increase the depth and period of inundation in the upper wetland. The depth and duration of flooding in the upper wetlands for the low peak discharge of 14.0 m^3/s is displayed in figure 20A. In general, for a flow of 14.0 m^3/s, the weirs increase water levels by approximately 0.5 m for 2 to 2 1/2 days.



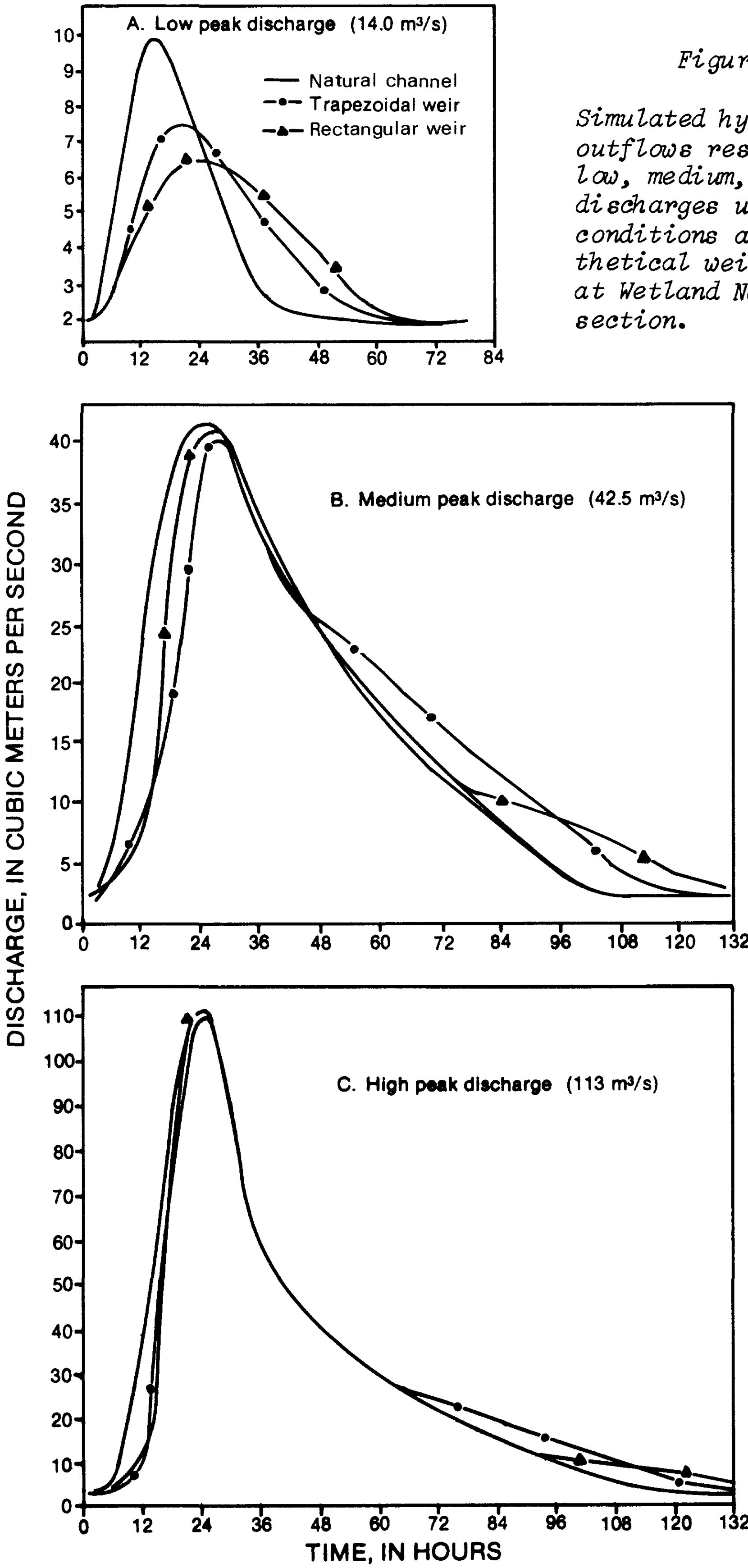


Figure 19.

Simulated hydrographs of outflows resulting from low, medium, and high peak discharges under present conditions and for two hypothetical weir configurations at Wetland Narrows cross section.

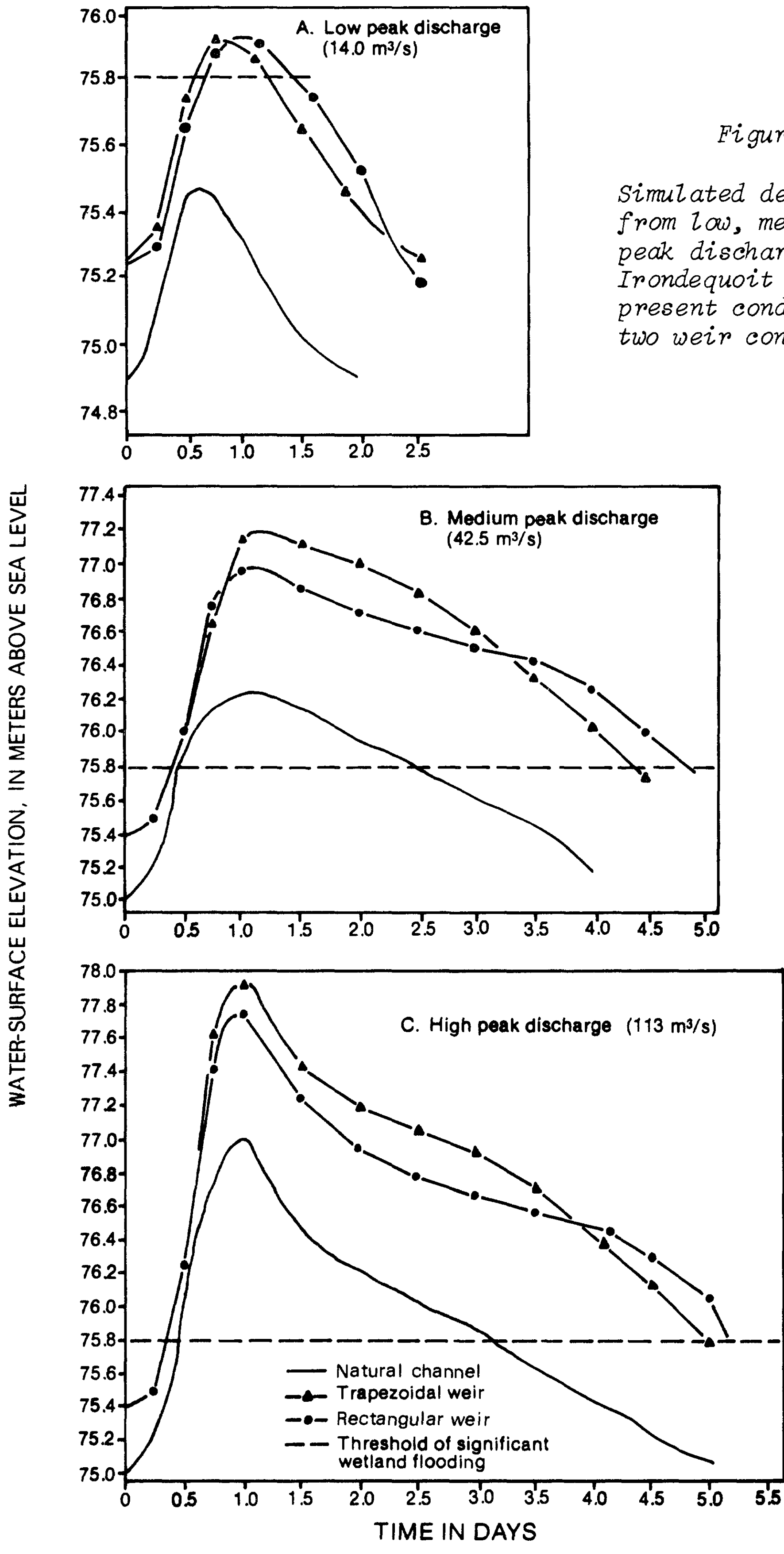


Figure 20.

Simulated depth of flooding from low, medium, and high peak discharges in the upper Irondequoit wetlands under present conditions and with two weir configurations.

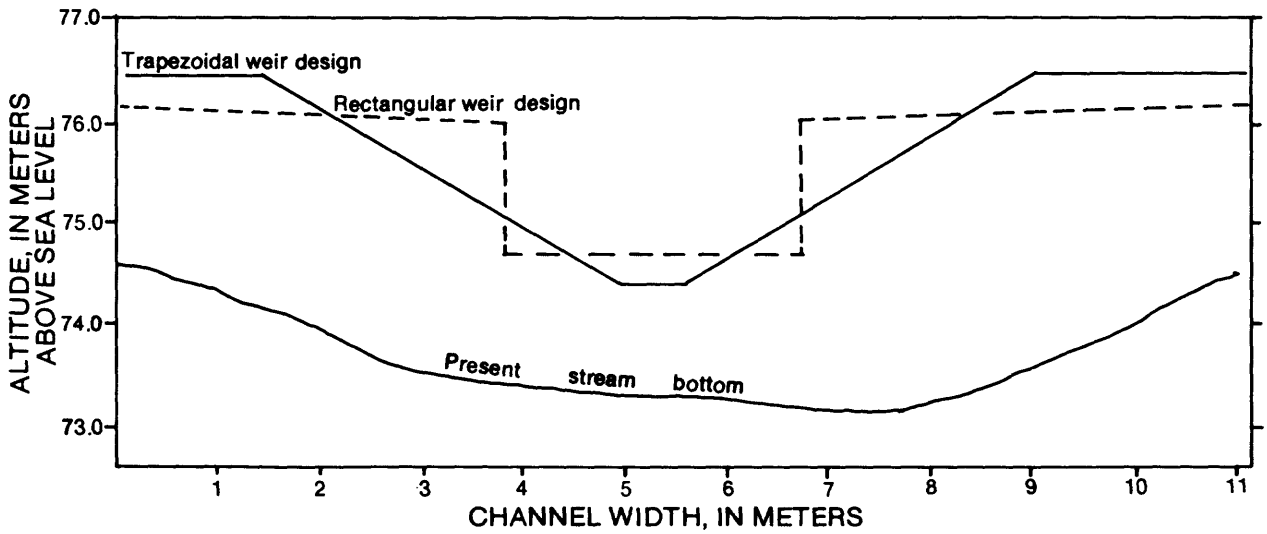


Figure 21.--Conceptual weir designs analyzed in the Wetland Narrows flow-regulation simulation. (Location is shown in fig. 15.)

A runoff event having a recurrence interval of 2 years and a peak discharge of 42.5 m^3/s produced slightly different hydrographs. The rising limb and peak of the outflow hydrograph were similar in shape to that simulated for the natural condition, but the recession limb was extended by the two control structure designs. Both control designs would increase maximum water depth in the wetland by approximately 1 m over natural conditions (fig. 20b), but the trapezoidal design would impound water to a slightly greater depth and maintain higher levels for the major part of the recession period. The rectangular design would maintain a slightly lower depth of inundation than the trapezoidal weir which results in a hydrograph similar to that for present conditions. The total duration of significant wetland flooding would be 3.5 to 4 days with the two theoretical weirs and about 2 days under present conditions.

The hydrographs for the two design simulations at stormflows with the high peak discharge (113 m^3/s) (fig. 19C) showed a similar response through the rising peak and the initial recession limb. Separation of the present-condition line from the other two lines appear at 36 hours--after most of the flow has passed through the upper wetland. The corresponding changes in stage are shown in fig. 20C; here, as under the medium stormflow condition (fig. 20B), the maximum wetland inundation would be nearly 1 m more than under present conditions. The total duration of significant wetland flooding at the high peak-flow rate would be approximately 4.5 days, 1 day longer than the value calculated for present conditions. The difference in effects of the two weir designs becomes apparent on the recession limb (fig. 20C). The differences between duration of flooding under present conditions and with the two theoretical weir designs for the three different flow conditions are plotted in figure 22.

Results of this analysis indicate that construction of a flow-regulation structure at the Wetland Narrows would increase the depth and duration of flooding in the upper wetland unit during low- and medium-flood runoff periods while not flooding Ellison Park more than occurs naturally during high runoff periods.

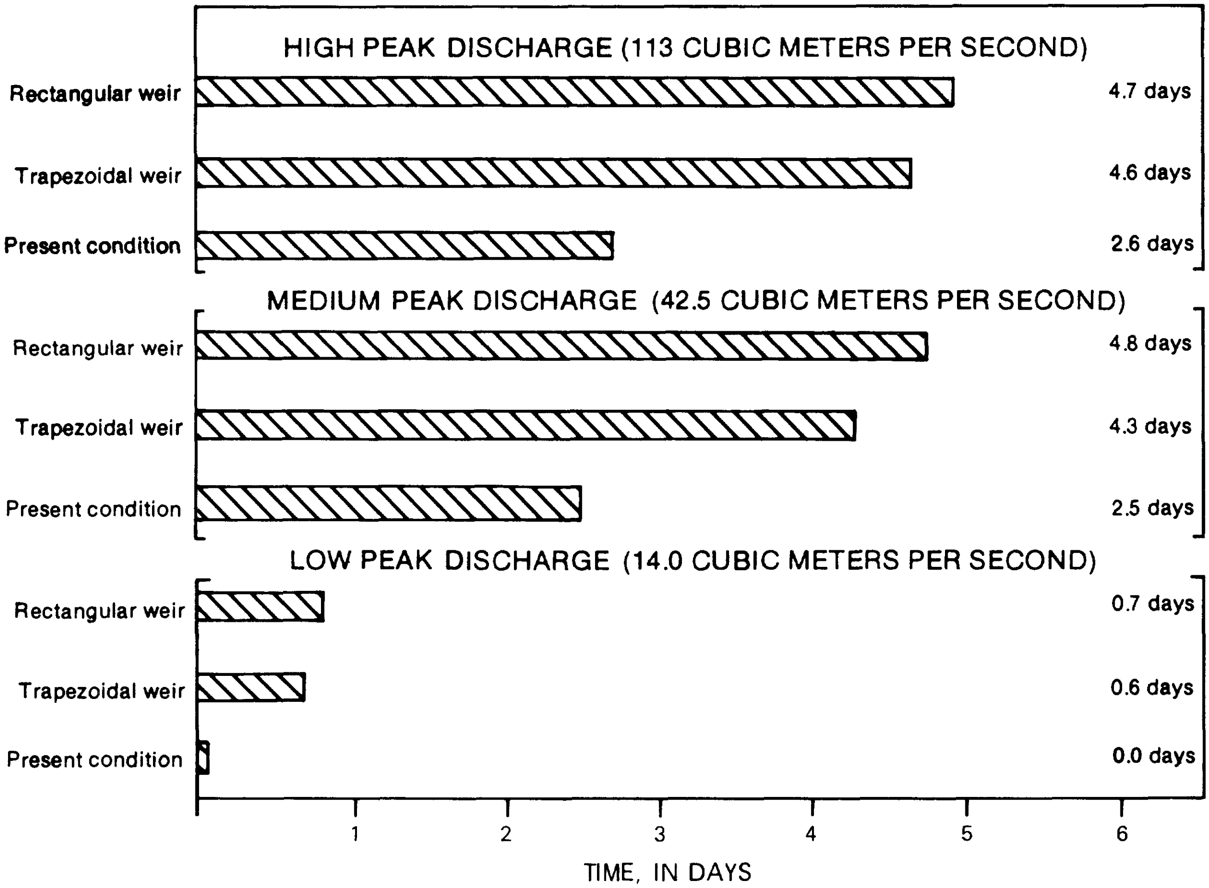


Figure 22.--Predicted duration of significant wetland inundation (above elevation of 75.8 m) in the upper wetland for storms producing high, medium, and low peak discharges.

Potential Retention Capabilities

The detention of flow within the wetland would permit removal of some of the suspended solids and nutrients from Irondequoit Creek. The percent removal of such materials is difficult to approximate owing to variable flow patterns within the wetland, the seasonal changes in wetland vegetation, and variable lake levels and intrawetland flow conditions. Most of the suspended materials that could be removed are in the silt and sand fractions (61 and 10 percent, respectively), as indicated by the average particle-size analyses for the basin (table 8). Of the total phosphorus load measured at Blossom Road, 85 percent was in the particulate form and is probably associated mostly with the clay and silt fractions. At present, the retention of clay and silt fractions within the wetland, measured as the difference between suspended sediment loads at Blossom Road and those at the Wetland Narrows stations, is quite low. On an annual average, approximately 12 percent of the clay and silt fraction entering the wetland is retained, and retention of flow in the upper wetland is sporadic and variable in extent.

Most stormwater runoff is retained for as much as 48 hours as channel and near-channel storage in approximately 20 percent of the wetlands area. Under the proposed management scheme, the retention period would increase by 1 to 2 days, and nearly 80 percent of the wetland would be inundated. From the projected increase in area, depth, and duration of inundation within the wetland, three to four times as much of the sand and silt fraction could be retained. If more storm runoff were detained within the wetland, sediment and nutrient retention in the wetland could also increase. The expansion of inundation from 20 percent of the wetland to 80 percent of it could cause a 100-percent increase in sediment and associated nutrient retention, or approximately 25 percent of the basin load. If the channel-bank and levee system were not continuous, and if flow from the main channel could be diverted into the wetland at several points upstream from the Wetland Narrows, additional flow dispersion and constituent retention could theoretically be attained.

Other Considerations

Little information is available on how wetland management would affect the flora and fauna. Typha spp. (cattail) is the dominant vegetative genus. In the upper wetland unit, Typha glauca and an immature hybrid of Typha latifolia and Typha augustifolia appear to be the dominant species (Lee Marsh, State University of New York at Oswego, oral commun., 1983). Because this wetland is already inundated periodically, more frequent flooding should have little effect on the vegetative structure of the wetland. Some increase in the more flood-tolerant glauca species may occur, but cattails would persist.

Periodic harvesting of the cattail biomass would constitute further removal of nutrients. Pratt (1982) and Linde (1973) have shown that during the growth period of Typha spp., the plant biomass can retain high amounts of phosphorus, nitrogen, and other chemical constituents of stormwater runoff. These constituents are normally released back to the water column during the senescense of the plant (late summer and fall) and during the period of plant decomposition (winter and early spring), but harvesting of the cattail rhizome (root) and leaves would remove a part of the inorganic constituents associated with the substrate in which the rhizomes grow. Careful harvesting and management of the extensive cattail mats within the wetland could be used to further increase the chemical removal capability of the wetland.

Data on fauna within the Irondequoit wetland system are also limited. Most use of the wetland by wildlife appears to be limited to forage, with little indication of any permanent wildlife population within the wetland proper.

In summary, the information provided in the hydrologic analysis shows that a control structure at the Narrows could regulate water levels within the wetland to meet detention requirements and meet the depth-of-flooding criteria for high flows. Resultant changes in quality of water leaving the wetland would improve with increased detention time and areal inundation. Increased flow dispersion into the wetland should also increase renovation of stormwater flows. The effects upon the flora and fauna will need to be studied, however, before any structure can be put in place.

SUMMARY AND CONCLUSIONS

Streamflow and water-quality data were collected at 16 sites within urbanized and rural parts of the 438-km^2 Irondequoit Creek basin from August 1980 through August 1981. These data were used (a) to calculate loads of eight constituents that enter Irondequoit Bay, (b) to calibrate a rainfall-runoff model of the basin, and (c) to assess the potential for increasing the extent and duration of ponding within the Irondequoit wetlands, which would increase sediment and nutrient retention. The principal conclusions resulting from this study are:

(1) Annual loads of the eight constituents to Irondequoit Bay from Irondequoit Creek at Blossom Road were: suspended sediments, 14,800 Mg; total phosphorus, 15.7 Mg; dissolved chloride, 12,700 Mg; total kjeldahl nitrogen, 166 Mg; chemical oxygen demand, 1,990 Mg; total lead, 2.78 Mg; total cadmium, 1.11 Mg; and total zinc, 68.6 Mg. Of the annual basin load, 50 to 75 percent was transported to the bay during a 3-month period that included the major seasonal snowmelt and spring runoff. The high loading rate during this period is attributed to constituent buildup in the snowpack and to erosion and transport of sediment by sustained high flows.

(2) Among the four single land-use sites, the highest loads of all constituents except cadmium were from a high-density residential site and a housing-construction site. Among the six large mixed-land-use subbasins, the highest loading rates were from the two that are most highly urbanized.

(3) At the housing-construction site, suspended-sediment loads were 10 times greater than at any other monitoring site. These loads occurred despite a grassed upstream detention pond and other erosion-control measures. Nutrient loads from this site were similar to those of the high-density residential basins, and loads of total lead, cadmium, and zinc were similar to those from both rural and developed areas.

(4) The average particle-size distribution of sediment samples collected in this study were: clay, 29 percent; silt, 61 percent; and sand, 10 percent. Comparison of total measured phosphorus to total dissolved phosphorus revealed that 60 to 85 percent of the phosphorus load was in the particulate form, but no definitive relationship between the particle-size distribution and particulate phosphorus concentration was detected.

(5) Estimated atmospheric wetfall and dustfall yields to the basin were similar to those found in other studies in the northeastern United States. The annual deposition of phosphorus equaled 65 percent of the annual yield measured at Blossom Road, and atmospheric deposition of total kjeldahl nitrogen equaled 135 percent of the total annual yield measured at Blossom Road. Of the total load of lead deposited by atmospheric sources in the basin, 95 percent was retained within the basin. A similar value for atmospheric lead retention was found in a study in the Adirondack Mountains, 325 km east of Irondequoit Bay (Troutman and Peters, 1982).

(6) Storm-runoff volumes and peak discharges predicted by the Distributed Rainfall-Runoff Routing Model (DR_3M) for three land-use sites were within 10 to 30 percent of the measured values. Results for the large mixed-land-use subbasin, Allen Creek, were just as accurate. Variation in the distribution and

intensity of precipitation in large subbasins seems to be the greatest source of error in the predicted volumes and peak flows. Seasonal changes in vegetation and temperature also affect the runoff process but could not be represented in the model. Several sets of soil-parameter values would have to be developed to improve accuracy of predicted runoff volumes and peak flows.

(7) Of the eight constituents simulated by the DR_3M-QUAL model for the three single-land-use sites, predicted loads of suspended sediment, total kjeldahl nitrogen, total phosphorus, dissolved chloride, total lead, and total cadmium were within 40 to 60 percent of the observed values. Of the predicted loads from the mixed land-use subbasin, Allen Creek, only suspended sediment, total phosphorus, and total lead were within this range of accuracy.

(8) The washoff equation of the DR_3M-QUAL model that represents a "first flush" of surface contaminants did not accurately predict the initial concentration of constituents analyzed. A modification of this equation to include the degree of rainfall intensity improved the accuracy of prediction.

(9) The present configuration of the upper Irondequoit wetland and creek confines most flow to the main channel and limits flow into the wetland. The period of maximum potential for wetland flooding is in June and July, when Lake Ontario's water level is highest.

(10) Computer simulation of two different control structures at the Wetland Narrows indicated that the duration of stormflow detention in the upper wetland during a semiannual flood would increase by several hours. Stormflow-detention time would increase by several days, and the depth of flooding would increase by as much as 1 m over natural levels during the 2-year to 20-year storm discharges. Such flooding would not adversely affect wetland vegetation or recreational use of the upstream flood-plain park.

(11) Circulation patterns within the wetland vary with Lake Ontario levels and discharge. Currently the sediment and nutrients retained within the wetland equal approximately 10 percent of the basin load; the use of a control structure at the Wetland Narrows could increase this to 25 percent. Nutrient retention within this cattail (Typha spp.)-dominated wetland would occur mainly through deposition and mineralization of particulate phosphorus and partly through uptake in the cattails. Further removal of nutrients and other constituents could occur only through harvesting and removal of the plant material.

(12) Although the above results suggest that flow in the upper Irondequoit wetland can be diverted to increase depth and duration of flooding, the present models cannot predict the resulting increase in sediment deposition and nutrient retention. The effects of flow diversion on the flora and fauna of the wetland ecosystem need to be evaluated before control measures can be installed.

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Table 20.--Consituent concentrations and runoff loads.

[Locations are shown in fig. 1. TSS, Total Suspended Sediment; P, Phosphorus; TKN, Total Kjeldahl Nitrogen; COD, Chemical Oxygen Demand; Cl, Chloride; Pb, Lead; Zn, Zinc; Cd, Cadmium. Dashes indicate missing data.]

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (Mg)	Total-P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
A. THORNELL ROAD (115 km^2, agricultural/rural subbasin)																		
Growing-season storms 08-05-80 to 10-28-80 05-10-81 to 08-13-81																		
08-05-80	15.2	0.94	-	0.26	0.60	-	47	0.019	-	0.001	-	28.1	64.9	-	5.45	2.04	-	0.091
08-30-80	7.62	0.48	-	0.13	0.40	-	45	0.006	-	0.001	-	7.26	22.2	-	2.72	.318	-	.045
09-01-80	54.9	2.41	422	0.40	1.20	-	43	-	-	-	117.	111.	334.	-	11.8	-	-	-
09-14-80	26.2	1.30	203	0.21	0.50	-	43	-	-	-	30.9	31.3	74.9	-	6.35	-	-	-
10-25-80	74.7	5.54	317	0.36	0.60	-	41	-	0.05	-	202.	229.	382.	-	26.3	-	31.8	-
05-10-81	21.1	2.84	30	0.11	1.30	23	81	0.016	0.22	0.003	9.98	35.9	426.	7.26	26.3	5.27	72.2	.999
05-15-81	19.1	4.22	66	0.15	1.50	29	69	0.011	0.60	0.003	31.8	72.6	727.	13.6	33.6	5.31	29.0	1.45
06-21-81	25.4	1.80	99	0.11	1.00	23	56	0.011	0.16	0.006	20.9	22.7	208.	4.54	11.8	2.27	33.1	1.26
07-02-81	14.7	0.10	130	0.21	1.7	11	55	0.021	0.72	0.002	1.82	2.27	20.0	0.09	.908	.227	8.63	.045
07-20-81	41.4	1.73	78	0.18	1.2	29	52	0.009	0.86	0.004	15.4	35.9	239.	5.45	9.99	1.77	171.	.817
07-28-81	25.4	1.24	49	0.12	1.1	22	44	0.010	0.06	0.004	7.26	17.2	157.	2.72	6.35	1.41	8.63	.590
08-04-81	33.3	1.47	117	0.14	1.6	22	-	0.007	0.17	0.029	20.0	23.6	270.	3.63	-	1.18	28.6	4.90
08-10-81	37.1	2.62	129	0.12	1.3	36	53	0.013	3.6	0.007	38.1	35.9	388.	10.9	15.4	3.90	1080.	2.09
											495	653	3310	48.1	157	23.7	1460	12.3
Growing season base flow (Between storms) 08-05-80 to 10-28-80 05-10-81 to 08-13-81		55.1	45	0.06	0.6	12	48	0.006	0.09	0.002	285.	380.	3800.	76.2	304.	38.0	570.	12.7
Winter runoff 10-28-80 to 01-24-81		54.9	50	0.06	0.7	-	53	-	-	-	315.	378.	4410.	-	334.	-	-	-
Snowmelt runoff 01-25-81 to 03-02-81		57.4	344	0.26	1.9	4	47	0.011	0.9	0.007	2270.	1700.	12600.	26.3	310.	72.6	5950.	46.3
Spring runoff 03-03-81 to 05-10-81		53.1	7	0.04	0.8	10	55	0.009	0.52	0.026	42.7	244.	4900.	60.8	335.	54.9	3170.	158.
Total sampled load 08-05-80 to 08-13-81		247.									3410.	3360.	29000.	211.	1440.	189.	11200.	229.
Estimated subbasin yield[1], in $(kg/km^2)/d$											79.7	.078	.679	6.51	33.7	.006	.345	.007

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (Mg)	Total-P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
B. THOMAS CREEK (71.7 km^2, rural headwaters, mixed land use subbasin)																		
Growing-season storms 08-05-80 to 10-28-80 05-10-81 to 08-13-81																		
08-05-80	34.5	0.81	-	0.20	0.60	-	61	0.031	-	0.001	-	11.8	35.4	-	3.63	1.82	-	0.045
08-30-80	11.2	0.25	-	0.23	0.70	-	87	0.005	-	0.001	-	4.09	12.2	-	1.82	.091	-	>.001
09-01-80	70.6	1.98	75	0.26	0.70	-	44	0.011	-	0.001	10.9	36.8	99.0	-	6.35	1.54	-	>.001
09-14-80	20.8	0.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-25-80	76.7	3.76	140	0.50	1.00	-	42	0.041	0.10	0.001	38.1	135.	269.	-	10.9	11.0	26.8	.272
05-10-81	23.9	1.65	37	0.11	1.4	30	88	0.031	0.34	0.004	4.54	13.2	165.	3.63	9.98	3.68	40.0	.454
05-15-81	21.8	2.21	47	0.18	1.8	31	82	0.016	0.05	0.003	7.26	28.6	285.	4.54	12.7	2.54	7.72	.454
06-21-81	28.9	1.17	41	0.11	1.2	23	61	0.013	0.19	0.007	3.63	9.08	101.	1.82	5.45	1.09	15.9	.590
07-02-81	11.4	1.17	132	0.15	-	-	88	0.011	0.82	0.002	10.9	12.7	-	-	7.26	.908	69.0	.182
07-20-81	43.4	1.40	-	0.21	-	-	-	0.005	1.90	0.004	-	20.9	-	-	-	.499	189.	.409
07-28-81	25.1	1.02	27	0.16	1.3	20	65	0.017	0.10	0.008	1.82	11.8	94.0	1.82	4.54	1.22	7.26	.590
08-04-81	23.1	0.64	21	0.10	1.2	19	88	0.008	0.14	0.004	.908	4.54	55.4	.908	3.63	.363	6.36	.182
08-10-81	30.5	1.75	42	0.14	1.1	35	59	0.034	5.34	0.011	5.45	17.7	138.	4.54	7.26	4.27	669.	1.36
											82.5	306.	1250.	17.2	73.5	29.0	1030.	4.54
Growing season base flow (Between storms) 08-05-80 to 10-28-80 05-10-81 to 08-13-81		26.7	31	0.12	1.0	14	77	0.005	0.26	0.002	59.0	229.	1910.	26.3	147.	9.53	496.	3.81
Winter runoff 10-28-80 to 01-24-81		35.6	-	0.09	0.86	-	-	-	-	-	-	229.	2190.	-	-	-	-	-
Snowmelt runoff 01-25-81 to 03-02-81		62.5	30	0.13	1.45	4	97	0.011	1.3	0.003	134.	582.	6490.	18.2	434.	49.0	5820.	13.4
Spring runoff 03-03-81 to 05-10-81		33.3	4	0.08	1.2	21	91	0.022	0.94	0.041	9.98	191.	2870.	49.9	218.	52.6	2250.	98.0
Total sampled load 08-05-80 to 08-13-81		176.									285.	1540.	14700.	112.	872.	140.	9600.	120.
Estimated subbasin yield[1], in (kg/km^2)/d											14.1	.058	.551	5.54	43.1	.007	.475	.006

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (Mg)	Total-P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
C. LINDEN AVENUE (249 km², urban subbasin)																		
Growing-season storms																		
08-05-80 to 10-28-80																		
05-10-81 to 08-13-81																		
08-05-80	33.3	1.45	-	-	-	-	38	-	-	-	-	-	-	-	13.6	-	-	-
08-30-80	13.2	0.53	-	0.09	0.40	-	91	0.005	-	>0.001	-	11.8	53.1	-	11.8	.681	-	> .001
09-01-80	62.5	3.71	236	0.37	0.80	-	49	0.037	-	0.001	218.	341.	737.	-	45.4	34.1	-	.908
09-14-80	23.6	1.35	243	0.27	1.20	-	65	0.025	-	0.001	80.8	89.9	399.	-	21.8	8.31	-	.318
10-25-80	73.2	7.01	-	0.23	0.60	-	77	-	0.05	-	-	401.	1050.	-	134.	-	87.2	-
05-10-81	21.8	2.90	40	0.11	1.50	30	80	0.012	0.20	0.003	29.0	79.9	1090.	21.8	58.1	8.72	145.	2.18
05-15-81	13.2	3.42	57	0.18	1.6	29	87	0.014	0.10	0.003	49.0	153.	1360.	24.5	74.4	11.9	85.4	2.54
06-21-81	26.9	1.78	122	0.09	1.7	28	88	0.015	0.15	0.004	53.6	39.5	750.	12.7	39.0	6.63	66.3	1.36
07-02-81	9.9	0.74	-	0.09	0.20	42	83	0.027	0.37	0.003	-	16.8	37.2	8.17	15.4	4.99	68.6	.545
07-20-81	43.9	1.75	285	0.25	2.00	48	59	0.028	0.17	0.005	123.	108.	870.	20.7	25.4	12.2	74.0	2.18
07-28-81	26.7	1.73	152	0.22	1.8	34	-	0.021	0.15	0.003	64.4	93.5	765.	14.5	-	8.95	63.6	1.27
08-04-81	23.9	1.35	216	0.26	1.8	40	79	0.009	0.78	0.010	72.6	86.7	602.	13.6	26.3	3.00	261.	3.36
08-10-81	41.4	2.44	471	0.16	2.5	48	37	0.033	2.98	0.005	285.	96.7	1510.	29.0	22.7	20.0	1800.	3.04
											975.	1520.	9220.	145.	488.	119.	2650.	17.7
Growing season base flow (Between storms)																		
08-05-80 to 10-28-80																		
05-10-81 to 08-13-81		42.7	51	0.12	1.1	18	101	0.009	0.39	0.002	542.	1280.	11700.	192.	1070.	95.7	4150.	21.2
Winter runoff																		
10-28-80 to 01-24-81		51.8	-	0.08	0.8	-	120	-	-	-	-	1030.	10300.	-	1550.	-	-	-
Snowmelt runoff																		
01-25-81 to 03-02-81		56.9	199	0.24	1.7	5	87	0.015	1.1	0.006	2810.	3390.	24000.	70.8	1230.	212.	15500.	84.8
Spring runoff																		
03-03-81 to 05-10-81		46.0	9	0.05	1.2	19	97	0.012	0.63	0.029	103.	570.	13700.	217.	1110.	137.	7180.	330.
Total sampled load																		
08-05-80 to 08-13-81		228.									4430.	7790.	68900.	625.	5450.	564.	29500.	454.
Estimated subbasin yield[1], in (kg/km²)/d											63.1	.084	.744	8.90	58.8	.008	.420	.006

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (Mg)	Total-P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
							D. ALLEN CREEK (66.6 km^2, mixed land-use subbasin)											
Growing-season storms 08-05-80 to 10-28-80 05-10-81 to 08-13-81																		
08-05-80	35.6	2.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08-30-80	7.11	0.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
09-01-80	43.9	4.90	199	-	-	-	-	-	-	-	65.4	-	-	-	-	-	-	-
09-14-80	23.9	1.83	60	-	-	-	-	-	-	-	7.26	-	-	-	-	-	-	-
10-25-80	82.6	17.1	-	0.2	0.7	-	74	0.018	-	0.001	-	227.	795.	-	84.4	20.5	-	1.14
05-10-81	22.9	3.43	67	0.13	2.0	32	136	0.023	0.21	0.003	15.4	29.5	456.	7.26	30.9	5.22	47.7	.681
05-15-81	24.1	4.29	139	0.17	2.2	34	106	0.035	0.26	0.003	39.9	48.6	628.	9.98	29.9	9.99	74.0	.863
06-21-81	32.2	3.66	111	0.23	2.1	-	69	0.087	0.31	0.054	27.2	55.8	510.	-	16.3	21.2	75.4	13.1
07-02-81	18.3	1.45	356	0.14	2.7	-	73	0.121	1.80	0.003	34.5	13.6	260.	-	7.26	11.7	173.	.272
07-20-81	52.6	6.60	225	0.29	1.9	-	53	0.070	0.18	0.001	99.0	128.	835.	-	23.6	30.8	79.0	.454
07-28-81	32.0	3.63	146	0.22	1.9	40	-	0.057	0.13	0.002	35.4	58.1	460.	9.98	-	13.8	31.3	.499
08-04-81	49.0	7.14	257	0.31	1.8	51	45	0.066	0.24	0.003	122.	147.	854.	24.5	21.8	31.3	114.	1.41
08-10-81	37.1	8.58	240	0.18	1.9	40	36	0.082	0.79	0.006	137.	103.	1050.	22.7	20.9	46.8	451.	3.45
											583.	811.	5850.	74.4	235.	191.	1050.	21.9
Growing season base flow (Between storms) 08-05-80 to 10-28-80 05-10-81 to 08-13-81		48.8	43	0.14	1.6	16	109	0.017	0.35	0.003	140.	455.	5200.	51.7	354.	55.3	1140.	9.76
Winter runoff 10-28-80 to 01-24-81		55.9	57	0.08	0.9	-	242	-	-	-	212.	297.	2970.	-	899.	-	-	-
Snowmelt runoff 01-25-81 to 03-02-81		108.	162	0.25	1.9	7	215	0.071	1.05	0.006	1160.	1800.	13700.	49.9	1540.	510.	7550.	43.1
Spring runoff 03-03-81 to 05-10-81		50.0	22	0.06	1.7	28	190	0.046	0.571	0.063	73.5	200.	5670.	93.5	634.	154.	1910.	210.
Total sampled load 08-05-80 to 08-13-81		329.									2170.	3560.	33400.	270.	3660.	911.	11600.	285.
Estimated subbasin yield[1], in (kg/km^2)/d											89.2	.146	1.37	14.7	150.	.048	.618	.015

[1] Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (Mg)	Total-P (kg)	TKN (kg)	COD (Mg)	Cl (Mg)	Pb (kg)	Zn (kg)	Cd (kg)
E. BLOSSOM ROAD (342 km^2, entire watershed upstream of wetlands)																		
Growing-season storms 05-10-81 to 08-13-81																		
05-10-81	46.0	7.59	82	0.14	1.8	25	100	0.020	0.12	0.003	213.	364.	4680.	65.4	260.	51.9	312.	7.81
06-21-81	28.2	2.82	82	0.50	3.1	41	81	0.047	0.15	0.003	270.	480.	3000.	39.0	78.1	45.1	144.	2.86
07-02-81	14.2	1.17	-	1.50	3.2	34	93	0.063	1.15	0.002	-	603.	1290.	13.7	37.2	25.3	462.	.817
07-20-81	44.7	4.39	-	0.23	2.5	55	58	0.054	0.28	0.004	-	345.	3750.	82.6	87.1	81.0	420.	5.99
07-28-81	29.5	2.31	179	0.26	2.2	36	65	0.035	0.13	0.002	142.	206.	1750.	29.0	51.7	27.8	104.	1.59
08-04-81	17.8	3.05	237	0.22	1.9	38	57	0.031	0.56	0.013	247.	230.	1980.	39.9	59.9	32.3	584.	13.6
08-10-81	42.2	4.14	382	0.23	1.9	47	80	0.065	1.70	0.006	541.	326.	2690.	66.3	113.	92.1	2410.	8.49
											1410.	2550.	19100.	336.	687.	356.	4440.	41.2
Growing season base flow (Between storms) 05-10-81 to 08-13-81		24.7	66	0.16	1.5	20	105	0.01	0.26	0.003	558.	1350.	12700.	169.	888.	84.6	2200.	25.4
Winter runoff 12-15-80 to 01-24-81		40.1	89	0.09	1.3	-	136	-	-	-	1220.	1230.	17800.	-	1870.	-	-	-
Snowmelt runoff 01-25-81 to 03-02-81		79.8	271	0.17	1.6	6	143	0.03	0.86	0.006	7400.	4640.	43700.	164.	3910.	819.	23500.	164.
Spring runoff 03-03-81 to 05-10-81		48.8	56	0.06	1.3	16	120	0.021	0.86	0.032	934.	1000.	21700.	267.	2000.	350.	14400.	534.
Total sampled load 12-15-80 to 08-13-81		219.									11500.	10810.	115000.	936.	9360.	1610.	44500.	765.
Estimated subbasin yield[1], in (kg/km^2)/d											114.	.116	1.27	13.7	101.	.020	.476	.008

1 The daily yields for the 1980 storms, the 1980 growing season baseflow, and the first 48 days of winter runoff were estimated using corresponding runoff periods in 1980 and 1981 to develop the estimated subbasin yield.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (kg)	Total-P (kg)	TKN (kg)	COD (kg)	Cl (kg)	Pb (kg)	Zn (kg)	Cd (kg)
F. CRANSTON ROAD (0.67 km², moderate-density residential site)																		
Growing-season storms																		
08-05-80 to 10-28-80																		
05-10-81 to 08-13-81																		
08-05-80	19.6	2.44	-	0.28	0.90	-	12	0.059	-	0.001	-	0.454	1.50	-	19.5	0.095	-	0.002
08-30-80	19.8	2.00	-	0.52	2.00	-	36	0.064	-	0.001	-	.681	2.68	-	48.6	.086	-	.001
09-01-80	70.4	12.1	101	0.50	0.80	-	27	0.017	-	0.002	825.	4.09	6.54	-	221.	.141	-	.016
09-14-80	19.8	2.83	43	0.12	0.60	-	17	0.013	-	0.001	81.7	.227	1.14	-	32.2	.023	-	.002
10-25-80	74.7	20.5	-	0.35	0.80	-	22	0.011	0.07	0.001	-	4.81	11.0	-	303.	.150	.953	>.001
05-10-81	23.1	5.74	319	0.22	1.70	60	40	0.066	0.47	0.003	1230.	.863	6.58	232.	154.	.254	1.82	.012
05-15-81	17.3	3.48	59	0.17	1.50	39	31	0.026	0.25	0.003	138.	.409	3.50	91.2	72.6	.059	.590	.007
06-21-81	25.1	4.62	67	0.14	1.30	26	35	0.022	0.23	0.009	208.	.454	4.04	80.8	109.	.068	.726	.028
07-02-81	14.8	1.47	173	0.49	2.10	24	14	0.040	0.73	0.003	172.	.499	2.09	23.6	14.1	.041	.726	.003
07-20-81	41.7	7.29	101	0.33	1.40	32	14	0.046	0.68	0.006	495.	1.63	6.86	157.	68.6	.227	3.31	.030
07-28-81	25.1	3.40	12	0.15	1.90	18	13	0.009	0.23	0.003	27.2	.363	4.36	41.3	29.5	.023	.545	.007
08-04-81	38.1	5.00	145	0.35	1.90	45	11	0.021	0.21	0.003	489.	1.18	6.40	152.	37.2	.073	.726	.010
08-10-81	36.8	6.48	169	0.23	2.20	20	-	0.038	0.61	0.003	736.	.999	9.58	87.2	-	.163	2.86	.013
											4400.	16.7	66.3	865.	1110.	1.40	12.2	.131
Growing season base flow (Between storms)																		
08-05-80 to 10-28-80																		
05-10-81 to 08-13-81		49.1	79	0.22	2.40	30	175	0.220	0.38	0.002	2610.	7.26	79.4	993.	5790.	7.26	12.6.	.066
Winter runoff																		
10-28-80 to 01-24-81		53.8	45	0.17	1.10	-	160	-	-	-	1630.	6.17	39.8	-	5790.	-	-	-
Snowmelt runoff																		
01-25-81 to 03-02-81		70.6	73	0.25	1.60	-	170	0.052	2.90	0.012	3470.	11.9.	76.0	-	8080.	2.47	138.	.570
Spring runoff																		
03-03-81 to 05-10-81		40.7	170	0.22	2.90	82	62	0.059	0.93	0.013	4650.	6.04	79.4	2240.	1700.	1.62	25.2	.356
Total sampled load																		
08-05-80 to 08-13-81		292.									16800.	48.1	341.	4100.	22470.	12.8	188.	1.12
Estimated site yield [1], in (kg/km²)/d											67.4	.188	1.37	24.9	90.28	.068	995.	.006

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (kg)	Total-P (kg)	TKN (kg)	COD (kg)	Cl (kg)	Pb (kg)	Zn (kg)	Cd (kg)
G. SOUTHGATE ROAD (0.73 km^2, commercial/residential site)																		
Growing-season storms 08-05-80 to 10-28-80, 05-10-81 to 08-13-81																		
08-05-80	36.3	6.70	-	-	1.3	-	45	0.151	-	0.005	-	-	6.31	-	219.	.735	-	0.024
08-30-80	14.5	2.06	82	0.26	1.1	-	68	0.032	-	0.001	123.	.409	1.63	-	102.	.050	-	.001
09-01-80	71.1	14.0	695	0.24	0.5	-	36	0.043	-	0.001	7060.	2.45	5.08	-	365.	.436	-	.010
09-14-80	19.1	3.40	107	0.16	0.6	-	48	0.036	-	0.001	263.	.409	1.50	-	118.	.091	-	>.001
10-25-80	78.2	19.5	96	0.32	0.7	32	27	0.036	0.07	0.001	1360.	4.54	9.90	53.	382.	.508	.990	.014
05-10-81	22.9	5.92	61	0.15	1.7	46	115	0.050	0.36	0.002	262.	.636	7.31	98.	494.	.213	1.55	.009
05-15-81	16.8	6.99	118	0.26	2.1	66	80	0.039	0.19	0.003	597.	1.32	10.6	34.	405.	.195	.965	.015
06-21-81	30.5	5.51	142	0.21	1.5	50	61	0.031	0.22	0.011	566.	.817	6.00	99.	243.	.122	.881	.044
07-02-81	8.8	1.45	110	0.23	1.9	46	58	0.057	1.79	0.003	115.	.227	2.00	48.	60.8	.059	1.89	.003
07-20-81	42.9	7.87	100	0.23	1.3	24	43	0.035	2.16	0.005	571.	1.32	7.44	37.	246.	.200	10.2	.029
07-28-81	24.9	5.16	43	0.17	1.1	26	50	0.020	0.39	0.003	161.	.636	4.09	97.	187.	.073	1.45	.011
08-04-81	26.4	5.23	160	0.21	1.2	35	42	0.036	0.27	0.003	606.	.817	4.54	32.	159.	.136	1.04	.011
08-10-81	40.6	8.08	89	0.14	1.1	32	15	0.052	6.18	0.005	521.	.817	6.45	88.	87.6	.305	36.2	.029
											12200.	14.4	72.8	1790.	3070.	3.12	55.1	.200
Growing season base flow (Between storms) 08-05-80 to 10-28-80, 05-10-81 to 08-13-81		54.4	107	0.19	1.5	36	190	0.054	0.26	0.002	4210.	7.49	59.0	1420.	7500.	2.12	10.2	.078
Winter runoff 10-28-80 to 01-24-81		51.8	99	0.12	1.1	-	307	-	-	-	3720.	4.49	41.4	-	11500.	-	-	-
Snowmelt runoff 01-25-81 to 03-02-81		103.	94	0.20	1.4	25	298	0.05	0.64	0.003	7050.	15.0	105.	9400.	22300.	3.75	48.4	.225
Spring runoff 03-03-81 to 05-10-81		79.2	270	0.26	2.3	71	160	0.092	0.98	0.052	5500.	14.9	132.	4080.	9200.	5.28	56.2	2.99
Total sampled load 08-05-80 to 08-13-81		380.									42700.	56.3	410.	16700.	53600.	14.3	170.	3.49
Estimated site yield[1], in $(kg/km^2)/d$											157.	.207	1.51	61.5	197.	.069	.862	.017

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent.

Table 20.--Constituent concentrations and runoff loads (continued).

Date	Rainfall (mm)	Runoff (mm)	Mean concentrations (milligrams per liter) TSS	Total P	TKN	COD	Cl	Pb	Zn	Cd	Runoff load TSS (kg)	Total-P (kg)	TKN (kg)	COD (kg)	Cl (kg)	Pb (kg)	Zn (kg)	Cd (kg)
G. EAST ROCHESTER (1.40 km^2, high density residential site)																		
Growing-season storms																		
10-25-80																		
05-10-81 to 08-13-81																		
10-25-80	77.7	13.7	-	0.24	0.6	-	15	0.06	0.07	0.002	-	4.58	11.5	-	288.	1.15	1.36	0.038
05-10-81	22.1	9.09	28	0.23	1.3	69	58	0.04	0.40	0.002	356.	2.90	16.5	878.	738.	.508	5.08	.025
05-15-81	20.8	5.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06-21-81	26.7	6.63	228	0.35	3.1	67	16	0.22	0.38	0.005	2120.	3.27	28.7	622.	148.	2.04	3.54	.046
07-02-81	15.2	1.75	270	0.76	4.4	129	18	0.34	1.33	0.004	664.	1.86	10.8	317.	44.5	.835	3.27	.010
07-20-81	41.4	9.40	276	0.42	1.6	58	9	0.13	0.20	0.002	3630.	5.54	21.1	763.	118.	1.71	2.63	.026
07-28-81	29.7	3.33	191	0.73	1.7	68	12	0.13	0.23	0.003	886.	3.40	7.9	316.	55.8	.604	1.04	.014
08-04-81	20.1	3.84	260	0.35	3.8	110	10	0.19	0.26	0.002	1400.	1.86	20.4	591.	53.6	1.02	1.41	.011
08-10-81	28.7	4.84	470	0.46	5.6	97	-	0.32	0.78	0.013	3180.	3.09	37.9	656.	-	2.16	5.27	.020
											12200.	26.5.	155.	4140.	1450.	10.	23.6	.190
Estimated site yield[1], in (kg/km^2)/d											512.	1.11	6.52	174.	61.2	.420	.994	.008

1 Sampling periods for which no data were recorded for a particular constituent were excluded in the calculation of estimated yield for that constituent. Estimated yields for the East Rochester site are based solely on sampled loads from storm events. Data were not available for other parts of the study period.

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