

A9
2.45

United States
Environmental Protection
Agency

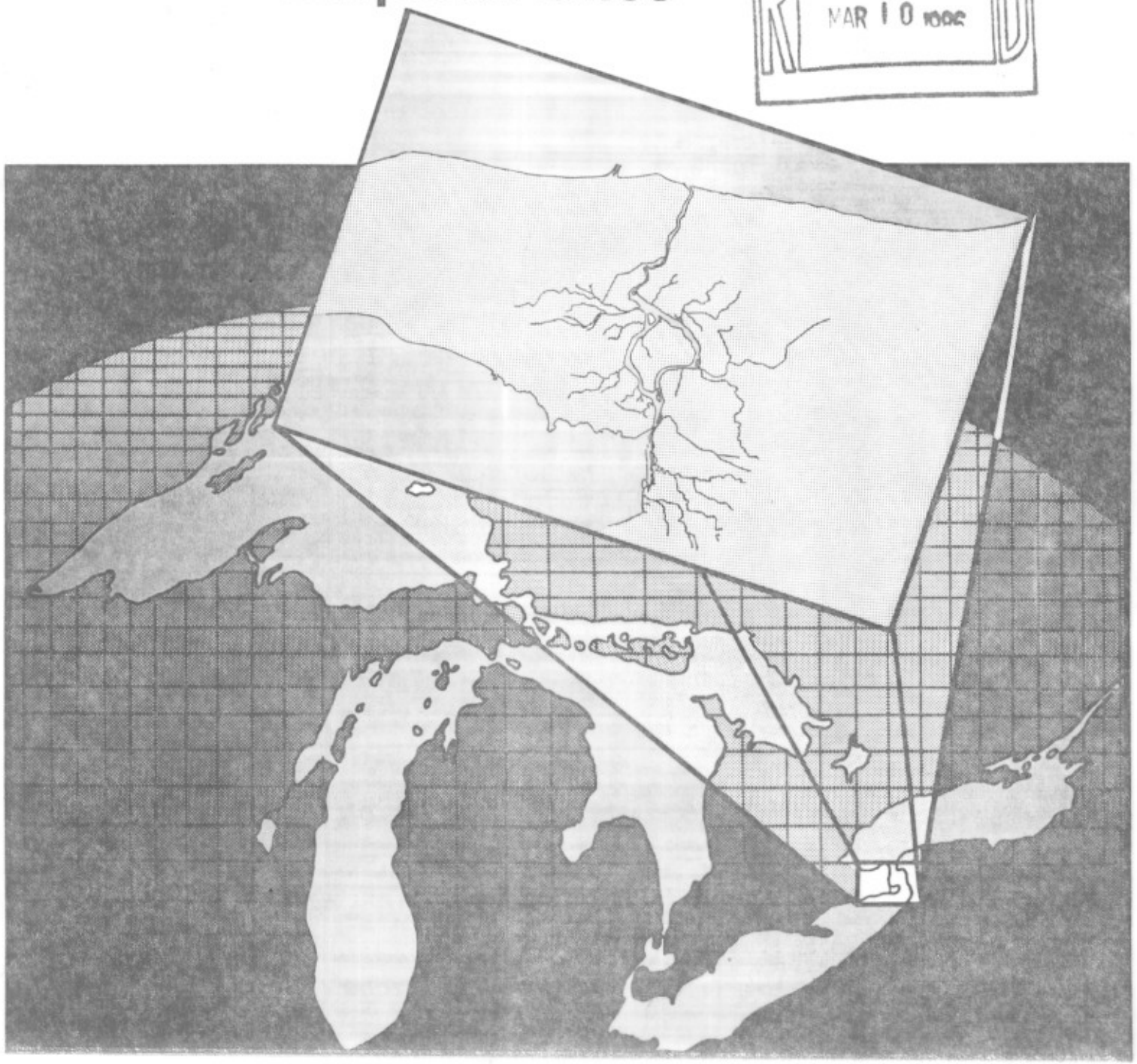
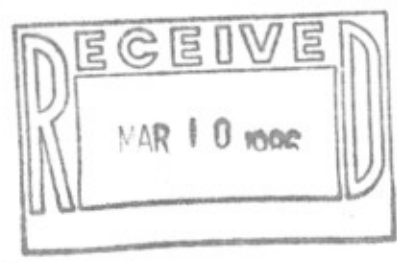
Great Lakes National
Program Office
536 South Clark Street
Chicago, Illinois 60605

A9

EPA-905/4-85-001
March 1985



Preliminary Evaluation Of Chemical Migration To Groundwater and The Niagara River from Selected Waste- Disposal Sites



CONTENTS

	Page
List of sites studied.....	xxiif
Abstract.....	1
Introduction.....	1
Purpose and scope.....	3
Acknowledgments.....	3
Methods of investigation.....	4
Individual site studies.....	4
Assignment of site numbers.....	4
Literature review.....	5
Drilling and coring.....	5
Substrate and water sampling.....	5
Electromagnetic-conductivity survey.....	9
Study of dredge-spoil-containment sites.....	9
Regional hydrologic investigation.....	9
Hydrogeology, stratigraphy, and water quality.....	9
Monitoring wells.....	12
Bedrock drilling.....	13
Quality assurance for chemical data.....	13
Practices.....	13
Results.....	17
Evaluation of contaminant migration.....	30
Qualitative assessment.....	30
Quantitative assessment.....	30
General considerations.....	30
Method of computation.....	32
Regional hydrologic evaluation.....	34
Buffalo area.....	35
Geology.....	35
Aquifer lithology and water-bearing characteristics.....	39
Ground-water quality.....	40
Tonawanda area.....	42
Geology.....	42
Aquifer lithology and water-bearing characteristics.....	44
Ground-water quality.....	45
Niagara Falls area.....	49
Geology.....	49
Aquifer lithology and water-bearing characteristics.....	52
Ground-water quality.....	56
Results of hydrologic and chemical evaluation.....	71
Guidelines for future studies.....	75
Site studies.....	75
Modeling of regional ground-water flow.....	77
Summary.....	78
Sources of data.....	80
Appendices.....	85
A. Buffalo area site descriptions.....	91
B. Tonawanda area site descriptions.....	175
C. Niagara Falls area site descriptions.....	289

Preliminary Evaluation of Chemical Migration To Groundwater and the Niagara River From Selected Waste-Disposal Sites

by

Edward J. Koszalka, James E. Paschal, Jr.,
Todd S. Miller, and Philip B. Duran

ABSTRACT

In 1982, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation, made a preliminary hydrogeologic and chemical evaluation of 138 known toxic waste-disposal sites along the United States side of the Niagara River from Lake Erie to Lewiston, approximately 20 miles downstream. The purpose of the investigation was to identify sites that are a possible source of contamination to the ground-water system.

The 138 sites were grouped into three areas--Buffalo, Tonawanda, and Niagara Falls. Results from the geologic and hydrologic investigations and chemical analyses are as follows:

Buffalo area.--25 sites were studied, of which 19 were drilled and sampled, and 6 evaluated through a literature review. Of the 25 sites, 10 were designated as having a major potential for contaminant migration.

Tonawanda area.--50 sites were studied, of which 29 were drilled and sampled, and 21 evaluated through a literature review. Of the 50 sites, 20 were designated as having a major potential for chemical migration.

Niagara Falls area.--63 sites were studied, of which 31 were drilled and sampled, and 32 evaluated through a literature review. Of the 63 sites, 31 were designated as having a major potential for contaminant migration.

INTRODUCTION

United States and Canadian monitoring of the Niagara River, which flows 37 miles north from Lake Erie to Lake Ontario, has indicated the presence of contamination. A report issued in March 1979 by an Interagency Task Force on Hazardous Waste, composed of representatives of the New York State Department of Environmental Conservation, the New York State Department of Health, and the U.S. Environmental Protection Agency, identified 215 hazardous waste-disposal sites in Erie and Niagara Counties. Of these and additional sites identified since 1979, 164 are within a strip 3 miles wide along the east bank of the Niagara River (fig. 1). The possibility that toxic substances from these sites could migrate to the ground-water system and from there to the Niagara River and into Lake Ontario has become of increasing concern in recent years.

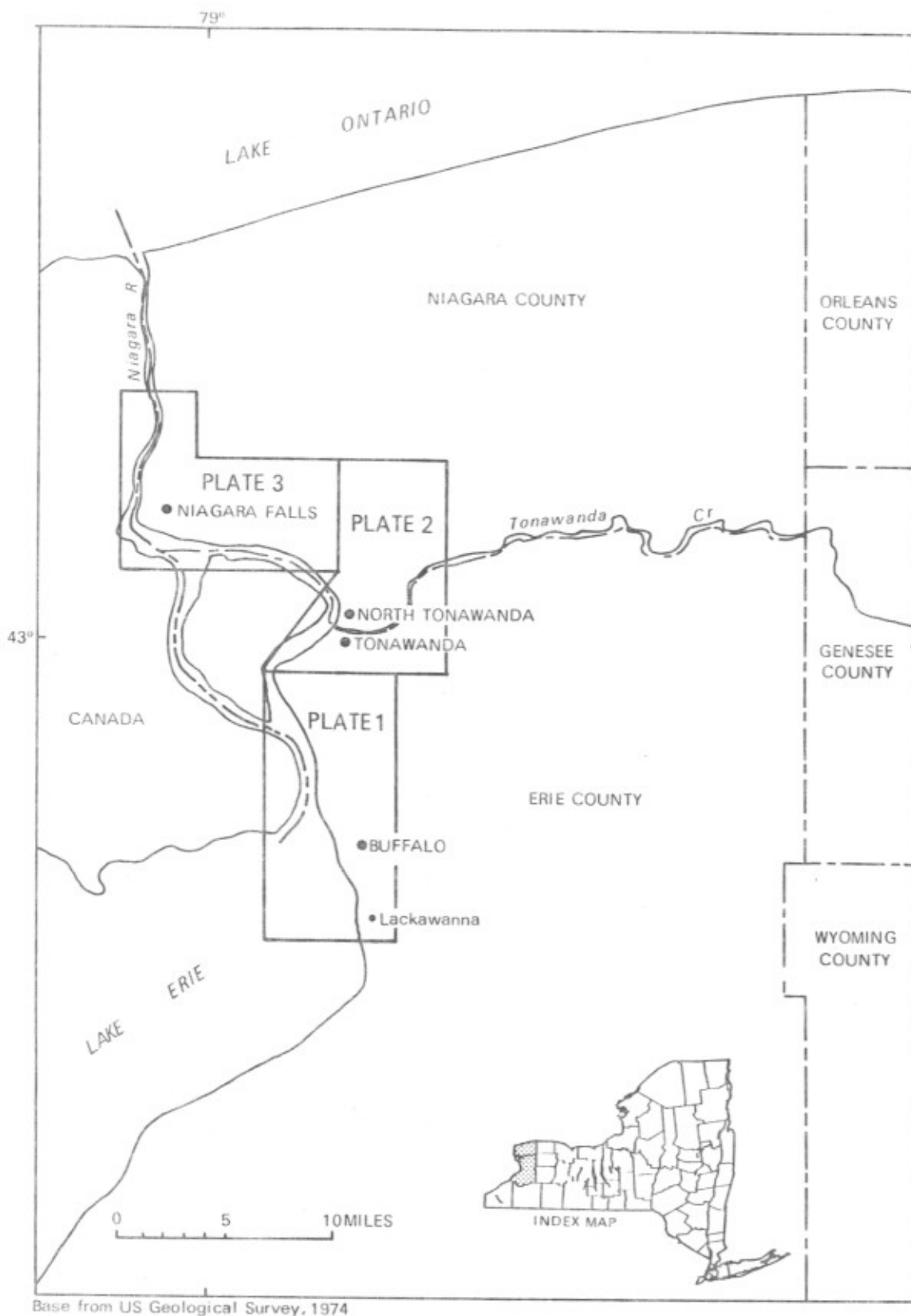


Figure 1. Location of study area in Erie and Niagara Counties.

Effective remedial action requires information on the hydrogeology and the potential for migration of contaminants into the ground water.

Purpose and Scope

In 1982, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency (USEPA) and the New York State Department of Environmental Conservation (NYSDEC), began a preliminary hydrogeologic evaluation of 138 of the 164 known toxic waste-disposal sites along the Niagara River from Lake Erie to Lake Ontario, on the United States side of the river. The main objectives of the investigation were to evaluate the hydrogeology and potential for chemical migration to ground water at the 138 sites. Test drilling and core analysis were done at selected sites to obtain information on the composition of the overburden, and ground-water and core samples were collected and analyzed to identify the substances present and their concentration. The location and extent of the disposal area at some sites were unknown; therefore, some wells and test holes may not have been installed at the most significant locations.

The project was limited to preliminary investigations only and was not designed to assess the actual effect of ground-water contamination on the Niagara River nor to establish whether contaminant migration has actually occurred.

This report presents the hydrologic and chemical data collected during the investigation, describes the probable ground-water flow patterns as inferred from the available data, and categorizes each site in terms of its potential for contaminant migration. It also contains suggestions for future studies to evaluate the regional effects of contaminant migration on the Niagara River.

Acknowledgments

This report was done in cooperation with the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation. The authors express special thanks to NYSDEC, Region 9, particularly John McMahon, Peter Buechi, and their technical staff, for assistance during the field investigations and for report review. Thanks are also extended to the members of USEPA Great Lakes National Program Office (GLNPO) and Region II. Appreciation is extended to Vacys Saulys (GLNPO) and to Rolland Hemmett and Gerard McKenna of USEPA, Region II, for technical guidance and report review.

Thanks are also extended to Donald Campbell of Erie County Department of Environment and Planning, and Michael Hopkins of Niagara County Health Department, for help in the field investigation of several sites and for their review of this report.

Thanks are also extended to the contract drillers.



EVALUATION OF CONTAMINANT MIGRATION

This report evaluates the potential for ground-water contamination from migration of hazardous wastes in a qualitative manner only; a quantitative assessment would require efforts beyond the scope of this preliminary survey. The following paragraphs give (1) criteria for the qualitative assessment of contaminant-migration potential, (2) a general method for computing the rate and quantity of chemical discharges, should sufficient data become available, and (3) suggestions for future quantitative studies to assess the regional effects of contaminant migration on the Niagara River.

Qualitative Assessment

All sites are designated as having either a major or indeterminable potential for contaminant migration in ground water, as described below:

Major potential.--These sites are close to the river or a tributary and (1) contain hazardous constituents or chemicals and have permeable soils or sufficient ground-water gradients for ground-water movement, as evidenced by site records, chemical analyses, and water-level or core analyses; and(or) (2) have evidence that offsite migration of hazardous contaminants has already occurred.

Indeterminable.--These sites were those for which data were inadequate to make a realistic assessment of contaminant migration; that is, where either the geohydrologic data or the chemical data were insufficient to indicate the potential for offsite migration.

Of the 138 sites evaluated in this study, 61 were judged to have a major potential for contaminant migration and are listed in table 12. The sites having a major potential may already be contaminating the river(s). The sites designated as having indeterminable potential may be reclassified as other data become available.

Quantitative Assessment

A quantitative assessment of migration rates and amount of contamination was beyond the scope of this study; however, a general procedure for calculating chemical discharges to the river, based on representative data from this study as an example, is given below. The methods presented herein should be used with extreme caution. The values would be, at best, an indication of relative differences between sites.

General Considerations

At some sites, the ground-water or substrate samples may have been obtained from within the disposal area and therefore could not be used to determine off-site migration. Many of the soil samples were taken from above a clay or confining unit that was unsaturated; chemical migration in such layers would be considerably slower than in saturated units.

BUFFALO AREA

Geology

The Buffalo study area (pl. 1) consists of units of sedimentary bedrock composed of shale, limestone, and dolomite overlain by unconsolidated deposits of clay, sand, and till. The bedrock units are of Silurian and Devonian age; the unconsolidated deposits are primarily of Pleistocene age. The extent of the sedimentary bedrock units is shown in figure 3; the distribution of the unconsolidated units is shown in figure 4.

The bedrock units of concern in this study are: Camillus Shale, Bertie Limestone, and Akron Dolomite (described as one unit); Onondaga Limestone; Marcellus Shale, and the Skaneateles Formation. The unconsolidated deposits of interest are of glacial origin and consist of a glaciolacustrine clay-sand deposit, end-moraine deposits, and an outwash-terrace-delta gravel deposit.

Bedrock Units.--The oldest sedimentary bedrock unit encountered in this study is the Camillus Shale of Silurian age (fig. 3), which occurs only in the northern part of the Buffalo area. This unit has been described by LaSala (1968) as a gray, red, and green thin-bedded shale containing massive mudstone; the unit also contains beds and lenses of gypsum approaching 5 ft in thickness. Subsurface information indicates a dolomitic mudrock to be interbedded within the unit also. The Camillus Shale, estimated to be about 400 ft in thickness, dips southward throughout the area at approximately 40 ft/mi. Information from gypsum miners indicates that the dip of the formation is undulatory within a range of a few feet.

Two other units of Silurian age overlie the Camillus Shale--the Bertie Limestone and the overlying Akron Dolomite. The Bertie Limestone is a gray and brown dolomite with some interbedded shale; the Akron Dolomite is a greenish-gray and buff fine-grained dolomite (LaSala, 1968). The Bertie Limestone, the thicker of the two units, ranges from 50 to 60 ft thick, whereas the Akron Dolomite is estimated to be 8 ft thick. Both formations dip southward, as does the underlying Camillus Shale.

The Onondaga Limestone of middle Devonian age overlies this limestone-dolomite unit; the two units are separated by an unconformity or an erosional contact. The Onondaga Limestone consists of three members. The lowest, which overlies the Akron Dolomite, is a gray, coarse-grained limestone generally a few feet thick. This member, according to Buehler and Tesmer (1963), grades laterally into reef deposits, thereby increasing its thickness. The middle member consists of a gray limestone and blue chert and reaches a thickness of 40 to 45 ft. The upper member is a dark gray to tan limestone ranging in thickness from 50 to 60 ft. The overall thickness of the Onondaga Limestone is approximately 110 ft.

The Marcellus Shale overlies this limestone unit; the formation is described by LaSala (1968) as being black and fissile. The unit ranges in thickness from 30 to 55 ft and dips generally southward at 40 ft/mi. The uppermost unit within the study area is the Skaneateles Formation. It is olive-gray to dark-gray and black, fissile shale with calcareous beds. The lower 10 feet of the unit is gray limestone. Total thickness is 60 to 90 feet. This unit is found in the southernmost part of the study area.

No additional data on the bedrock units within the Buffalo area were obtained. The geology of the units is summarized by La Sala (1968) in his report about ground-water resources of the Erie-Niagara basin.

Unconsolidated Deposits.--The unconsolidated units (fig. 4) consist of glacial material deposited during the latter part of the Pleistocene epoch. The main unconsolidated unit in the Buffalo area is a glaciolacustrine clay-sand deposit consisting of silt, fine to medium sand, and clay and containing laminae of alternating sand and clay.

Two other unconsolidated deposits of lesser extent are present in the area--an end-moraine deposit and a small area of outwash, terrace, and delta gravel. The end-moraine material, which consists of ablation and lodgment tills or poorly sorted gravel that contain more than 20 percent carbonate and crystalline clasts, was deposited at the edge of an ice sheet by meltwater either at the end of an advance or during a stillstand of glacial retreat. The outwash, terrace, and delta gravels, which consist of well-sorted pebbles and cobbles with sand, contain more than 30 percent carbonate and crystalline clasts. The material was deposited by meltwater streams forming coalescent aprons near the ice sheet or as stream terraces or terrace remnants.

Three test holes were drilled to bedrock in the Buffalo area to help define the subsurface geology; their locations are shown in plate 1. The geologic descriptions are as follows:

<u>Boring no.</u>	<u>Depth (ft)</u>	<u>Description</u>
SA-9	0 - 1.5	Topsoil
	1.5 - 6.5	Sand, brown
	6.5 - 11.5	Clay, sandy, with gravel, dark brown
	11.5 - 25.5	Clay, sand with clay, gray, wet at 11.5 ft
	25.5	Bedrock
SA-10	0 - 1.5	Topsoil
	1.5 - 6.5	Clay, sandy, red
	6.5 - 11.0	Clay, some gravel, red
	11.0	Bedrock, material was dry throughout
SA-11	0 - 16.5	Fill, black, ground water at 10 ft
	16.5 - 21.5	Clay, silty, green
	21.5 - 36.5	Clay, silty, gray-green
	36.5 - 60.0	Clay, silty, pinkish-gray
	60.0	Bedrock

The geologic information from these test holes, combined with the data from the waste-disposal sites, enables a general characterization of the area.

The unconsolidated deposits, primarily the glaciolacustrine clay, tend to decrease in thickness toward the east and north, where bedrock rises to less than 5 ft below land surface. Also, the clay unit is generally less than 2 ft below land surface except where it has been removed by landfilling and waste-disposal operations or urbanization.

Aquifer Lithology and Water-Bearing Characteristics

The ground-water system within the Buffalo area consists of a fractured bedrock aquifer and an overlying aquifer of unconsolidated deposits.

Bedrock aquifer.--The bedrock aquifer consists of all the bedrock units discussed previously. The main sources of water are the fractures and solution cavities. The specific-capacity and transmissivity values of selected bedrock aquifer units are shown below.

Bedrock unit ¹	Specific capacity ² (gal/min)/ft		Transmissivity ² (gal/d)/ft	
	Min	Max	Min	Max
Akron Dolomite	2	13	4,000	25,000
Camillus Shale	4	83	7,000	70,000

¹ Position of units is shown in figure 3.

² Data from LaSala (1968)

The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of the water level within the well. If the specific capacity is constant except for the time variation, it is roughly proportional to the transmissivity of the aquifer. Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

The data above indicate that these two properties differ considerably within and among the units. This variation reflects the amount and size of the fractures and solution cavities.

Unconsolidated aquifer.--The unconsolidated aquifer consists of a glaciolacustrine clay and sand and gravel deposits. The thicker unit is the glaciolacustrine clay. The test drilling during the summer of 1982 encountered the water table at various depths within the clay, and saturated sand stringers up to 3 inches thick were common. These stringers were not large, however, and generally thinned out within a few feet.

A seasonal water table above the clay unit was observed during wet periods but not during the summer. This water table is formed by the ponding of infiltrated precipitation above the relatively impermeable clay. As the water mounds upward, gradients toward natural or manmade topographic lows develop and eventually discharge to nearby surface-water bodies. As the season becomes drier and warmer, vegetation increases and takes up the remaining ground water through transpiration.

The hydrologic properties of the unconsolidated aquifer within the Buffalo area are also described in consultants' reports for Buffalo Color Corporation (sites 120-122), Bethlehem Steel Corporation (site 118), and the Alltift Landfill (site 162).

The general range of hydraulic conductivity was 0.0328 to 155.8 ft/d. The larger value can be attributed to slag fill material, which would have a considerably greater permeability than the glaciolacustrine clay. A permeability test was performed on a clay sample from the Alltift landfill; the permeability ranged from 1.6×10^{-4} to 1.8×10^{-4} ft/d.

The rate of ground-water movement within the unconsolidated aquifer at the Buffalo Color Corporation (sites 120-122) was calculated and ranges from 0.02 to 0.06 ft/yr.

The direction of ground-water movement in the unconsolidated aquifer is generally toward the major surface-water bodies--Lake Erie, Niagara River, and Buffalo River (fig. 4). The ground-water flow pattern is dissected in the northern part of the area, where impermeable bedrock is less than 5 ft below land surface, as indicated in figure 4. This unsaturated zone diverts the flow northward and southward.

Ground-Water Quality

The quality of ground water in the bedrock aquifer in the Buffalo area has been documented by LaSala (1968), who included maps showing the concentration ranges for sulfate, hardness, and chloride. Sulfate concentrations given in that report ranges from 100 to 500 ppm and hardness (as CaCO₃) from 150 to 1,000 ppm; chloride concentrations range from 100 to 1,500 ppm, and specific conductance ranges from 1,000 to 9,000 μ mho/cm.

To estimate background water quality in the Buffalo area, a water sample was collected from the unconsolidated deposits in the fall of 1982 and analyzed for priority pollutants. The observation well was on Seneca Street (well SA-9, pl. 1), in the eastern part of the area just east of the Buffalo city line, and was screened above the bedrock contact. The results are given in table 14. Cadmium, lead, and zinc exceeded USEPA drinking-water criteria; minor amounts of some organic compounds were also detected. Additional sampling of the ground water in the unconsolidated aquifer would be needed to define the quality of water in this aquifer in the Buffalo area.

Three substrate samples were collected in the Buffalo area at localities not affected by waste-disposal sites to compare their concentrations of heavy metals with those in substrate samples from waste-disposal sites. Results are given in table 13.

Table 13.--Heavy-metal concentrations in samples from undisturbed soils in Buffalo, N.Y., June 1, 1983
[Locations shown in pl. 1. Concentrations in μ g/kg.]

Location	Sample number	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Forest Lawn Cemetery	SB-1	5,000	8,000	7,000	20,000	100	10,000	31,000
Martin Luther King Park	SB-2	5,000	8,000	10,000	40,000	90	20,000	42,000
Holy Cross Cemetery ¹	SB-3	9,000	30,000	40,000	290,000	280	40,000	160,000

¹ This location is downwind from a major industrial area.

Table 14.--Analyses of a ground-water sample from well SA-9 in the unconsolidated deposits along Seneca Street, West Seneca, N.Y., November 13, 1982.

[Location shown in pl. 1. Concentrations are in $\mu\text{g/L}$. Dashes indicate that constituent or compound was not found, LT indicates it was found but below the quantifiable detection limit.]

Inorganic constituents

Antimony	2	Lead	490†
Arsenic	17	Mercury	--
Beryllium	--	Nickel	210
Cadmium	22†	Selenium	1
Chromium	1	Zinc	53,000†
Copper	160		

Organic compounds

Priority pollutants

Methylene chloride	3.2	Phenol	LT
Toluene	3.9	Naphthalene	LT
Ethylbenzene	LT	Dimethyl phthalate	LT
DDT	0.17†	Diethyl phthalate	19
		Dibutyl phthalate	LT

Nonpriority pollutants

Chlordene	0.19	1,3-Dimethylbenzene ¹	LT
1-Methyl-3-phenoxybenzene ¹	LT	2-Butoxyethanol ¹	LT
1-(2-butoxyethoxy)ethanol ¹	490	1-(1-isobutyl-3-methyl-1-butenyl)-pyrrolidine ¹	LT
2-Ethylhexanoic acid ¹	15.7	2,3,3,4-Tetramethylpentane ¹	LT
Exo-2-chloro-1-methyl-bicyclo[2.2.1]heptane ¹	LT	Methyl-3,5-di-O-methyl-alpha-D-xylofuranoside ¹	550
Cis-1-bromo-2-chlorocyclohexane ¹	LT	N-Ethylbutanamide ¹	100
Benzenepropanoic acid ¹	67		

¹ Tentative identification based on comparison with the National Bureau of Standards (NBS) library. No external standard was available. Concentration reported is semiquantitative and is based only on an internal standard. GC/MS spectra were examined and interpreted by GC/MS analysts.

† Exceeds USEPA criterion for maximum permissible concentration in drinking water.

TONAWANDA AREA

Geology

The Tonawanda study area (pl. 2) consists of unconsolidated deposits of clay, sand, and till of Pleistocene and Holocene age overlying Camillus Shale bedrock of Silurian age.

Bedrock Units.--The Camillus Shale is the only bedrock unit encountered in the area. As described previously, it is a gray, red, and green thin-bedded unit with massive mudstone and also contains beds and lenses of gypsum. Thickness of the shale is estimated to be 400 ft but decreases to the north near the contact with the Lockport Dolomite.

Unconsolidated Deposits.--The unconsolidated units consist of glacial material deposited during the latter part of the Pleistocene epoch and lacustrine material deposited during the early Holocene. The distribution of unconsolidated deposits in the area is shown in figure 5.

The Pleistocene materials are similar to those in the Buffalo area except for a ground-moraine deposit, which consists mainly of lodgment till, silty clay till, and sandy till. This deposit was formed by the transport and deposition of material beneath the southward flowing continental ice sheet (Muller, 1977) and is thus compacted and relatively impermeable.

The northern part of the area contains a Holocene lacustrine deposit consisting primarily of clay with stringers of sand and silt. Most stringers are less than 3 inches thick and are discontinuous throughout the area.

The U.S. Geological Survey drilled five test holes in 1982 to obtain additional data on the subsurface geology of the area. (Locations of these holes, SA-4 through SA-8, are shown on pl. 2.) The geologic logs are as follows:

<u>Boring No.</u>	<u>Depth (ft)</u>	<u>Description</u>
SA-4	0 - 1.5	Topsoil
	1.5 - 6.5	Clay, sand, green
	6.5 - 18.5	Clay, pink
	18.5	Bedrock
SA-5	0 - 6.5	Road fill, rubble
	6.5 - 19.0	Clay, pink
	19.0 - 24.5	Sand
	24.5	Bedrock
SA-6	0 - 3.0	Topsoil, rubble
	3.0 - 28.0	Clay, pink
	28.0 - 44.0	Sand, silty
	44.0	Bedrock
SA-7	0 - 1.5	Topsoil
	1.5 - 16.5	Clay, gray-green
	16.4 - 19.0	Clay, pink
	19.0 - 27.0	Clay, sandy pink
	27.0	Bedrock

<u>Boring No.</u>	<u>Depth (ft)</u>	<u>Description</u>
SA-8	0 - 1.5	Topsoil
	1.5 - 31.5	Clay, red
	31.5 - 63.0	Clay, red, interbedded with gravel
	63.0	Bedrock

The information obtained from these test borings, together with the data from the disposal sites, can be used to characterize the geology of the area in general terms. The unconsolidated deposits, primarily the Pleistocene and Holocene lacustrine clays, are encountered within 6 ft of land surface. Their thickness, which seems to be dependent upon the depth to bedrock, ranges from 18.5 to 63.0 ft. The test drilling confirmed the boundaries of the unconsolidated deposits as drawn by Muller (1977). Also, the Pleistocene and Holocene clay units are similar except in color and the presence of sand stringers in the latter.

Aquifer Lithology and Water-Bearing Characteristics

The hydrologic system of the Tonawanda area is similar to that of the Buffalo area--a bedrock aquifer consisting of Camillus shale overlain by an aquifer of unconsolidated deposits.

Water within the bedrock aquifer flows through the joints, fractures, and solution cavities within the unit. The Camillus Shale is estimated to have a transmissivity ranging from 7,000 to 70,000 (gal/d)/ft (LaSala, 1968). Regionally, under nonpumping conditions, ground water in the shale moves west and south. Ground water in shallow bedrock discharges into Tonawanda Creek, Ellicott Creek, and the Niagara River (pl. 2)

The overlying aquifer consists of unconsolidated morainal and clay deposits. The morainal material is generally a clayey till whose permeability is as low as that of the lacustrine clays. During the test drilling, ground water was encountered at various depths within the clayey units; also encountered were stringers of permeable sand that initially yielded considerable amounts of water. The yield diminished with time, however, as the stringers became dewatered.

The low permeability of the deposits causes a seasonal perched water table, similar to that of the Buffalo area, during periods of high precipitation. This water table discharges into areas of low topography and eventually into nearby surface-water bodies.

The hydrologic properties of the unconsolidated aquifer have been discussed in several consultant reports on the geohydrology of the major disposal sites; these reports are cited in the site descriptions (appendix B).

Permeability tests done by consultants on clay samples from several of the disposal sites indicate that the vertical permeability is low, ranging from 10^{-6} to 10^{-8} cm/s. This is probably the reason for the nearly steady water levels in monitoring wells screened in this aquifer. Horizontal permeability may be orders of magnitude greater than vertical permeability.

The direction of ground-water movement in the aquifer is generally toward the major surface-water bodies--the Niagara River and Ellicott, Sawyer, and Tonawanda Creeks (pl. 2).

Ground-Water Quality

The chemical quality of ground water in the bedrock aquifer has been investigated by LaSala (1968). Concentrations of sulfate ranged from 100 to 1,000 mg/L and hardness (as CaCO₃) from 1,500 to 3,000 mg/L. Chloride concentrations ranged from 100 to 1,500 mg/L, and specific conductance from 1,500 to 9,000 µmho/cm at 25°C.

Water samples were collected in the fall of 1982 from five observation wells (SA-4, 5, 6, 7, and 8; locations shown in pl. 2) screened in the unconsolidated deposits above the bedrock contact and were analysed for priority pollutants. Four of the wells were along the eastern edge of the area and one was adjacent to the Niagara River. Results of the analyses (table 16) indicate that concentrations of cadmium, lead, and zinc exceeded USEPA drinking-water criteria and NYS ground-water standards. A few organic compounds were detected, all in minimal quantities except methylene chloride and toluene. Chlordane was detected at a well along the eastern edge of the area, and α-chlordane was detected at one well adjacent to the Gratwick-Riverside Park site along the Niagara River. Additional sampling of ground water in the aquifer would be needed to define its quality in the Tonawanda area.

Three substrate samples were collected at localities not affected by waste-disposal sites in the Tonawanda area and were analyzed for heavy metals; results are given in table 15.

Table 15.--Heavy-metal concentrations in substrate samples from undisturbed soils in Tonawanda, N.Y., May 31, 1983 and June 1, 1983.
[Concentrations in µg/kg. Locations shown in pl. 2]

Location	Sample number	Cadmium	Chromium	Copper	Lead
Beaver Island State Park	SB-4	4,000	8,000	10,000	100,000
Mount Olive Cemetery	SB-5	4,000	20,000	20,000	30,000
Oppenheim Park	SB-6	1,000	20,000	20,000	20,000
Ellicott Creek Park	SB-7	4,000	10,000	20,000	20,000
		Mercury	Nickel	Zinc	
Beaver Island State Park	SB-4	200	20,000	57,000	
Mount Olive Cemetery	SB-5	120	30,000	58,000	
Oppenheim Park	SB-6	110	20,000	59,000	
Ellicott Creek Park	SB-7	120	20,000	47,000	

Table 16.--Analyses of ground-water samples from wells in the unconsolidated deposits along the Niagara River, Tonawanda, N.Y., November 13, 1982

[Concentrations are in $\mu\text{g/L}$, dash indicates that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit. Locations shown in pl. 2.]

	Well number and depth below land surface (ft)		
	(SA-4) Whitmer Road	(SA-5) Gratwick Park	(SA-6) Niagara Falls Boulevard
pH	6.9	6.6	6.8
Specific conductance ($\mu\text{mho/cm}$)	975	2,590	985
Temperature ($^{\circ}\text{C}$)	18.2		
<u>Inorganic Constituents</u>			
Antimony	--	--	--
Arsenic	2†	2†	1†
Beryllium	--	--	--
Cadmium	12†	20†	10
Chromium	1	1	1
Copper	65	33	18
Lead	180†	220†	120†
Mercury	--	--	--
Nickel	33	18	18
Selenium	--	--	--
Zinc	16,000†	1,400	630
<u>Organic Compounds</u>			
Priority pollutants			
Methylene chloride	42	110	210
Toluene	41	170	410
Ethylbenzene	LT	LT	25
Dibutylphthalate	LT	11	--
Phenol	5.6†	--	--
Pentachlorophenol	LT	--	--
α -chlordane	--	1.08†	--
Nonpriority pollutants			
Diethylphthalate	--	8.2	--
Methylcyclopentane ¹	LT	--	14
3-Methylpentane ¹	LT	--	--
1-Methylpentylhydroperoxide ¹	--	--	6.3
2,2,3-Trimethylbutane ¹	--	--	LT
2-Methyl-1-propene	-	LT	--
Hexane	41	--	40
2,4-Dimethylpentanol ¹	LT	--	--
Chlordene		0.05	1.6

¹ Tentative identification based on comparison with the National Bureau of Standards (NBS) library. No external standard was available.

Concentration reported is semiquantitative and is based only on an internal standard. GC/MS spectra were examined and interpreted by GC/MS analysts.

† Exceeds USEPA criterion for maximum permissible concentration in drinking water or NYS standard for maximum concentration in ground water.

Table 16.--Analyses of ground-water samples from wells in the unconsolidated deposits along the Niagara River, Tonawanda, N.Y., November 13, 1982 (continued)

[Concentrations are in $\mu\text{g/L}$, dash indicates that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit. Locations shown in pl. 1.]

	Well number and depth below land surface (ft)		
	(SA-4) Whitmer Road	(SA-5) Gratwick Park	(SA-6) Niagara Falls Boulevard
Organic compounds (continued)			
Nonpriority pollutants (continued)			
1,3-Dimethylbenzene ¹	--	--	LT
2-Ethylhexanoic acid ¹	--	--	140
Octanoic acid ¹	--	--	47
Nonanoic acid ¹	--	--	22
4-Hydroxy-3,5-dimethylbenzaldehyde ¹	--	--	LT
2,2,4-Trimethylpentane ¹	15	--	--
Methylcyclohexane ¹	28	--	--
2,5-Dimethylhexane ¹	40	--	--
2,4-Dimethylhexane ¹	43	--	--
Ethylcyclopentane ¹	7.8	--	--
2,3,3-Trimethylpentane ¹	19	--	--
2-Methylheptane ¹	48	--	--
3-Methylheptane ¹	25	--	--
3,3-Dimethylhexane ¹	14	--	--
2,3,4-Trimethylhexane ¹	15	--	--
2-Methyl-4-heptanone ¹	18	--	--
1,4-Dimethylbenzene ¹	26	--	--
1,2-Dimethylbenzene ¹	4.7	--	--
2-Heptanone	3.1	--	--
2,2,4,4-Tetramethyl-3-pentanone ¹	94	--	--
2,6-Dimethyl-4-heptanol ¹	5.4	--	--
2-Decanone ¹	40	--	--
2-Decanol ¹	LT	--	--
1,4-Dioxane ¹	61	--	--
4-Chloro-trans-cyclohexanol ¹	7.4	--	--
5-Ethyl-dihydro-2(3H)-furanone ¹	7.2	--	--
4-Methylbenzoic acid ¹	LT	--	--
Compound potentially of natural origin			
Hexanoic acid ¹	--	--	160
2-Hexanone ¹	5.4	--	--

Table 16.--Analyses of ground-water samples from wells in the unconsolidated deposits along the Niagara River, Tonawanda, N.Y., November 13, 1982 (continued)

[Concentrations are in $\mu\text{g/L}$, dash indicates that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit. Locations shown in pl. 2.]

	Well number and depth below land surface (ft)	
	(SA-7) Shawnee Road	(SA-8) Department of Transportation
pH	7.3	6.6
Specific conductance ($\mu\text{mho/cm}$)	585	2,400
Temperature ($^{\circ}\text{C}$)		
<u>Inorganic Constituents</u>		
Antimony	--	--
Arsenic	2†	7†
Beryllium	--	--
Cadmium	10	22†
Chromium	2	1
Copper	40	18
Lead	290†	210†
Mercury	--	--
Nickel	24	8
Selenium	--	--
Zinc	690	3,800
<u>Organic Compounds</u>		
Priority pollutants		
Methylene chloride	30	3.6
Toluene	15	5.1
Ethylbenzene	--	LT
Dimethyl phthalate	--	130
Dibutylphthalate	--	2
1,4-Dioxane ¹	--	LT
Nonpriority pollutants		
Diethylphthalate	--	LT
Methylcyclopentane ¹	3.8	--
1-Methylpentylhydroperoxide ¹	--	1.4
Chlordene	0.13	--
Butyl-2-methylpropyl/phthalate	--	86
2-(2-Butoxyethoxy)-ethanol	--	140
1,1-Oxybis(2-ethoxy)ethane ¹	--	6
Acetic acid, 1-methylpropylester ¹	--	550
2-Pentanol ¹	--	LT
1-Chloro-2-ethenyl-methyl-cyclopropane ¹	--	LT
1,3-Isobenzofurandione	--	LT

NIAGARA FALLS AREA

Geology

The Niagara Falls study area (pl. 3) consists of unconsolidated Pleistocene and Holocene-age deposits of till, lacustrine clay and silt, and alluvial fine sand underlain by dolomite of middle Silurian age. The bedrock units studied are the Lockport Dolomite and the upper part of the Rochester Shale. The bedrock stratigraphy beneath this area is shown in figure 6; the distribution of unconsolidated deposits is shown in figure 7.

Bedrock Units.--The Lockport Dolomite is a hard and resistant calcium-magnesium carbonate sedimentary rock that crops out in the study area and forms the Niagara Escarpment north of Niagara Falls. In the northern part of the area, erosion has removed much of its upper part, leaving a thickness of only 30 ft at the escarpment, but the unit thickens to the south and, in the southern part of the city of Niagara Falls, it is 155 ft thick.

In 1982, the U.S. Geological Survey installed 11 observation wells in the upper part of the dolomite in the city of Niagara Falls and two open-hole wells through the entire thickness of the Lockport Dolomite adjacent to the gorge face. (Locations of the wells are shown on pl. 3.)

Unconsolidated Deposits.--A relatively thin layer of unconsolidated deposits, 3 to 35 ft thick, overlies bedrock (fig. 7). Along the upper Niagara River, in the southern part of Niagara Falls, fill and (or) alluvial fine sand overlie clay and till or bedrock; elsewhere lacustrine clay and silt overlie the bedrock. In the middle and northern parts of the area, a layer of till 5 to 20 ft thick overlies bedrock. The till consists of a silty clay or sandy matrix that was formed by the transport and lodgment of material beneath the flowing continental ice sheet (Muller, 1977) and is thus compacted and relatively impermeable.

In 1982, the U.S. Geological Survey drilled three test holes (SA-1, SA-2, and SA-3) to the top of the bedrock; the geologic logs are as follows:

<u>Boring no.</u>	<u>Depth below land surface (ft)</u>	<u>Description</u>
SA-1	0 - 3.0	Topsoil and fill
	3.0 - 18.0	Clay, pink
	18.0 - 24.0	Sand, clayey, with gravel
	24.0	Bedrock
SA-2	0 - 1.5	Topsoil
	1.5 - 6.5	Fill, black
	6.5 - 24.0	Clay, pink
	24.0 - 34.0	Clay and gravel (till?)
34.0	Bedrock	
SA-3	0 - 1.5	Topsoil
	1.5 - 16.5	Clay, pink
	16.5 - 20.0	Clay, pink, some gravel
	20.0	Bedrock

The Geological Survey drilled six other test holes (RMP-2 through RMP-6) along the Robert Moses Parkway in 1982. Test-hole locations are shown on pl. 3.

Aquifer Lithology and Water-Bearing Characteristics

The ground-water system within the Niagara Falls area (pl. 3) consists of the Lockport Dolomite and an overlying aquifer of unconsolidated deposits, as shown in the generalized geologic column of the area in figure 6.

Bedrock aquifer.--The Lockport Dolomite consists of a predominantly fine crystalline matrix with some poorly connected vugs, mostly in the upper part, but few primary openings through which ground water can move. Significant ground-water movement occurs in secondary openings such as joints and fractures, and these may have been slightly widened by solution. The secondary openings are more numerous in the upper part of the dolomite as a result of weathering. Some joints and fractures have developed in the underlying Rochester Shale (fig. 6), but not nearly to the extent as in the Dolomite because the shale is less brittle. Little hydrologic information on the deeper rock units is available.

Most of the ground-water movement occurs along the horizontal bedding joints of the Lockport, in which Johnston (1964) identified seven major zones. Some movement also occurs in other thin-bedded zones (0.5 to 4 inches thick), which tend to be weaker and more likely to fracture than the more massive beds, which are 2 to 10 ft thick. Johnston (1964) noted that major water movement occurs within thin-bedded zones that are overlain by thick, massive beds.

Movement of ground water in vertical joints is greatest in the upper 10 to 15 ft of the Dolomite (weathered zone) and in the vicinity of the gorge wall. Tension-release joints have formed to about 200 ft inland from the gorge wall since the erosion of the supporting rock mass. These joints are probably significant avenues for downward flow of ground water to the Niagara River. The vertical joints near the gorge wall may explain the lack of seepage springs from the dolomite along the gorge wall. Ground water has been observed to seep out along the top of the underlying Rochester Shale and other deeper rock units.

Water levels in wells installed in the Lockport Dolomite at depths of 5 to 20 ft below the water table were used to compile a map showing the potentiometric surface of the upper water-bearing zones (fig. 8). The differences among potentiometric heads in deeper water-bearing zones could not be defined because not enough wells could be installed in each water-bearing zone nor grouted to seal off the effects of other zones. Johnston (1964) described the water-bearing bedding joints as being separated by essentially impermeable rock and considered them as distinct artesian aquifers. The horizontal joints are probably connected to some extent by vertical fractures, but little information is available to determine the extent of hydraulic connection.

An unlined storm-sewer tunnel, the Falls Street Tunnel, runs through the upper part of the Lockport Dolomite in the Niagara Falls area (fig. 8). The tunnel starts 1 mi east of the power conduits and 0.7 mi north of the upper Niagara River and extends westward to a gorge interceptor tunnel near the gorge wall just north of American Falls. Flow is then pumped to the Niagara Falls Wastewater Treatment Plant. The Tunnel is 3.5 mi long and slopes at an average rate of 20 ft/mi toward the gorge face.

South of the Falls Street Tunnel and east of the power conduits, ground water in the upper water-bearing zones of the Lockport Dolomite moves northwest from the Niagara River to the tunnel and the power conduits. This reach of the tunnel is in the upper 15 ft of the Dolomite, which Johnston (1964) described as being the most permeable zone owing to weathering, small solution cavities, and relatively abundant vertical joints. At the east end of the tunnel, water levels at wells NFB-9 and 10 were 3 to 5 ft above the top of the tunnel, which indicates a relatively low slope in potentiometric surface, ranging 0.3 to 0.8 ft per 100 ft between the wells and the tunnel.

The potentiometric surface near the intersection of the conduits and the Falls Street Tunnel may be controlled by the water level in the forebay canal of the powerplant at the north end of the area (fig. 8). The backfill on top of the conduits may be more permeable than the dolomite, which would create a hydraulic connection between the forebay canal and conduit system. Water-level altitudes measured on March 2, 1983, at wells NFB-11, -12, and -13 adjacent to the conduits near the Falls Street Tunnel were 547.91, 546.41, and 547.80 ft, respectively. These altitudes are below that of the weir control (560 ft) at the sump station at Royal Ave., which would enable ground water in the backfill to move into the aqueducts if the water level were above 560 ft. Because the ground-water altitude in the backfill was below the weir control on that date, no flow into the conduits occurred at that time. A possible discharge area for ground water in the backfill may be the forebay canal, in which the water level usually fluctuates between 541 and 546 ft during the winter. During periods of low water levels in the forebay canal, ground water may be able to flow through the backfill above the conduits and discharge into the canal. Thus, the direction of ground-water flow in the immediate area may oscillate according to the water level in the forebay canal.

The Falls Street Tunnel is a significant ground-water discharge area in the vicinity of the conduits, where ground-water seepage (estimated 6 Mgal/d) into the tunnel has been observed at pipe joints where the tunnel crosses the conduits (Camp, Dresser, and McKee, 1982). Lesser ground-water seepage, mostly along the northern wall, has been observed along the entire length of the tunnel.

North of the Falls Street Tunnel and more than 1 mi east of the conduits, ground water flows southward from the Niagara Escarpment and pumped-storage reservoir toward the Falls Street Tunnel and the Niagara River. North of the Falls Street Tunnel and less than 1 mi east of the conduits, ground water also flows southwest toward the tunnel. Along a 1-mi-wide band along the east side of the conduits, ground water moves westward toward the conduits.

South of the Falls Street Tunnel and 0.75 mi west of the conduit, an industrial pumping center withdraws large quantities of ground water (2,000 to 4,000 gal/min). Johnston (1964) reports that part of the pumped water is induced river water from the Niagara River.

Water-level data are insufficient to indicate the effects of the industrial pumping center on the upper water-bearing zone of the dolomite. If the well field has a large cone of influence affecting the upper water zones, ground water probably moves radially into the well field. If the well field does not greatly effect the upper water-bearing zone, however, ground water may flow north-northeast from the river toward the conduits.

Approximately 0.75 mi west of the conduits, water levels in the shallow bedrock wells (NFB-7 and NFB-8, pl. 3) on either side of the Falls Street Tunnel were 20 ft above the top of the tunnel in December 1982, indicating that vertical downward flow of ground water into the tunnel is impeded by the massive, relatively unfractured rock units. West of the conduits, the tunnel dips below the fractured layer (upper 10 to 15 ft of the Lockport Dolomite) and penetrates less fractured and less weathered dolomite. In this area, ground water in the upper water-bearing zone flows over the top of the tunnel. Adjacent to shallow well NFB-7, a deeper well (NFB-7A) was installed and screened at the same depth as the bottom of the tunnel. The water level in the deeper well was 17.5 ft lower than that in the adjacent shallow well, which suggests that west of the conduits, the tunnel drains the water-bearing zones it intercepts but probably has little effect on the zones above or below. The same phenomenon was seen at another pair of wells (NFB-5 and 5A) 1.5 mi west of the conduits, in which the water level in the deeper well (NFB-5A) was 9 ft lower than that in the shallow well (NFB-5).

From 0.5 to 1.0 mi west of the industrial pumping center, water from the Niagara River recharges the Lockport Dolomite and flows northwestward to discharge at the gorge wall. Wells adjacent to the Niagara River at Prospect and Terrapin Points reveal a steeply declining potentiometric surface toward the Niagara River in the gorge. The steep potentiometric gradient within 200 ft of the gorge wall is probably due to the large drop of the river at the falls and the presence of vertical stress-release joints in the bedrock that allow ground water to move downward toward the lower river elevation.

In the northwest part of Niagara Falls, ground water flows radially outward from the apex of a ground-water mound south of the forebay canal. Discharge areas include the Niagara River to the west and northwest, the forebay canal to the north, the conduits to the east, and the city to the south. (The central part of the city has little water-level information to determine ground-water flow paths). A ground-water divide trending roughly north-south runs through the central part of the city. Ground water west of the divide flows toward the Niagara River, and ground water east of the divide flows east-southeast toward the conduits or possibly south to the industrial pumping center.

Unconsolidated aquifer.--The unconsolidated deposits (fig. 7) consist of till, lacustrine silt and clay, and alluvial fine sand overlying bedrock. The till has pebble to cobble clasts embedded in a clayey silt matrix. Permeability of till and lake deposits is low. During the test drilling of 1982, ground water was usually encountered 5 to 15 ft below land surface. The unconsolidated deposits were unsaturated in some areas to the north and along the gorge, where they are thin.

The low permeability of the deposits causes a seasonal water table to form in many places, particularly where fill and coarse-grained material overlie the till or clay. This perched water table usually develops mounds that discharge radially into topographic lows, drainage ditches, and streams.

The hydrologic properties of the unconsolidated aquifer are discussed in consultant reports referred to in the site descriptions in appendix C. The direction of ground-water movement in the aquifer is generally toward the major surface-water bodies--the Niagara River, Bergholtz Creek, and Cayuga Creeks (pl. 3).

Ground-Water Quality

Canadian studies of chemical quality in natural ground water near the river indicate that water in the Lockport Dolomite contains lead and zinc concentrations of 300 to 800 $\mu\text{g/L}$, with the concentrations increasing with depth (Haynes and Mostaghal, 1982). The lead and zinc are leached from lead- and zinc-sulfide minerals (galena and sphalerite) in the host rock. Natural lead concentrations in most places exceed the USEPA drinking-water criterion of 50 $\mu\text{g/L}$, whereas zinc concentration is generally less than the Federal and State criteria of 5,000 $\mu\text{g/L}$. Little information is available about concentrations of other heavy metals in ground water in the dolomite.

To evaluate whether lead and zinc concentrations are natural or man-induced, the highest naturally occurring concentration was doubled, giving a value of 1,600 $\mu\text{g/L}$. Analytical results above 1,600 $\mu\text{g/L}$ were interpreted to be the result of man's activity.

The presence of natural organic compounds in the rock was evident during drilling, when an acrid oil smell arose during the crushing of the dolomite. Natural gas and oil water have been detected in gas-exploration wells in western New York (Kreidler, 1963). Some of the volatile alkanes of low molecular weight (methane, propane, n-butane, and n-pentane) may occur as natural gas in the Lockport Dolomite.

Ground-water samples were collected and analyzed for USEPA priority pollutants in November and December of 1982 and in January 1983. Three wells (SA-1, SA-2, and SA-3, pl. 3) were screened in the unconsolidated deposits above the bedrock in the eastern part of the Niagara Falls area, five wells (RMP-2 through RMP-6) were screened at or just above the bedrock contact along the Robert Moses Parkway adjacent to the upper Niagara River, four wells (NFB-1 through NFB-4) were installed in the Lockport Dolomite near the gorge wall within the city of Niagara Falls, and nine wells (NFB-5 through NFB-13) were screened in the Dolomite along the Falls Street Tunnel (pl. 3). The results of the analyses are given in tables 17, 18, and 19.

Water from wells SA-1, SA-2, and SA-3 showed cadmium, lead, and zinc concentrations that exceed USEPA criteria for drinking water and the New York State ground-water standards. Methylene chloride and toluene were found in significant concentrations, and other organic compounds were also detected.

Water from wells RMP-2 through RMP-6 had high concentrations of heavy metals, inorganic constituents, and organic compounds, particularly cyanide, methylene chloride, dichloroethylene, chloroform, trichloroethylene, tetrachloroethane, tetrachloroethylene, and toluene. The presence of these compounds in these concentrations can probably be attributed to the disposal practices of the industrial complex bordering the northern part of the Parkway. Cyanide exceeded the USEPA criterion for drinking water; and cyanide, lead, chloroform, trichloroethylene, benzene, and the BHC's exceeded New York State ground-water standards.

A deep and a shallow well were installed in the Lockport Dolomite at each of two sites along the gorge wall. Wells NFB-2 and NFB-4 were screened several feet below the first water-bearing zone encountered, and wells NFB-1 and NFB-3 penetrated the entire thickness of the Lockport and were left as open holes so

that a composite sample could be collected from all water-bearing zones in the formation. Generally, the ground-water quality of the deep wells was similar to that of the Niagara River, which may indicate that river water discharges into the dolomite in this area.

Heavy-metal concentrations were high in the shallow wells (NFB-2 and NFB-4) along the gorge wall, especially in well NFB-2, where of cadmium, lead, and zinc (66, 3,600 and 8,700 $\mu\text{g/L}$, respectively) exceeded USEPA criteria for drinking water and New York State standards for ground water. The mercury concentration in well NFB-3 also exceeded the criterion and standard.

Several organic compounds were present in the wells along the gorge wall. Heptachlor exceeded New York State ground-water standards in wells NFB-1 through NFB-4, and α -BHC exceeded the standard in well NFB-4.

Except for hexane and 2-methyl-1-pentene, both in concentrations of 20 $\mu\text{g/L}$, the concentration of other organic compounds in well NFB-3 were below 5 $\mu\text{g/L}$. Higher concentrations and several more compounds were detected in wells NFB-1 and NFB-2. Several of the alkanes and alkenes may be derived from natural gas in the dolomite. Heavy-metal concentrations at wells NFB-11 through NFB-13 were less than the USEPA drinking-water standards, although the zinc concentration (3,500 $\mu\text{g/L}$) at well NFB-11 is probably higher than in natural ground water in the dolomite.

The largest variety and highest concentrations of organic compounds were detected in ground-water samples from two wells (NFB-11 and NFB-13) along the east side of the conduits. In well NFB-11, toluene, benzene, and trans-1,2-dichloroethylene were detected at 34, 180, and 1,400 $\mu\text{g/L}$, respectively, and in well NFB-13 at 5.7, 250, and 1,400 $\mu\text{g/L}$, respectively. A total of 56 organic compounds were found in ground water at well NFB-11, and 24 at well NFB-13.

Ground water from well NFB-12, on the opposite (west) side of the conduits, contained fewer compounds (12) and at generally much lower concentrations. The significant difference in water quality on the two sides of the conduits suggests that ground water does not flow across the conduits, but probably into the backfill material, then northward toward the forebay canal.

The highest heavy-metal concentrations were detected at well NFB-7, where cadmium, lead, zinc, and selenium (89, 3,500, 30,000, and 760 $\mu\text{g/L}$, respectively) exceeded the USEPA drinking-water standards. A seepage sample collected from the dolomite wall inside the Falls Street Tunnel at 27th Street was found to contain 14,000 $\mu\text{g/L}$ of zinc and 430 $\mu\text{g/L}$ of lead (Camp, Dresser and McKee Eng., 1982). Another seepage sample collected from the tunnel wall 1,600 ft west of 27th Street contained natural levels of zinc (220 $\mu\text{g/L}$). The high concentrations of heavy metals in the vicinity south of the Falls Street Tunnel and 27th Street may be due to leaching of metal debris from several vacant lots in the area or possibly from leachate moving from the industrial area to the south. More ground-water-level data would be needed to determine the effects of the industrial pumping center on ground-water flow in that area, however.

Several organic compounds were detected in wells NFB-5 through NFB-8 (table 19), but the concentrations were less than 9 $\mu\text{g/L}$ for all constituents except hexane (20 to 160 $\mu\text{g/L}$) in all four wells and trans-1,2-dichloroethylene (80 $\mu\text{g/L}$)

in well NFB-7. The hexane may have been introduced when used as a solvent to wash the sampling bailer.

Three substrate samples were collected in the Niagara Falls area at localities not affected by waste-disposal sites to compare their concentration of heavy metals with those in substrate samples from waste-disposal sites. Results are given in table 20.

Table 17.--Analyses of ground-water samples from wells in unconsolidated deposits along the Niagara River, Niagara Falls, N.Y., November 10, 1983.

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit.]

	Well number and depth below land surface (ft)		
	(SA-1) I190-I62 Interchange (24.0)	(SA-2) Griffon Park	(SA-3) Airport Triangle (20.0)
pH	7.2		
Specific conductance ($\mu\text{mho/cm}$)	480		
<u>Inorganic Constituents</u>			
Antimony	--	--	4
Arsenic	1	2	4†
Beryllium	--	--	--
Cadmium	13†	17†	100†
Chromium	1	1	8
Copper	39	31	800
Lead	230†	130†	2,200†
Mercury	--	--	--
Nickel	28	14	980
Selenium	--	--	--
Zinc	3,300	8,900†	640,000†

¹ Tentative identification based on comparison with the National Bureau of Standards (NBS) library. No external standard was available. Concentration reported is semiquantitative and is based only on an internal standard. GC/MS spectra were examined and interpreted by GC/MS analysts.

† Exceeds USEPA criterion for maximum permissible concentration in drinking water or NYS standards for maximum concentration in ground water.

Table 17.--Analyses of ground-water samples from wells in unconsolidated deposits along the Niagara River, Niagara Falls, N.Y., November 10, 1983 (continued)

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit.]

	Well number and depth below land surface (ft)		
	(SA-1)	(SA-2)	(SA-3)
	I190-I62 Interchange	Griffon Park	Airport Triangle
<u>Organic Compounds</u>			
Priority pollutants			
Methylene chloride	140	7.1	375
Toluene	150	10	230
Ethylbenzene	5.9	LT	4.5
Chloroform	4.2	--	--
Dibutylphthalate	12	0	2.05
Mirex	--	0.21	--
Trans-1,2-dichloroethylene	--	--	23
Nonpriority pollutants			
Diethylphthalate	LT	7.7	2.5
Methylcyclopentane ¹	4.2	5.6	3.7
1-Methylpentylhydro- peroxide ¹ (or 1-butanol)	2.0	2.0	--
Hexane	--	12	--
Chlordene	--	--	0.08
1,1-Ethandiol, diacetate ¹ heptane ¹	--	--	44
(2,2-Dimethylpropyl)oxirane ¹	--	--	240
Methylcyclohexane ¹	--	--	LT
Ethylcyclopentane ¹	--	--	17
2,3,5-Trimethylpentane ¹	--	--	7.7
1,2,3-Trimethylcyclopentane ¹	--	--	14
3-Methyl-2,4-hexadiene ¹	--	--	LT
2,3-Dimethylhexane ¹	--	--	LT
2-Methylheptane ¹	--	--	5.8
3,3-Dimethylhexanol ¹	--	--	44
1,4-Dimethyl,cis-cyclohexane ¹	--	--	21
2,5-Dimethyl-1-hexene ¹	--	--	LT
2,3,4-Trimethylhexane ¹	--	--	5.2
(1,1-Dimethylbutyl)oxirane ¹	--	--	14
2-Bromohexane ¹	--	--	2.3
2,6-Dimethylheptane	--	--	14
1,2-Dimethylbenzene ¹	11	--	18
1,4-Dimethylbenzene ¹	5.1	--	46
2,2,4,4-Tetramethyl-3- pentanone ¹	10	--	15

Table 17.--Analyses of ground-water samples from wells in unconsolidated deposits along the Niagara River, Niagara Falls, N.Y., November 10, 1983 (continued)

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit.]

	Well number		
	(SA-1) I190-I62 Interchange	(SA-2) Griffon Park	(SA-3) Airport Triangle
<u>Organic compounds (continued)</u>			
Nonpriority pollutants (continued)			
2-Decanone	--	--	57
2-Ethoxybutane ¹	290	--	270
2-Pentanone ¹	--	--	9.1
4-Chloro-trans-cyclohexanol ¹	--	--	LT
1-chloro-2-ethenyl-1-methylcyclopropane	--	--	LT
3-Ethylhexane ¹	11	--	--
2-Chloronaphthalene ¹	LT	--	--
2,6-Bis(1,1-dimethylpropyl)-2,5-cyclohexadiene,1,4-dione ¹	5.9	--	--
5-Ethyl-dihydro-2(3H)-furanone ¹	2.8	--	--
3,5,5-Trimethylhexanoic acid ¹	5.1	--	--
2-(2-Butoxyethoxy)ethanol ¹	93	--	--
Nonanoic acid ¹	85	--	--
1,2-Benzenedicarboxylic acid ¹	LT	--	--
Decanoic acid ¹	29	--	--
2,5-Bis(1,1-dimethylpropyl)-2,5-cyclohexadiene-1,4-dione ¹	LT	--	--
2-Ethylhexanoic acid ¹	--	31	--
Benzoic anhydride ¹	--	59	--
4-Chlorobenzoic acid ¹	--	13	--
3-Ethylpentene ¹	--	6.7	--
Methylcyclodecane ¹	--	LT	--
2-Methylundecane ¹	--	LT	--
4,11-Dimethyltetradecane ¹	--	LT	--
5-Propyltridecane ¹	--	LT	--
1-(2-Butoxyethoxy)ethanol	--	--	8.0
Compounds potentially of natural origin			
Hexanoic acid ¹	13	--	--

Table 18.--Analyses of ground-water samples from unconsolidated deposits along the Niagara River-Robert Moses Parkway, Niagara Falls, N.Y., January 13, 1983.

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number and depth below land surface (ft)				
	(RMP-2) 29.0	(RMP-3) 26.0	(RMP-4) 23.0	(RMP-5) 25.0	(RMP-6) 25.0
pH				6.6	7.7
Specific conductance ($\mu\text{mho/cm}$)				2,500	627
Temperature ($^{\circ}\text{C}$)				9.3	8.0
<u>Inorganic Constituents</u>					
Antimony	1.3	0.7		1.0	1.3
Arsenic	1†	27†	2†	1†	1†
Beryllium	--	--	10†	--	--
Cadmium	2	2	2	2	3
Chromium	10	5	5	4	11†
Copper	7	5	1	6	71
Cyanide	130†	--	3,000†	--	--
Lead	47†	15	6	27	430†
Mercury	0.1†	0.1†	0.1†	5.9†	0.1†
Nickel	5	20	2	7	10
Selenium	1	--	1	--	--
Silver	--	--	--	--	--
Zinc	2,500	9,200†	3,600	2,400	520
<u>Organic Compounds</u>					
Priority pollutants					
Methylene Chloride	--	2,200,000	120,000	2,300	11
Chloroform	100	11,000†	150,000†	62	2.9
Trichlorethylene	110†	470,000†	52,000†	130†	7.2†
1,1,2,2-tetrachloroethane	39 ¹	310,000	11,000	66	11
Tetrachloroethylene	6.1†	48,000†	2,000†	13†	1.7†
Benzene	--	2,000†	--	10 ¹ †	44†
Toluene	28	820	1,200	2.8 ¹	1.1 ¹
Chlorobenzene	1.2 ¹	510 ¹ †	460 ¹ †	4.3	--

¹ Tentative identification based on comparison with the National Bureau of Standards (NBS) library. No external standard was available. Concentration reported is semiquantitative and is based only on an internal standard. GC/MS spectra were examined and interpreted by GC/MS analysts.

† Exceeds USEPA criterion for maximum permissible concentration in drinking water or NYS standard for maximum concentration in ground water.

Table 18.--Analyses of ground-water samples from unconsolidated deposits along the Niagara River-Robert Moses Parkway, Niagara Falls, N.Y., January 13, 1983 (continued)

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number				
	(RMP-2)	(RMP-3)	(RMP-4)	(RMP-5)	(RMP-6)
Organic compounds (continued)					
Priority pollutants (continued)					
α -BHC	0.12†	49†	--	0.68†	0.22†
β -BHC	0.68†	47†	--	0.64†	0.14†
Lindane (γ -BHC)	--	7.9†	--	0.28	--
Heptachlor	--	--	--	0.67†	--
Trans-1,2-dichloro- ethylene	160 ¹	20,000	9,100	180	--
Ethylbenzene	--	--	--	LT	LT
1,1,2-Trichloroethane	--	270†	--	--	--
Tetrachloroethane	--	3,100†	--	--	--
1,3-Dichlorobenzene	--	LT	20	--	--
1,2-Dichlorobenzene	--	LT	14	--	--
1,4-Dichlorobenzene	--	-	13	--	--
Hexachloroethane	--	280†	--	--	--
1,2,4-Trichlorobenzene	--	72	22	--	--
Hexachlorobutadiene	--	15†	--	--	--
Naphthalene	LT	--	--	--	--
Dibutylphthalate	9.9	--	23	13	7.3
Butylbenzylphthalate	--	--	--	29	--
Bis(2-ethylhexyl) phthalate	22	--	17	--	7.1
Phenol	--	--	14†	--	--
Nonpriority pollutants					
Diethylphthalate	10	LT	10	--	8.3
Hexane ¹	170	--	3,100	22	220
Octachloropentene	--	--	LT	--	--
Dibenzoanthracene	10	--	--	--	--
Acetone(2-propanone) ¹	--	8,800	--	--	--
2,2,4-Trimethylpentane ¹	--	1,600	--	--	--
Methylcyclopentane ¹	--	--	--	LT	22
3-Methylpentane ¹	--	--	--	--	5.6
2-Methylthietane ¹	5.7	--	15	--	--
1,3-Dichlorobutane ¹	LT	--	--	--	--
1-(2-Butoxyethoxy)- ethanol ¹	LT	--	--	--	15
1,1'-Oxybis(4-chloro)- butane ¹	36	--	--	--	--
1,2,3,4,7,7-Hexachloro- bicyclo-(2,2,1)hepta- 2,5-diene ¹	LT	--	--	--	--

Table 18.--Analyses of ground-water samples from unconsolidated deposits along the Niagara River-Robert Moses Parkway, Niagara Falls, N.Y., January 13, 1983 (continued)

[Locations are shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number				
	(RMP-2)	(RMP-3)	(RMP-4)	(RMP-5)	(RMP-6)
<u>Organic compounds (continued)</u>					
Nonpriority pollutants (continued)					
Hexanedioic acid, dioctylester ¹	LT	--	--	--	--
Pentachloroethane ¹	--	1,500	--	--	--
Pentachlorocyclopropane ¹	--	50	--	--	--
1,1,3,4-Tetrachloro-1,3-butadiene ¹	--	280	--	--	--
Hexanedinitrile ¹	--	77	--	--	--
1,2,3-Trichlorobenzene ¹	--	47	--	--	--
Hexachlorobutene ¹	--	14	--	--	--
1,3,5-Trithiane ¹	--	31	26	--	--
1-Propoxybutane ¹	--	52	--	--	--
1,2,3,4,5,6-Hexachloro-(1 alpha,2 beta,3 alpha,4 beta,5 alpha,6 beta)-cyclohexane ¹	--	20	--	--	--
1,2,3,4,5,6-Hexachloro-(1 alpha,2 alpha,3 beta,4 alpha,5 alpha,6 beta)-cyclohexane ¹	--	110	--	--	--
1,2,3,4,5,6-Hexachloro-(1 alpha,2 alpha,3 beta,4 alpha,5 beta,6 beta)-cyclohexane ¹	--	35	--	--	--
1,2,3,4,5,6-Hexachloro-(1 alpha,2 alpha,3 alpha,4 beta,5 alpha,6 beta)-cyclohexane ¹	--	8.5	--	--	--
2-Butoxyethylbutyl phthalate ¹	--	31	--	--	--
Dimethylsulfide	--	--	31	--	--
1-(1-Isobutyl-3-methyl-1-butenyl)pyrrolidine ¹	--	--	LT	--	--
O-Cresol ¹	--	--	LT	--	--
1,2,4-Trimethylbenzene ¹	--	--	-	LT	--
1,3,5-Trimethylbenzene ¹	--	--	-	LT	--
Compounds potentially of natural origin					
1,7,7-Trimethylbicyclo-(2.2.1)-heptan-2-one (camphor) ¹	--	--	12	--	--

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983.

[Locations shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number and depth below land surface (ft)			
	(NFB-1) American Falls 109 ft well (48.0)	(NFB-2) American Falls 47 ft well (45.0)	(NFB-3) Robert Moses Parkway North #1 (73.7)	(NFB-4) Robert Moses Parkway North #2 (72.2)

Inorganic Constituents

Antimony		--		
Arsenic	1†	5†	6†	7†
Beryllium	--	10†		--
Cadmium	--	66†	--	6
Chromium	--	--	--	--
Copper	12	580	26	190
Cyanide		--		
Lead	3	3,600†	24	630†
Mercury	0.3†	0.1†	6.8†	1.2†
Nickel	120	460	32	10
Selenium	1	1	--	2
Silver	2	2	4	5
Zinc	230	8,700†	250	1,200

Organic Compounds

Priority pollutants

Chloroform	1.7	LT	--	--
Toluene	LT	3.7	LT	--
α -BHC	--	--	--	0.2†
Heptachlor	0.04†	--	0.02†	0.03†
Endosulfan	--	--	--	0.04
Bis(2-ethylhexyl) phthalate	15	--	--	--
Di-n-octylphthalate	13	--	--	--
Trichloroethylene	6.2†	--	--	--
Tetrachloroethylene	58	6.0	1.7	--

¹ Tentative identification based on comparison with the National Bureau of Standards (NBS) library. No external standard was available. Concentration reported is semiquantitative and is based only on an internal standard. GC/MS spectra were examined and interpreted by GC/MS analysts.

† Exceeds USEPA criterion for maximum permissible concentration in drinking water or NYS standard for maximum concentration in ground water.

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in µg/L,
dashes indicate that constituents or compound was not
found, LT indicates it was found but at less than the
quantifiable detection limit, blanks indicate not analyzed.]

	Well number			
	(NFB-1) American Falls 109-ft well	(NFB-2) American Falls 47-ft well	(NFB-3) Robert Moses Parkway North #1	(NFB-4) Robert Moses Parkway North #2

Organic Compounds (continued)

Nonpriority pollutants

1,1,2-Trichloro-1,2,2- trifluoroethane ¹	--	2.1	--	--
2-Methyl-1-pentene ¹	--	130	20	930
3-Methylpentane ¹	--	15	1.3	74
Hexane ¹	--	320	20	5,100
2,3-Dimethyl-2-pentene ¹	--	LT	--	--
Butane ¹	--	--	LT	--
2-Butene ¹	--	--	LT	--
2-Methylbutane ¹	--	--	LT	--

Well number and depth below land surface (ft)

(NFB-5) 13th Street (22.0)	(NFB-6) 14th Street (21.0)	(NFB-7) Cudaback Avenue (20.0)	(NFB-8) Niagara Avenue (20.0)
-------------------------------------	-------------------------------------	---	--

Inorganic Constituents

Antimony	--	--	5	1
Arsenic	2†	3†	2†	14†
Beryllium	--	--	--	--
Cadmium	20†	16†	89†	13†
Chromium	13	6	--	16
Copper	110	49	800	53
Cyanide	--	60†	--	--
Lead	570†	400†	3,500†	300†
Mercury	0.1†	0.1†	0.1†	0.1†
Nickel	130	90	--	130
Selenium	2	1	760†	1
Silver	2	1	1	1
Zinc	1,900	310	30,000†	1,400

Organic Compounds

Priority pollutants

Toluene	5.4	LT	7.8	1.6
Trichloroethylene	LT	--	33†	--
Tetrachloroethylene	--	LT†	8.8†	LT†

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in $\mu\text{g/L}$,
dashes indicate that constituents or compound was not
found, LT indicates it was found but at less than the
quantifiable detection limit, blanks indicate not analyzed.]

	Well number			
	(NFB-5) 13th Street	(NFB-6) 14th Street	(NFB-7) Cudaback Avenue	(NFB-8) Niagara Avenue

Organic Compounds (continued)

Nonpriority pollutants				
2-Methyl-1-pentene ¹	56	7.1	6.9	--
Methylcyclopentane ¹	--	--	--	8.0
3-Methylpentane ¹	6.0	LT	--	--
Hexane ¹	160	47	20	24
Isooctane ¹	1.5	--	--	--
Trans-1,2-dichloro- ethylene	--	--	80	--
Trichlorofluoro- methane ¹	--	--	--	4.7
1,1,2-Trichloro-1,2,2- trifluoroethane ¹	--	--	--	4.4
7-Oxabicyclo[4.1.0]- heptane ¹	18	--	--	--
2,2-Dichlorobutyl- propanoate ¹	8.8	--	--	--
E-2-Hexen-1-ol ¹	--	16	--	--
1-Chloro-2-nitroso- cyclohexane ¹	--	15	--	--
Methylcyclohexane ¹	--	--	10	--
Trans-4-chlorocyclo- hexane ¹	--	--	11	--
Trans-2-chlorocyclo- hexanol ¹	--	--	--	16
2-Bromo-1-phenylethanol ¹	--	--	--	2.8
N-(Aminocarbonyl)- benzamide ¹	--	--	--	7.0

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number and depth below land surface (ft)	
	(NFB-9)	(NFB-10)
	61st Street (22.0)	60th Street (21.0)
pH		7.5
Temperature ($^{\circ}\text{C}$)		9
<u>Inorganic Constituents</u>		
Antimony	--	--
Arsenic	4†	3†
Beryllium	--	--
Cadmium	30†	23†
Chromium	37	44
Copper	180	190
Cyanide	90†	360†
Lead	400†	630†
Mercury	0.1†	0.1†
Nickel	190	200
Selenium	1	1
Silver	2	1
Zinc	670	720
<u>Organic Compounds</u>		
Priority pollutants		
Toluene	LT	--
Bis(2-ethylhexyl)phthalate	9.4	--
Trichlorofluoromethane	15	LT
Nonpriority pollutants		
1,1,2-Trichloro-1,2,2-trifluoroethane ¹	14	4.6
Hexane ¹	LT	16
Methylcyclopentane ¹	--	6.4
Trans-4-chlorocyclohexanol ¹	8.6	--
1,1'-Bicyclohexyl ¹	15	--

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in $\mu\text{g/L}$,
dashes indicate that constituents or compound was not
found, LT indicates it was found but at less than the
quantifiable detection limit, blanks indicate not analyzed.]

	Well number and depth below land surface (ft)		
	Power Authority of State of New York		
	(NFB-11)	(NFB-12)	(NFB-13)
	PASNY #1 (37.0)	PASNY #2 (37.0)	PASNY#3 (36.0)
pH	7.4	8.4	8.3
Specific conductance ($\mu\text{mho/cm}$)	1,290	450	1,750
Temperature ($^{\circ}\text{C}$)	10.4	7.9	8.4
<u>Inorganic Constituents</u>			
Antimony	1.0	--	1.5
Arsenic	4†	4†	3†
Beryllium	--	--	--
Cadmium	3	3	5
Chromium	20	20	12
Copper	92	63	61
Cyanide	--	--	0.04
Lead	410†	420†	390†
Mercury	0.9†	0.1†	0.2†
Nickel	43	20	16
Selenium	--	1	--
Silver	--	--	--
Zinc	3,500	710	280
Molecular sulfur (S6)	25	--	30
Molecular sulfur (S8)	1,450	--	330
<u>Organic Compounds</u>			
<u>Priority pollutants</u>			
Benzene	180†	--	250†
Toluene	34	2.2	5.7
Chlorobenzene	15	LT	35
Ethylbenzene	5.6	1.4	1.4
Hexachlorobenzene	0.47†	0.09†	--
α -BHC	0.44†	0.78†	1.4†
β -BHC	0.26†	0.25†	1.4†
Lindane	LT	LT	0.13
Heptachlor	LT†	LT†	--
1,4-Dichlorobenzene	10	--	65
1,3-Dichlorobenzene	18	--	30
1,2-Dichlorobenzene	15	--	33
Nitrobenzene	8.5	--	--
1,2,4-Trichlorobenzene	11	--	27
Naphthalene	31	--	LT

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in µg/L,
dashes indicate that constituents or compound was not
found, LT indicates it was found but at less than the
quantifiable detection limit, blanks indicate not analyzed.]

	Well number		
	Power Authority of State of New York		
	(NFB-11) PASNY #1	(NFB-12) PASNY #2	(NFB-13) PASNY #3
<u>Organic Compounds (continued)</u>			
Priority pollutants (continued)			
Di-n-butylphthalate	17	--	18
Butylbenzylphthalate	36	--	61
Bis(2-ethylhexyl)phthalate	13	9.4	10
Trans-1,2-dichloroethylene	1,400	24	1,400
Trichloroethylene	LT†	26†	15†
Tetrachloroethylene	LT	8.8	3.4
Nonpriority pollutants			
Diethylphthalate	-	12	LT
Hexane ¹	64	12	20
1,1,2,2-Tetrachloroethane ¹	17	--	--
1-Chloro-2-methylbenzene ¹	71	--	14
4-Bromobutylbenzene ¹	90	--	--
1-Chloro-4-methylbenzene ¹	14	--	--
1,3,5-Trimethylbenzene ¹	150	--	--
1-Ethyl-2-methylbenzene ¹	31	--	--
1,2,3-Trimethylbenzene ¹	11	--	--
1,2,4-Trimethylbenzene ¹	84	--	--
1-Ethenyl-2-methylbenzene ¹	8.5	--	--
1,4-Diethylbenzene ¹	5.9	--	--
1-Methyl-2-propylbenzene ¹	7.2	--	--
Decylbenzene ¹	9.6	--	--
1-Methyl-3-(1-methylethyl)- benzene ¹	5.7	--	--
1,2-Diethylbenzene ¹	LT	--	--
1-Methyl-3-propylbenzene ¹	18	--	--
1-Ethyl-2,4-dimethylbenzene ¹	29	--	--
1-Methyl-2-(1-methylethyl)- benzene ¹	22	--	--
2-Methyl-2-propenylbenzene ¹	LT	--	--
1-Methyl-3-(1-methylethyl) benzene ¹	24	--	--
2-Ethyl-1,4-dimethylbenzene ¹	5.3	--	--
1-methyl-4-(1-methylethyl) benzene ¹	8.5	--	--
1,2,3,5-Tetramethylbenzene ¹	9.6	--	--

Table 19.--Analyses of ground-water samples from bedrock wells in
Niagara Falls, N.Y., December 1982-January 1983 (continued)

[Locations shown in pl. 3. Concentrations are in $\mu\text{g/L}$, dashes indicate that constituents or compound was not found, LT indicates it was found but at less than the quantifiable detection limit, blanks indicate not analyzed.]

	Well number		
	Power Authority of State of New York		
	(NFB-11) PASNY #1	(NFB-12) PASNY #2	(NFB-13) PASNY #3
<u>Organic Compounds (continued)</u>			
Nonpriority pollutants (continued)			
1,2,3,4-Tetramethylbenzene ¹	24	--	--
1-Ethyl-2,4-dimethylbenzene ¹	28	--	--
2,3-Dihydro-1-methyl-1-H-indene ¹	6.3	--	--
1,2,3,4-Tetrahydronaphthalene ¹	2.5	--	--
1,3,5-Trichlorobenzene ¹	1.5	--	--
2-Methylnaphthalene ¹	3.7	--	--
1,1'-Biphenyl ¹	LT	--	--
1,1'Oxybisbenzene ¹	5.4	--	--
1,5-Dimethylnaphthalene ¹	LT	--	--
1,4-Dimethylnaphthalene ¹	LT	--	--
4-(1,1,3,3-Tetramethylbutylphenol ¹	5.7	--	--
Hexathiopane ¹	LT	--	--
Unknown hydrocarbons ¹	--	19	--
2,4-Dichloro-2-Methylbenzene ¹	--	--	LT
μ -BHC	--	--	LT
N-Methyl-1H-imidazole-4-ethanamine ¹	--	--	11

Table 20.--Heavy-metal concentrations in samples obtained from undisturbed soils in Niagara Falls, N.Y., May 31, 1983 and June 1, 1983

[Locations are shown in pl. 3. Concentrations in $\mu\text{g/kg}$; dashes indicate that constituent was not found.]

Location	Sample number	Cadmium	Chromium	Copper	Lead
DeVeaux School	SB-8	--	7,000	9,000	20,000
Oakwood Cemetery	SB-9	5,000	10,000	20,000	30,000
Liberty Park	SB-10	5,000	10,000	20,000	50,000
		Mercury	Nickel	Zinc	
DeVeaux School	SB-8	150	--	23,000	
Oakwood Cemetery	SB-9	80	20,000	46,000	
Liberty Park	SB-10	130	20,000	130,000	

RESULTS OF HYDROLOGIC AND CHEMICAL EVALUATION

Results of the field investigations and literature reviews for the 138 hazardous-waste-disposal sites (plus the 26 sites not recommended for investigation by NYSDEC) are summarized in tables 21 and 22. Table 21 identifies each site as having either a major or indeterminable potential for contaminant migration on the basis of available chemical and hydrologic data; table 22 lists the sites designated as having a major potential for contaminant migration. These designations are based on the data available as of 1983 and are preliminary only. More accurate predictions as to the rate and extent of leachate migration would require additional hydrologic data to define the ground-water flow patterns within the unconsolidated deposits and the fractured bedrock below, and additional sampling to determine the type, amount, and concentration of chemicals buried at each site.

Table 21.--Potential for contaminant migration from sites studied

Site number	Registry number	Site	Type of investigation ¹	Migration potential		Type of data		
				Major	Indeterminate	Geo-hydrologic	Chemical	Offsite migration
BUFFALO AREA (pl. 1)								
107	915004	Allied Chemical	F	X		X	X	-
113	915007	Anaconda	F		X	-	X	-
118	915009	Bethlehem Steel	L	X		X	X	XX
120-122	915012 (a,b,c)	Buffalo Color	L	X		X	X	-
132	915024	Fedder Automotive	L		X	-	-	-
135	915029	Hanna Furnace	F		X	*	X	-
138	915034	McNaughton Brooks	F	X		-	X	XX
140	915037	Houdaille-Manzel	F		X	-	X	-
141	915040	Mobil Oil	F	X		-	X	XX
142	915041	Mollenberg-Betz	L		X	-	-	-
144	915073	Otis Elevator	F		X	-	X	-
146	915045	Pratt & Letchworth	L		X	-	X	-
147	915046	Ramco Steel	F		X	-	X	-
148	915047	Republic Steel	F		X	-	X	-
162	915054	Alltift Landfill	L	X		-	X	XX
173	915065	Empire Waste	F		X	-	X	-
180	915011	Hopkins Street	L		X	-	-	-
184	915095	Kelly Island	L		X	-	-	-
190	915781	Lehigh Valley Railroad	F		X	-	X	-
196	915026	Niagara Falls Port Authority	F		X	*	X	-
200	915085	Procknall & Katra	L		X	-	X	-
203	915052	Squaw Island	F	X		X	X	-
206	915072	Tifft Farm	L		X	-	-	-
216	915013	Erie Basin Marina	L		X	X	-	-
217	915017	Donner Hanna Coke	F		X	-	X	-
219	915030	Hartwell Street Landfill	L		X	-	X	-
220	915039	W. Seneca Transfer Station	F		X	*	X	-
241	915080	Times Beach	F	X		X	X	-
249	915120	Allied Chemical, Hurwitz-Ranne	F		X	-	X	-
†253	--	Small Boat Harbor	F	X		X	X	-
†254	--	Buffalo Harbor	F	X		X	X	-

¹ F field investigation
 L literature review only
 X information available
 - no information available

† not a source of ground-water contamination but hydraulically connected to Lake Erie
 * limited information
 XX contaminant migration reported or observed

Table 21.--Potential for contaminant migration from sites studied (continued)

Site number	Registry number	Site	Type of investigation ¹	Migration potential		Type of data		
				Major	Indeter- minate	Geo- hydro- logic	Chem- ical	Offsite migration
TONAWANDA AREA (pl. 2)								
6	932044	Buffalo Pumps Division	F		X	-	X	-
24-37	932018	Occidental Chemical-Durez Div.	L	X				XX
50	932066	National Grinding Wheel	L		X	-	X	-
60	932059	Roblin Steel Company	L		X	-	*	-
67	932043	Frontier Chemical-Pendleton	F		X	*	*	-
68	932060	Gratwick Park	F	X		X	X	-
72		Holiday Park	F		X	*	X	*
93	932054	Nash Road	F		X	-	X	-
103	915001	R. P. Adams	F		X	-	X	-
105	915003-b	Allied Chemical, Tonawanda		X		-	X	XX
106	915003-c	Allied Chemical, Tonawanda			X	-	X	-
108	915055-a	Tonawanda Coke	F	X		X	X	*
109	915055-b	Tonawanda Coke	F		X	-	X	-
110	915055-c	Tonawanda Coke	F		X	-	X	-
111	915055	Aluminum Match Plate	F		X	-	*	-
114	915061	Ashland Petroleum	L		X	-	-	-
115	915008-c	Ashland Petroleum	L		X	-	*	*
116	915008-a	Ashland Petroleum	L		X	-	X	-
117	915008-b	Ashland Petroleum	L		X	-	-	-
123	915016	Columbus McKinnon	L	X		*	X	XX
125-127	915018 (a,b,c)	Dunlop Tire	F		X	-	X	-
128	--	Dupont	F		X	-	X	-
130	915023	Exolon	L		X	-	-	-
131	915025	FMC	F		X	-	X	-
136	--	INS	F	X		X	X	-
137	915035	Pennwalt-Lucidol Div.	F		X	-	X	-
143	--	O-Cel-O	L		X	-	-	-
149	915036	Roblin Steel	F		X	*	*	-
150-151	915048	Shanco Plastics	F		X	-	X	-
153-155- (a,b)	915050 (a-d)	Spaulding Fibre	F/L		X	-	X	-
158		Union Carbide	L		X	-	*	-
160	915057	J. H. Williams	F		X	-	X	-
167	915014	Chemical Leaman	F		X	*	X	-
182	915063	Huntley Power Station	F	X		X	X	-
201	915074	Seaway Industrial Park	L		X	X	X	-
204	915083	William Strassman	F		X	*	X	-
207	915079	City of Tonawanda Landfill	F		X	-	X	*
208	915078	Veteran's Park	L		X	-	*	-
211	915067	Air Force Plant no. 40	L		X	-	-	-
243	932068	Botanical Gardens	F		X	*	X	-
252	915123	Creekside Golf Course	F		X	*	X	-
NIAGARA FALLS AREA (pl. 3)								
1	932001	Airco Alloys	L		X	-	X	*
2	932002	Airco Speer Carbon-Graphite	F		X	*	X	-
4	932004	Basic Carbon Co.	F		X	-	X	-
5	932052	Bell Aerospace	F	X		-	X	XX
7	932048-a	Carborundum, Bldg. 89	L		X	-	-	-
8	932048-b	Carborundum, Bldg. 82	L		X	-	-	-
9	932007	Carborundum-Abrasive Div.	L		X	-	X	-

Table 21.--Potential for contaminant migration from sites studied (continued)

Site number	Registry number	Site	Type of investigation ¹	Migration potential		Type of data		
				Major	Indeterminate	Geo-hydro-logic	Chem-ical	Offsite migration
TONAWANDA AREA (pl. 2)								
6	932044	Buffalo Pumps Division	F		X	-	X	-
24-37	932018	Occidental Chemical-Durez Div.	L	X				XX
10	932036	Carborundum-Globar Plant	L		X	-	-	-
11	932009	Chisholm Ryder	F		X	*	X	-
14	932047	Dupont, Necco Park	L	X		-	X	XX
15-19, 250	932013 (a-f)	Dupont, Buffalo Avenue	L	X		X	X	-
21	932015	Frontier Bronze	F		X	-	X	-
22	932016	Great Lakes Carbon	F		X	-	X	-
38	932020	Occidental-Love Canal	L	X		X	X	XX
39	932021	Occidental-Hyde Park	L	X		*	X	XX
40	932022	Occidental-102nd Street	L	X		X	X	XX
41a	932019-a	Occidental-S-area	L	X		-	X	XX
41h-49	932019b-c	Occidental-Buffalo Ave. Plant	L	X		-	X	XX
51	932028	TAM Ceramics	L		X	-	X	-
56	932031	Olin-102nd Street Landfill	L	X		-	X	XX
57	932050	Olin-Industrial Welding	L		X	-	*	-
58,59, 248	932051 (a,b)	Olin-Buffalo Avenue	F	X		X	X	-
62	932034	Stauffer Chemical, N Love Canal	L		X	-	X	*
63	932049	Stauffer-Art Park	F		X	*	X	-
64	932035	Union Carbide	F		X	-	X	-
66	932040	Reichold-Varcum	L	X		-	X	XX
73	932067	La Salle Expressway	L		X	-	X	-
76	932006	Lynch Park	F		X	-	X	*
77	932025	Modern Disposal Service	F		X	-	X	-
78a,78b	932046, 932042	CECOS & Niagara Recycling	L		X	-	X	-
79	952091	Power Authority Road Site	L		X	-	-	-
81	932026	Niagara County Refuse Disposal	F		X	-	X	-
82	932079	Adams Generating Plant	F		X	-	*	-
83	932080	Buffalo Avenue	F	X		X	X	-
84	932008	Cayuga Island	F		X	*	X	-
85	932081	Griffon Park	F	X		X	X	-
86	932082	Hydraulic Canal	F		X	-	X	-
87	932083	New Road	F		X	-	X	-
88	932085	64th Street	F		X	-	X	-
89	932088	Whirlpool Site	F		X	-	X	-
90	932027	Witmer Road	F		X	-	X	-
91	932089	Town of Niagara Landfill, Lockport Road	L		X	-	X	-
92	932090	Niagara Falls Transportation Authority	F		X	*	X	-
94	932055	Niagara River-Belden Site	F		X	-	X	*
95	932056-a	Old Creek Bed-Dibacco	F		X	*	X	-
96	932067	Robert Moses Parkway	F/L		X	*	X	-
100	932093	Sibergeld Junk Yard	F		X	-	X	-
237	932086	Rodeway Inn	F		X	*	X	-
238	932087	St. Marys School	F		X	-	X	-
242	932063	Charles Gibson Site	L	X		X	X	-
245	932084	97th St. Methodist Church	F		X	*	X	-
247	932037	Olin Well	L		X	-	-	-
251		Solvent Chemical	L	X		-	X	XX
255	932053	Stauffer-PASNY	F		X	-	X	-

Table 22.--Sites that have a major potential for contaminant migration

Buffalo area.--19 sites were field checked and 6 evaluated through a literature review. Of these 25 sites, the 10 listed below were designated as having a major potential for contaminant migration:

107	Allied Chemical	915004
118	Bethlehem Steel Company	915009
120-122	Buffalo Color Corp.	915012a-c
138	McNaughton-Brooks, Inc.	915034
141	Mobil Oil Corporation	915040
162	Alltift	915054
203	Squaw Island	915052
241	Times Beach	915080

Tonawanda area.--29 sites were field checked and 21 evaluated through a literature review. Of these 50 sites, the 20 listed below were designated as having a major potential for chemical migration:

24-37	Occidental Chemical-Durez	932018
68	Gratwick-Riverside Park	932060
105	Allied Chemical	915003-b
108	Tonawanda Coke	915055-a
123	Columbus McKinnon Corporation	915016
136	INS Equipment Corporation	915031
182	Huntley Power Station	915063

Niagara Falls area.--31 sites were field checked and 32 evaluated through a literature review. Of these 63 sites, the 31 listed below were designated as having a major potential for contaminant migration:

5	Bell Aerospace	932052
14	Dupont, Necco Park	932047
15-19,250	Dupont, Buffalo Avenue	932013a-f
38	Occidental, Love Canal	932020
39	Occidental, Hyde Park	932021
40	Occidental, 102nd Street	932022
41	Occidental, Buffalo Avenue S-Area	932019a
41a-49	Occidental, Buffalo Avenue Plant	932019b-i
56	Olin, 102nd Street	932031
58,59,248	Olin, Buffalo Avenue Plant	932051a,b
		932038
66	Reichold-Varcum	932040
81	Niagara County Refuse Disposal	932026
83	Buffalo Avenue	932080
85	Griffon Park	932081
242	Charles Gibson	932096
251	Solvent Chemical	--

GUIDELINES FOR FUTURE STUDIES

This study indicates that some hazardous-waste sites will require further investigation to determine the potential for contaminant migration. At other sites, however, either there is no evidence of hazardous materials, or the hydrogeologic character of the site does not appear to allow for contaminant migration, so the need for further investigation may not be required.

Hazardous wastes have been disposed of in five ways: (1) in permeable deposits adjacent to the Niagara River or tributaries to the river, (2) in relatively impermeable deposits more than 15 ft thick and overlying bedrock, (3) in relatively impermeable deposits that are less than 15 ft and overlying bedrock, (4) in relatively impermeable deposits originally thicker than 15 ft and overlying bedrock but where thickness has been reduced by excavation to less than 15 ft and overlying bedrock, and (5) in relatively impermeable deposits where manmade interferences have altered site characteristics and increased the potential for flow of water from the site. Where contaminants from sites have reached bedrock, their effects have become regional. Some general guidelines for studying these five types of sites and the related regional contamination problems are given below.

Site Studies

Sites in Permeable Deposits Adjacent to the River

Where wastes are buried in or on permeable fill or alluvial sand adjacent to the Niagara River or its tributaries, contaminants can move laterally toward the river. An example of a hydrologic investigation that addressed this concern is that conducted by Dames and Moore (1981) at the Bethlehem Steel site in the Buffalo area (see appendix A, site 118).

In an investigation of this type of site, the wastes produced and buried would be identified, the stratigraphy of the site documented, the quantity of ground water and the direction of flow delineated, and mean concentrations of the contaminant plume determined. Several observation wells would be installed in the unconsolidated deposits between the site and the river and on the upgradient side of the site to determine ground-water gradients and extent and depth of geologic units. Where possible, wells would penetrate to below yearly low water-table levels. Single measurements of water levels would give only instantaneous gradient; seasonal monitoring would indicate changes throughout the year. Water-level recorders on wells would allow correlation of ground-water fluctuations with storms and river stage. Pumping tests and slug tests could be used to measure the conductivity of geologic units.

If contaminants could have infiltrated to bedrock, or if the ground-water flow system in the bedrock differs from that in the unconsolidated deposits, several wells would need to be installed in the bedrock to determine direction of ground-water flow. Several wells would also be needed to delineate the extent of the plume and the average concentration of selected constituents in the plume. Sampling methods would depend on whether contaminant transport was relatively uniform, varied seasonally, or was influenced primarily by recharge, river fluctuations, or other influences. Initially, a wide range of contaminants would be tested at each well. Routine analyses could then be restricted to selected constituents, with a wider range analyzed periodically.

Sites in Relatively Impermeable Deposits More Than 15 Feet Thick

Where wastes are buried in relatively impermeable deposits such as lacustrine silt, clay, or till some distance from the Niagara River, tributaries, or manmade disturbances, the major form of contaminant transport is overland runoff or vertical movement to the underlying bedrock. An example of a hydrogeologic investigation that addressed this concern was that conducted at Occidental Chemical Durez by Recra Research Inc. (1980) in the Tonawanda area (appendix B, sites 24-37).

In an investigation of this kind of site, wastes produced and buried would be identified, runoff from the site measured or estimated, stratigraphy of the site documented, vertical ground-water gradients and direction of flow delineated, and mean concentrations of contaminants in ground water and in overland runoff determined. One or more wells would be installed in bedrock below the disposal area to test for contaminants.

Test drilling would be done close to the disposal area to determine the thickness of geologic units. Nested piezometers would be placed on or close to the disposal area to define vertical and horizontal hydraulic gradient, and slug or pumping tests could be done to determine the permeability of the sediments; these data could then be used to calculate rate and quantity of ground-water discharge. Where materials are unsaturated or where wells do not produce enough water for sampling, cores and associated core water could be obtained by suction lysimeter or other means for chemical analysis. The relationship between concentrations in cores and those in core water, once established at representative sites, could subsequently be used at other sites where only soil cores are obtained for analysis.

Runoff and water quality would be monitored for those sites where overland flow is significant. In addition to routine sampling, stage-activated flow monitoring and water sampling may be required during and immediately after intense storms. Substrate samples collected from dry channel bottoms may indicate presence of contaminants, but negative findings do not rule out the possibility of contaminant transport.

Sites in Relatively Impermeable Deposits Less Than 15 Feet Thick

Where wastes are buried in lacustrine silt, clay, sand, or till less than 15 ft thick, weathering and desiccation cracks may create secondary avenues for movement to underlying bedrock and significantly increase the potential for lateral movement offsite. Examples of hydrogeologic investigations that addressed this concern are those done in the Niagara Falls area at Necco Park (site 14) by Weston (1979) and at Tam Industries (site 51) by the Conestoga-Rovers and Associates (1979 Hyde Park monitoring program).

Further investigation of this type of site would entail identification of (1) wastes produced and buried, (2) runoff from the site (measured or estimated), (3) stratigraphy of the site, (4) vertical ground-water gradients and direction of flow, and (5) mean concentrations of contaminants in ground water and in overland runoff. Observation wells would be installed in the unconsolidated deposits both upgradient and downgradient of the site to determine horizontal movement of contaminants, and slug or pumping tests could determine permeability. Several wells would be installed in the bedrock to sample for contaminants.

Sites with Identifiable Bedrock Contamination

Where contamination from a site has reached the underlying bedrock in large, relatively permeable units such as Lockport Dolomite and Onondaga Limestone, the potential for contaminant migration offsite and to underlying bedrock units is increased significantly. A system of wells along lines radiating from the site may be needed to determine the extent of the contaminant plume in a multilayered bedrock such as that at the Hyde Park landfill in Niagara Falls (site 39, appendix C) by Occidental Chemical Corporation (1983).

At sites near a ground-water divide or mound, concentric sets of nested piezometers or wells with packers would be installed along vectors radiating from the site to define the contaminant plume. If ground water moves regionally in one direction, most observation wells would be installed downgradient from the site. Each major water-bearing zone should be screened or packed and sampled for contaminants. Water levels would be measured to determine hydraulic gradients, and pumping tests would determine permeability of the water-bearing units.

Sites With Manmade Interferences

Drainage ditches, french drains, unlined sewers, power lines, aqueducts, trenches, or pumping wells significantly increase the potential for lateral migration of contaminants in the unconsolidated deposits. Examples of studies at such sites include that by Recra Research, Inc. and Wehran Engineering Corporation (1979) at Seaway (site 201, Tonawanda, appendix B) and by the U.S. Environmental Protection Agency (1982) at Occidental Chemical Love Canal (site 38, Niagara Falls, appendix C).

In addition to installing wells and sampling water flowing horizontally, conduits and fill around conduits would be sampled for contaminants, particularly during storms.

Modeling of Regional Ground-Water Flow

A regional ground-water model of flow patterns in both the unconsolidated material and in the bedrock units would be needed to assess the regional effects of contaminant migration. An example of a flow model of part of a region is that developed by Bergeron (U.S. Geological Survey, written commun., 1984) for the Hyde Park Landfill (site 39) in Niagara Falls.

Because ground water moves vertically, a three-dimensional model or cross-sectional model would be required, and in some areas, multiple layers would be needed to represent the bedrock units. The modeled area should be large enough to include hydrologic boundaries (Niagara River, Lake Erie, forebay canal, underground conduits, etc.). Water-level data from wells would be needed for model calibration and verification, and, where data were inadequate, additional observation wells would need to be installed. Also, the location, type, thickness, and permeability of the geologic units would need to be determined. Maps of depth to top of bedrock, thickness of unconsolidated overburden, and maps of bedrock stratigraphy would be useful guides.

A model could provide information about (1) direction and rate of ground-water flow, (2) effects of external hydrologic fluctuations such as changes of

river stage and seasonal recharge on ground-water fluctuations and boundary discharges, (3) effects of pumping on flow patterns, (4) rate of leakage to deep aquifers, (5) effects of removing or adding discharge wells, and (6) effects of proposed remedial measures. The model could also serve as a basis for solute-transport models to evaluate the effects of contaminant migration from individual sites.

SUMMARY

American and Canadian monitoring of the quality of the Niagara River has indicated a need to assess contamination entering the river through the ground-water system. The contamination probably emanates from point and nonpoint sources in the adjacent area, which contains a high density of chemical-manufacturing facilities and waste-disposal sites.

An Interagency Task Force on Hazardous Waste, composed of representatives of the New York State Department of Environmental Conservation, New York State Department of Health, and U.S. Environmental Protection Agency, identified 215 hazardous waste-disposal sites in Erie and Niagara Counties in a report issued in March 1979. Of these sites, 164 are within 3 miles of the Niagara River in Erie and Niagara Counties, N.Y. Of the 164 sites, 138 were studied as having a potential for offsite contaminant migration.

The U.S. Geological Survey reviewed records and, during the summer of 1982, obtained chemical analyses of ground-water and core samples from 79 sites. The objectives of the investigation were to (1) determine which sites are a possible source of contamination to the ground-water system, (2) classify the sites as to potential for ground-water contaminant migration, and (3) determine, where data were sufficient, the potential effects of site leachate on the quality of ground water.

The study area, a 37-mile band 3 miles wide along the Niagara River from Lake Erie to Lake Ontario, was divided into three areas--Buffalo, Tonawanda, and Niagara Falls on the basis of site density. The study entailed three phases--a general literature review, site reconnaissance and sampling, and a regional drilling and sampling program to obtain background hydrogeologic data for reference.

This report describes the methods of investigation, the field procedures, and the quality-control system for chemical sampling and analysis. It also categorizes the sites' potential for contaminant migration either as major or indeterminable from the data available. Hydrogeologic and chemical data from the individual sites are given in the appendices; the sources of data are included. For the few sites having sufficient data, the probable effects of leachate on the ground-water quality are discussed.

Records of past and current disposal practices and geohydrologic and chemical data on 85 of the 138 sites were provided by the U.S. Environmental Protection Agency (USEPA), New York State Department of Environmental Conservation (NYSDEC), the U.S. Geological Survey, consultants to the site owner, or the site operator for use in a preliminary evaluation of the sites' potential for contaminant migration. Of these 85 site records, 59 were used as complete evaluations for this study. The remaining 26 sites along with 53 other sites were drilled and sampled as described below.

Ground water, surface water, and(or) substrates were sampled on the 79 sites mentioned above. All sampling was done according to a quality-assurance/quality-control plan acceptable to the New York State Department of Environmental Conservation, the U.S. Environmental Protection Agency, and the U.S. Geological Survey.

The number of sites studied, test holes drilled, samples collected, and the chemical constituents and compounds analyzed from each area are shown in table 23. (These summary values and individual site values are also given in table 1.)

Table 23. Sampling Summary

A. Number of sites studied, wells/test holes sampled, and samples obtained from chemical analysis														
Area	Sites	No. of test holes drilled	No. of existing wells sampled	Samples collected										
				Ground water	Surface water	Substrate								
Buffalo	19	121	10	18	6	109								
Tonawanda	29	129	14	35	12	129								
Niagara Falls	31	118	7	16	7	112								
TOTAL	79	368	31	59	25	350								

B. Number of samples analyzed for chemical constituents														
Area	Organic compounds		Inorganic constituents											
	GC/MS extractables	Volatile	As	Cd	Cr	Cu	Fe	Pb	Hg	Ni	V	Zn	CN	S
Buffalo	82	40	32	60	90	83	102	85	32	59	22	27	4	3
Tonawanda	143	57	38	54	67	38	105	56	42	43	2	16	4	0
Niagara Falls	128	34	9	15	19	27	67	13	61	9	5	13	0	0
TOTAL	352	131	79	129	176	148	274	154	135	111	29	56	8	3

In addition to the test-hole-drilling program, an electromagnetic conductivity survey was done on 21 of the 79 sites to help delineate the extent of the disposal areas.

Among the 79 sites that were drilled and sampled were three dredge-spoil-containment sites along Lake Erie in the Buffalo area, which were studied to evaluate the potential for leachate migration to the lake. They are the Times Beach containment site (site 241), the Small Boat Harbor containment site (site 253), and the Buffalo Harbor containment site (site 254).

SOURCES OF DATA

- American Falls International Board, 1974, Preservation and enhancement of the American Falls at Niagara, Appendix C - Geology and rock mechanics: 71 p.
- Anderson, E. G., 1982, Hydrogeology review, Hyde Park Landfill: Toronto, Canada, Gartner Lee and Associates, 19 p.
- Buehler, E. J., and Tesmer, I. H., 1963, Geology of Erie County, New York: Buffalo Society of Natural Sciences Bulletin, v. 21, no. 3, 118 p.
- Calspon Corporation, 1977, Soils, geology, and hydrology of the NEWCO-Niagara Recycling site, Niagara Falls, New York: Calspon, 96 p., 10 figs., 6 tables.
- Camp, Dresser, and McKee Engineers, 1982, City of Niagara Falls--Reports on Fall Street sewer tunnel, visual inspection and infiltration, air, and sediment evaluation: Camp, Dresser, and McKee Engineers, 230 p.
- Cartwright, R. H., and Ziarno, J. A., 1980, Chemical quality of water from community systems in New York, November 1970 to May 1975: U.S. Geological Survey Water-Resources Investigations 80-77, 444 p.
- CM CHAIN, Division Columbus McKinnon Corporation, 1982, Closure plans for inactive landfill site, Tonawanda, New York: CM Chain, 22 p., 6 tables, 3 figs.
- Conestoga-Rovers and Associates, 1979, Progress report I, Hyde Park Landfill: Waterloo, Ont., Canada, Conestoga-Rovers and Associates, 17 p.
- _____ 1979, Progress report III, Hyde Park Landfill, Bloody Run, and 102nd Street Landfill: Waterloo, Conestoga-Rovers and Associates, 27 p.
- _____ 1979, Progress report IV, Hyde Park Landfill and Bloody Run: Waterloo, Conestoga-Rovers and Associates, 33 p.
- _____ 1979, Progress report V, Hyde Park Landfill, Bloody Run and 102nd Street Landfill: Waterloo, Conestoga-Rovers and Associates, 23 p.
- _____ 1979, Progress report VI, Hyde Park Landfill, Bloody Run, 102nd Street Landfill, Hooker, Niagara Falls, New York: Waterloo, Conestoga-Rovers and Associates, 18 p., 1 append., 1 map.
- _____ 1979, Site investigation and monitoring programme, 102nd Street Landfill, Hooker, Niagara Falls, New York: Waterloo, Conestoga-Rovers and Associates, 20 p., 2 maps.
- _____ 1980, Progress report VIIIA, Hyde Park-Bloody Run: Waterloo, Conestoga-Rovers and Associates, 18 p.
- _____ 1980, Progress report VIIIB, 102nd Street Landfill, Hooker, Niagara Falls, New York: Waterloo, Conestoga-Rovers and Associates, 2 p., 2 tables, 1 append.