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Great Lakes Science Advisory Board. Groundwater Contamination Task Force

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Great Lakes Science Advisory Board
Report to the International Joint Commission

Ø Keep

We have the 1983 annual report (GLC 22... IJC.10 ..A56 ENG 1983) but not the appendices.

1983 Annual Report

Appendix II

Groundwater Contamination

Great Lakes Science Advisory Board

Report to the International Joint Commission

1983 Annual Report

Appendix II

Groundwater Contamination

Prepared by the
Groundwater Contamination Task Force
of the Science Advisory Board
of the International Joint Commission

February 1985
Windsor, Ontario

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LIST OF TABLES AND FIGURES

PREFACE

In 1983, the International Joint Commission's Great Lakes Science Advisory Board established a Groundwater Contamination Task Force to investigate the significance of contamination via groundwater on Great Lakes water quality. This Appendix includes two reports:

A. The Potential for Great Lakes Contamination by Groundwater in the United States, by L.A. Swain; and

B. The Potential for Great Lakes Contamination by Groundwater in Canada, by R.W. Gillham.

The first report was prepared by staff of the Northeastern Regional Office of the United States Geological Survey at the request of the Science Advisory Board Co-chairmen. Guidance and some input to this report was provided by the Groundwater Contamination Task Force. The report was peer reviewed by the United States Geological Survey and approved for publication on November 10, 1983.

The second report was prepared under a contract funded by the Science Advisory Board. Direction to the contractor and some input to the report was provided by the Groundwater Contamination Task Force. Some of the review comments provided by the Ontario Ministry of the Environment (Dr. George Hughes and Mr. Ulo Sibul) and by the National Hydrology Research Institute were incorporated into the report.

Any viewpoints contained in these reports should not necessarily be construed as those of the Great Lakes Science Advisory Board or the International Joint Commission. However, the Board had formulated certain conclusions and recommendations on the groundwater contamination issue based on the information contained in these reports. These were included in the Board's 1983 Annual Report to the Commission. Copies of this Report may be obtained from the International Joint Commission at the Great Lakes Regional Office in Windsor, Ontario, Canada.

A. THE POTENTIAL FOR GREAT LAKES CONTAMINATION BY GROUNDWATER IN THE UNITED STATES

by
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1. BACKGROUND

In 1982 the Great Lakes Science Advisory Board of the International Joint Commission recommended that:

> - groundwater resources of the Great Lakes System be studied to determine potential contamination routes via this source and to establish mitigative measures."

As a result of that recommendation, this present overview was initiated as a means of assessing the significance of groundwater contamination as a contributor to the Great Lakes water quality.

This paper examines the general aspects and potential sources of contamination to the groundwater system from the United States' side of the Great Lakes only. An evaluation of potential contamination from the Canadian side was prepared concurrently by Robert W. Gillham and is found in Appendix II-B.

Because of the limited time frame, this report is purely qualitative in addressing the significance of the problem and thus is neither comprehensive by including all sources, nor does it include the quantitative aspects of any specific site.

The area of concern in this report is mainly confined to only the 191 counties of the eight States situated in the Great Lakes Basin. The counties and states included are documented in Table A-1.

1.1 GENERAL GROUNDWATER CONTAMINATION CONCEPTS

Once a contaminant enters the groundwater system, attenuation is extremely slow. Because groundwater velocities may be only 0.3 meter (one foot) or less per day, contaminants do not readily mix with the water and may travel as a well-defined slug or plume. Concentrations generally decrease over time and distance either by adsorption onto the porous medium, through ion exchange; by dispersion, decay, mixing, alteration by biological means, chemical reactions; or by diffusion. The rate of dilution depends mostly on the type of contaminant and the hydrologic framework, but decades or even centuries may be required for its total attenuation.

An understanding of the geohydrologic framework is essential because porosity and permeability affect the hydraulic table gradient which determines the quantity and rate of flow of groundwater. In low-permeability material, such as consolidated rock or clay, the water and affiliated contaminants might be totally contained within the rock or move very slowly. If consolidated bedrock should have an interconnected fracture system or solution cavities, water may then move rapidly through the rock, transporting the contained contaminants very quickly through the system.

If the water table in either rock or unconsolidated deposits is intercepted by a stream channel, groundwater can then discharge to the stream. The contaminant, in that case, could be transported more quickly to the topographic low of the basin which, in the study area, would be one of the Great Lakes.

1.2 GEOHYDROLOGIC FRAMEWORK

The porous medium through which groundwater moves within the Great Lakes Basin can be generalized into three categories: glacial deposits, bedrock deposits, and artificial fill material. The specific character of the porous medium determines the rate of contaminant transport.

i) Glacial Deposits

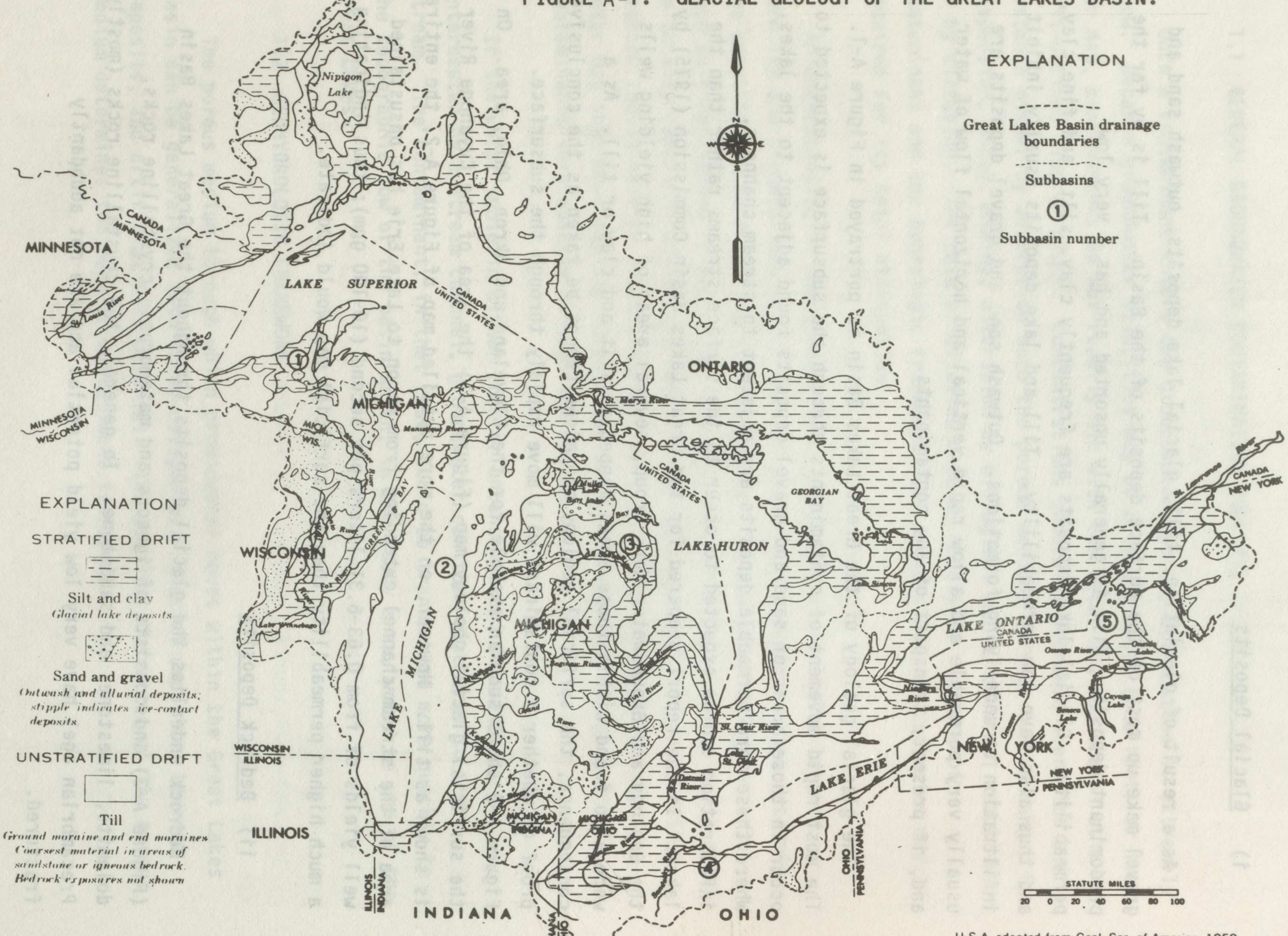
As a result of glaciation, till, glacial lake deposits, outwash sand and gravel make up most of the surface deposits of the Basin. Till is by far the predominant deposit. Till is generally unsorted and has a very low permeability. Glacial lake deposits are frequently clay, silt, and fine clay, and thus also have low permeabililty. Till and lake deposits usually inhibit infiltration to underlying formations. Outwash sand and gravel deposits are usually very permeable and allow rapid vertical and horizontal flow of water and, if present, transport of any contaminants.

The glacial geology of the Great Lakes Basin is portrayed in Figure A-1. The most rapid movement of contaminants through the subsurface is expected to occur in those areas of sand and gravel deposits found adjacent to the lakes. Where these more permeable deposits are adjacent to stream channels, infiltration can be expected to occur to the surface streams rather than the lakes. In the report prepared for the Great Lakes Basin Commission (1975) by the Geology and Groundwater Work Group, several areas of high yielding wells were also found within those areas mapped as silt and clay or till. As a consequence, the surficial geology map alone cannot be taken as the conclusive proof of whether a contaminant will move rapidly through the subsurface. Figure A-2 shows such an example for the Cleveland and Akron, Ohio, area. On the surficial glacial geology map (Figure A-1) the area of the Cuyahoga River is shown as till. However, on the more detailed map of Figure A-2, the entire area of the stream channel extending from Akron to Lake Erie has unsustained well yields of from 0.63-6.31 liters per second (10-100 gpm); thus indicating a much higher permeability than the surficial map would indicate.

ii) Bedrock Deposits

Bedrock underlies the glacial deposits throughout the Great Lakes Basin (Figure A-3) and consists of igneous and metamorphic crystalline rocks, dolomite, limestone, and sandstone. In general, the crystalline rocks (mostly Precambrian age) have very low yield potential and are not abundantly fractured.

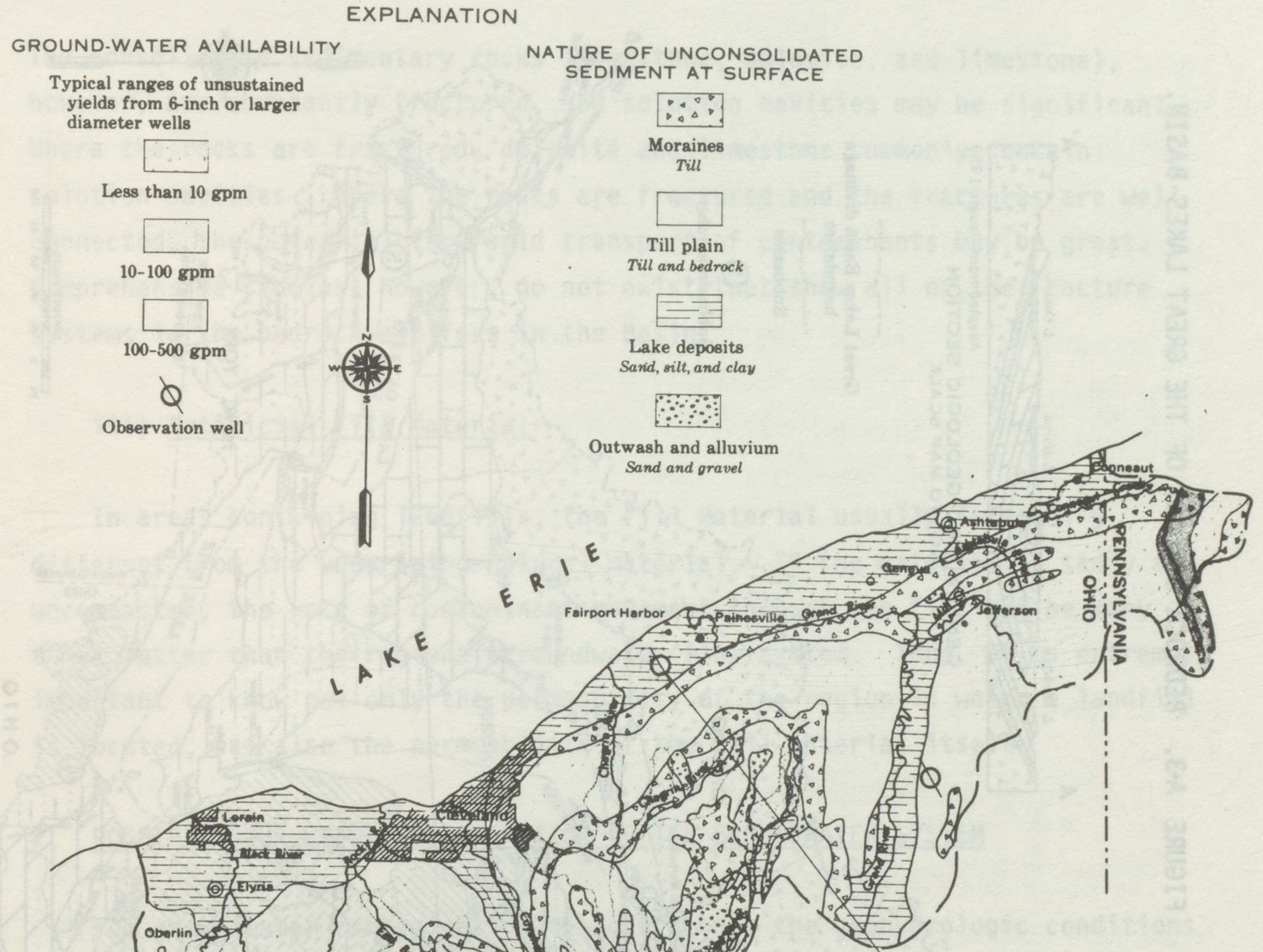
FIGURE A-1. GLACIAL GEOLOGY OF THE GREAT LAKES BASIN.



Base by Great Lakes Basin Commission

U.S.A. adapted from Geol. Soc. of America, 1959
Canada adapted from Geol. Survey of Canada, 1968

Source: Great Lakes Basin Commission. 1975. p. 34.



Base by Great Lakes Basin Commission

Geology adapted from Geol. Soc. Am., 1959; and Goldthwait and others, 1961

FIGURE A-2. GROUNDWATER IN THE UNCONSOLIDATED SEDIMENTS IN RIVER BASIN GROUP 4-3.

The consolidated sedimentary rocks (sandstone, dolomite, and limestone), however, are abundantly fractured, and solution cavities may be significant. Where the rocks are fractured, dolomite and limestone commonly contain solution cavities. Where the rocks are fractured and the fractures are well connected, the potential for rapid transport of contaminants may be great. Comprehensive studies, however, do not exist that show all of the fracture systems in the bedrock aquifers in the Basin.

iii) Artificial Fill Material

In areas containing landfills, the fill material usually is totally different from the underlying natural material. If the material is sandy and uncompacted, the rate of contaminant movement through the fill may be many times faster than the regional groundwater flow system. Thus, it is extremely important to know not only the permeability of the region in which a landfill is located, but also the permeability of the fill material itself.

2. POSSIBLE SOURCES OF CONTAMINATION TO THE GROUNDWATER SYSTEM

For groundwater contamination to occur, once the geohydrologic conditions are conducive to its infiltration, there must be a source of the contaminants. This source may be distributed over a large area (diffuse source) such as an agricultural field, or located at a defined location (point source) such as a landfill.

2.1 DIFFUSE CONTAMINATION

In southern Michigan, isolated areas of groundwater have become unfit for human consumption as a result of applying nitrogen as fertilizers. In a recent study of Van Buren County, Michigan (T.R. Cummings, U.S. Geological Survey, written commun., 1983), it was determined that 22 percent of the groundwater supplies in the southern half of the county contained more than 10 milligrams per liter (mg/l) nitrate as N, the maximum level permitted in public drinking water supplies (U.S. Environmental Protection Agency, 1977).

In parts of Wisconsin and New York, just outside the Great Lakes Basin, the pesticide aldicarb was discovered in wells in excess of the recommended as it is commonly called). The purpose was "to provide for liability, compensation, cleanup, and emergency response for hazardous substances released to the environment and clean up of inactive hazardous waste disposal sites." Section 103 (c) of CERCLA required that, within 180 days after enactment of the Act, every person who owned, operated or accepted hazardous wastes for transport, or selected a facility at which hazardous wastes were stored, treated, or disposed of, must notify the Administrator of the Environmental Protection Agency of the existence of such a facility; specifying the amount and type of any hazardous substance to be found there, and known, suspected, or likely releases of such substances from that facility. The penalty for non-reporting was a fine of up to $10,000 and up to one year imprisonment. As a result of this Act, over 10,000 hazardous waste sites were identified with the help of appropriate government agencies within the first year. Of these sites, a list of the top 400 highest priority, or "Superfund sites," was developed in 1982.

These sites include industrial landfills, municipal landfills, tank storage, contaminants of well fields, housing subdivisions where toxic chemicals have been spread on roads through waste oils, and abandoned lakes where uncontolled dumping has taken place.

Table A-1 gives the number of the CERCLA sites and of these the number of the priority Superfund sites which were identified in the 191 counties and eight States of the Great Lakes Basin. In total, 1,930 hazardous waste sites, or 20% of the U.S. total, were identified in the Great Lakes Basin. These sites, however, include only some of the known and reported sites and are certainly not inclusive of the numerous sites which were not reported. The county with the greatest number of CERCLA sites is Cook County, Illinois, in the Chicago area, which has 161 sites. The Niagara River area, made up of Niagara and Erie counties, New York, has a total of 268 sites. In the Cleveland, Akron and Ashtabula area of Ohio, 184 sites are located along Lake Erie.

TABLE A-1
CERCLA AND SUPERFUND HAZARDOUS WASTE SITE NUMBERS BY COUNTY WITHIN THE UNITED STATES GREAT LAKES BASIN

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
New York				
	1.	Jefferson	9	
	2.	Lewis	13	
	3.	Herkimer	13	
	4.	Hamilton	4	
	5.	Oneida	26	1
	6.	Oswego	28	2
	7.	Madison	0	
	8.	Onondaga	35	
	9.	Cayuga	4	
	10.	Wayne	6	
	11.	Monroe	38	
	12.	Orleans	5	
	13.	Niagara	136	5
	14.	Erie	132	1
	15.	Genesee	7	1
	16.	Wyoming	9	
	17.	Livingston	10	
	18.	Ontario	4	
	19.	Seneca	5	
	20.	Yates	5	
	21.	Schuyler	0	
	22.	Tompkins	0	
	23.	Cortland	0	
	24.	Allegany	7	1
	25.	Steuben	0	
	26.	Cattaraugus	10	1
	27.	Chautauqua	8	
	28.	Chemung	0	
		TOTAL	534	12
Pennsylvania				
	1.	Erie	11	2
	2.	Crawford	0	
	3.	Potter	0	
		TOTAL	11	2

TABLE A-1 (cont'd)

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
Ohio	1.	Williams	1	
	2.	Fulton	3	
	3.	Lucas	38	
	4.	Ottawa	5	
	5.	Defiance	0	
	6.	Henry	0	
	7.	Wood	6	
	8.	Sandusky	4	
	9.	Erie	5	
	10.	Lorain	19	
	11.	Cuyahoga	99	4
	12.	Lake	22	
	13.	Geauga	9	
	14.	Ashtabula	39	
	15.	Trumbull	0	
	16.	Portage	5	1
	17.	Summit	46	
	18.	Medina	6	
	19.	Ashland	0	
	20.	Huron	1	
	21.	Seneca	6	
	22.	Hancock	5	
	23.	Putnam	2	
	24.	Paulding	0	
	25.	Van Wert	2	
	26.	Allen	11	
	27.	Hardin	0	
	28.	Wyandot	1	
	29.	Crawford	3	
	30.	Richland	0	
	31.	Auglaive	0	
	32.	Mercer	3	
	33.	Marion	0	
		TOTAL	342	5
Michigan	1.	Gogebic	0	
	2.	Ontonagon	3	
	3.	Houghton	0	
	4.	Baraga	1	
	5.	Kewenaw	0	
	6.	Iron	5	

TABLE A-1 (cont'd)

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
	7.	Marquette	10	1
	8.	Dickinson	3	
	9.	Menominee	4	
	10.	Delta	5	
	11.	Alger	1	
	12.	Schoolcraft	0	
	13.	Luce	1	
	14.	Mackinac	1	
	15.	Chippewa	4	
	16.	Emmet	3	2
	17.	Cheboygan	0	
	18.	Presque Isle	2	
	19.	Alpena	4	1
	20.	Montmorency	2	
	21.	Otsego	2	
	22.	Charlevoix	4	1
	23.	Antrim	5	1
	24.	Leelanau	1	1
	25.	Benzie	0	
	26.	Grand Traverse	7	
	27.	Kal Kaska	2	
	28.	Crawford	0	
	29.	Oscoda	0	
	30.	Alcona	1	
	31.	Iosco	3	1
	32.	Ogemaw	1	
	33.	Roscommon	1	
	34.	Missaukee	0	
	35.	Wexford	3	1
	36.	Manistee	3	1
	37.	Mason	6	1
	38.	Lake	2	1
	39.	Osceola	2	
	40.	Clare	2	1
	41.	Gladwin	1	
	42.	Arenac	2	
	43.	Huron	2	
	44.	Bay	5	
	45.	Midland	8	
	46.	Isabella	0	
	47.	Mecosta	0	
	48.	Newaygo	1	
	49.	Oceana	1	

TABLE A-1 (cont'd)

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
	50.	Muskegon	41	4
	51.	Montcalm	3	
	52.	Gratiot	6	3
	53.	Saginaw	14	
	54.	Tuscalo	2	
	55.	Sanilac	1	
	56.	St. Clair	6	
	57.	La Peer	2	
	58.	Genesee	10	2
	59.	Shiawassee	1	
	60.	Clinton	2	
	61.	Ionia	5	1
	62.	Kent	31	6
	63.	Ottawa	10	1
	64.	Allegan	13	
	65.	Barry	7	
	66.	Eaton	5	
	67.	Ingham	9	
	68.	Livingston	9	3
	69.	Oakland	41	3
	70.	Macomb	21	2
	71.	Wayne	70	
	72.	Washtenaw	15	
	73.	Jackson	8	
	74.	Calhoun	9	2
	75.	Kalamazoo	26	2
	76.	VanBuren	7	
	77.	Berrien	11	1
	78.	Cass	4	1
	79.	St. Joseph	4	
	80.	Branch	6	
	81.	Hillsdale	6	
	82.	Lenawee	8	1
	83.	Monroe	11	1
		TOTAL	538	46
Indiana	1.	Lake	87	3
	2.	Porter	9	
	3.	LaPorte	14	1
	4.	St. Joseph	12	
	5.	Elkhart	13	1

TABLE A-1 (cont'd)

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
	6.	Lagrange	1	
	7.	Steuben	0	
	8.	De Kalb	4	
	9.	Noble	1	
	10.	Kosciusko	0	
	11.	Allen	13	1
	12.	Adams	0	
	13.	Wells	0	
		TOTAL	154	6
Illinois	1.	Lake	28	3
	2.	Cook	161	
	3.	Will	24	
		TOTAL	213	3
Wisconsin	1.	Douglas	4	
	2.	Bayfield	0	
	3.	Ashland	0	
	4.	Iron	0	
	5.	Vilas	0	
	6.	Forest	0	
	7.	Florence	0	
	8.	Marinette	5	
	9.	Oconto	1	
	10.	Langlade	0	
	11.	Menominee	0	
	12.	Shawano	0	
	13.	Marathon	0	
	14.	Door	0	
	15.	Keewaunee	1	
	16.	Brown	3	
	17.	Outagamie	3	
	18.	Waupaca	1	
	19.	Portage	0	
	20.	Waushara	4	
	21.	Winnebago	10	
	22.	Calumet	1	
	23.	Manitowoc	4	
	24.	Sheboygan	6	
	25.	Fond Du Lac	2	

TABLE A-1 (cont'd)

State	County		Number of Hazardous-Waste Disposal Sites	
	No.	Name	CERCLA (Priority)	Superfund
	26.	Green Lake	1	
	27.	Marquette	0	
	28.	Adams	0	
	29.	Columbia	0	
	30.	Oneida	0	
	31.	Washington	2	
	32.	Ozaukee	4	
	33.	Milwaukee	35	
	34.	Waukesha	13	
	35.	Racine	18	
	36.	Kenosha	5	
	37.	Dodge	0	
		TOTAL	123	0
Minnesota	1.	Cook	0	
	2.	Lake	1	
	3.	Saint Louis	14	
	4.	Itasca	0	
	5.	Aitken	0	
	6.	Carlton	0	
	7.	Pine	0	
		TOTAL	15	0
Grand Total			1,930	74

Note: CERCLA stands for the hazardous waste sites identified by the "Comprehensive Environmental Response Compensation and Liability Act" of 1980. Superfund sites are those CERCLA sites given the highest priority and slated for immediate clean-up with Superfund monies.

Of the 418 Superfund priority sites which were identified nation-wide in December 1982, 74, or 18 percent, were within the Great Lakes Basin. The criteria used in selecting the more than 400 priority sites as listed in Section 105(8)(A) of CERCLA is based upon the "relative risk or danger to public health or welfare of the environment, in the judgement of the President, taking into account the population at risk, the hazardous potential of the hazardous substances at such facilities, the potential for contamination of drinking water supplies, the potential for direct human contact, the potential for destruction of sensitive ecosystems, State preparedness to assume State costs and responsibilities, and other appropriate factors." Table A-2 lists just some of the hazardous wastes which were identified at the 74 Superfund sites within the Basin.

TABLE A-2

SOME HAZARDOUS WASTES IDENTIFIED AT GREAT LAKES SUPERFUND PRIORITY SITES

Boron Hydride
Cyanide
Copper
Chromium
Arsenic
Mercury
Heavy Metals Group
Sulfides Group
Asbestos
Vinyl Chloride
Methylene Chloride
cis-1,2,Dichloroethylene
Chloroform
Benzene
Dioxin
1,2,Dichloroethane

2,4,Dimethylphenol
Acetone
Ammonia
Picric Acid
Perchloroethylene (PCE)
1,1,1, Trichloroethane
Toluene
Trichlorophenol (TCP)
Trichloroethylene (TCE)
Polynuclear Aromatic Hydrocarbons
Phthalate Esters
Polychlorinated Biphenyls (PCB)
Polymer Gels
Polybrominated Biphenyls (PBB)
Xylenes

Based on a report by U.S. Environmental Protection Agency (Miller, 1980), calculated seepage into the Great Lakes groundwater system from reported waste ponds of only the major industries would have been over 51.1 million liters (13.5 billion gallons) in 1968. These reported ponds contained paper, petroleum, metal, and chemical industry wastes.

The high density of nonsewered residential areas in the Basin (40 septic systems per square mile), is also considered a high potential for nonpoint source contamination (Miller, 1980).

ii) By State

In addition to the CERCLA listing, the State of Michigan (Michigan Department of Natural Resources, 1982) has identified 441 sites where groundwater is known to be contaminated, and 456 additional sites where contamination is suspected. Known sites are those where investigations have been undertaken, the nature of the problem determined, and action taken. Suspected sites are those where insufficient data have been obtained to adequately evaluate the problem. Table A-3 lists the nature of the sources. One category worth noting is gasoline stations. Because of leaking and decaying storage tanks, gasoline leakage has been noted in Michigan as a significant problem, especially in areas where the density of stations is great and tanks are old.

In New York, underground contamination by petroleum products was discovered in 187 wells in 49 counties; this prompted the State to establish an Oil Spill Bureau to assist local agencies in dealing with leaks and spills. Contamination of groundwater by polychlorinated biphenyls (PCB) has resulted from spreading oil on gravel roads near Buffalo (Wide Beach and Snyder Beach). High lead concentrations of unknown source have also been discovered in wells near Philmore and Belfast in Alleghany County.

The State of New York has also identified approximately 700 sites Statewide where industrial wastes are known or thought to have been disposed (Pishdadazer and Moghissi, 1980). Of these sites, 12 were within the Great Lakes Basin and included in the Superfund priority list of 1982. According to the New York Department of Environmental Conservation, about 1.3 million tonnes (1.4 million tons) of hazardous wastes are generated in New York each year.

TABLE A-3. SOURCES OF GROUNDWATER CONTAMINATION IN THE STATE OF MICHIGAN

Nature of Source	Known		Suspected	
	Number	Percent	Number	Percent
1. Storage and handling of petroleum products: Total	112	25.5	27	6
--Gasoline stations	37	10.5	5	1
--Crude bulk storage, refining, pipelines	30	7.0	3	1
--Other storage/use (RR years, coops, industries)	39	6.5	12	2.5
--Transportation spills	2	.5	5	1
--Residential gasoline/fuel oil storage	4	1	2	.5
2. Heavy industry (mining, casting, chemical manufacturing, large volumes)	96	22	64	14
3. Unknown source (most appear to be gasoline contaminations)	59	13.5	2	.5
4. Surface and subsurface solid waste (sanitary landfills, illegal dumps, on-site industrial dumps)	57	13	215	47
5. Salt storage/road salting	33	7.5	86	19
6. Light industry (small metal plating, printing, manufacturing, woodworking, etc.)	24	5.5	19	4
7. Oil and gas exploration/production brines	19	4	8	2
8. Agriculture (animal/vegetable processors, fertilizer/herbicide applicators or distributors)	8	2	8	2
9. Municipal Wastewater	7	1.5	2	.5
10. Transportation spills (fertilizer, chemicals, etc.)	5	1	1	.5
11. Laundromats	5	1	19	4
12. All others, e.g. spill during fire	16	3.5	5	1
TOTAL	411		456	

Source: Michigan Department of Natural Resources. 1982. Assessment of Groundwater Contamination - Inventory of Sites.

In Pennsylvania, the Pennsylvania Department of Environmental Resources (DER) estimates that 7.3 million tonnes (8 million tons) of the 23.6 million tonnes (26 million tons) of industrial wastes created each year in the State are hazardous (Pennsylvanis Department of Environmental Resources, 1981). According to the DER there are numerous abandoned sites, 450 permitted hazardous waste storage areas, and about 45 hazardous disposal sites in the State. However, approximately 800 disposal sites Statewide are either causing, or have potential for causing, pollution problems within the State.

In Presque Isle, Pennsylvania, the U.S. Environmental Protection Agency (EPA) is examining the contamination of major aquifers with heavy metals and high concentration of other dissolved constituents from what was believed to have been deep-well disposal of injected industrial wastes.

In Minnesota, the Minnesota Pollution Control Agency has identified approximately 1,200 landfills Statewide that are or potentially are sources of groundwater pollution.

In Wisconsin (Braun, 1983), it has been estimated that there are over 2,000 abandoned or improper landfill sites Statewide. Some of these sites have already created groundwater contamination problems to adjacent lands. In addition, there are numerous municipal, industrial, and private lagoons and ponds throughout the State which may be leaking into the groundwater system (Wisconsin Department of Natural Resources, 1983).

In Indiana, the 13 Superfund sites in the State threaten the water quality of the underlying glacial deposits and fractured limestone aquifers. Remedial actions are being taken at three sites while studies are being conducted at two others. In Elkhart, Elkhart County, contamination of the municipal water supply is threatened by trichloroethylene. In Gary, Indiana, water is polluted with volatile organic compounds and toxic inorganic compounds at three disposal sites that overlie lacustrine dune sand deposits (U.S. Environmental Protection Agency, 1982).

In Ohio, one of the greatest groundwater problems of the Ohio Environmental Protection Agency has been brine contamination from the numerous oil and gas-producing wells. Contamination has occurred both from surface land disposal and illegal dumping. The disposal of sewage treatment effluent and runoff into wells has also contaminated groundwater in parts of Huron and Erie Counties.

3. INTENSIVE INVESTIGATIONS OF SPECIFIC SITES

Once the contaminated sites have been identified, the next step is for an extensive investigation of each specific site in order to determine the magnitude of the problem and assess the potential clean-up methods. As part of the extensive investigations, the hydrogeologic framework must be thoroughly quantified with respect to its transport capabilities and the areal extent of the contaminants, and also any specific characteristics for attenuation.

In 1982, a study of the Niagara River area (Vincent and Franzan, 1982) provided an overview of environmental conditions, sources of chemical substances and programs to control toxic substances in that area of New York. The study concluded that industrial manufacturing plants were the most important source of chemical substances in the Niagara Frontier (Niagara and Erie Counties). Furthermore, 15 major industrial dischargers in the study area were found to collectively account for 95 percent of the total direct industrial discharge of priority pollutants. The study also found that 90 percent of the chemical substances discharged by municipal plants came from four municipal wastewater treatment plants that receive industrial wastes as a major part of their influents.

Although the objective of the study did not include a quantification of the substances, it was noted that the major source of chemicals transported to surface water by contaminated groundwater and surface runoff was from the numerous inactive and inadequately controlled hazardous waste disposal sites. The study further estimated that probably half of the organic priority pollutants discharged by point-sources occur from contaminated groundwater discharging into industrial and municipal sewers and into industrial water supply wells.

As a followup to the Vincent and Franzen study, a recent study of 155 hazardous waste disposal sites within three miles of the Niagara River along a 20 mile long corridor has just been completed by the U. S. Geological Survey (Edward Koszalka, personal communication, June 1983). The purpose of that study was to (1) discover which sites are possible sources of contamination to the groundwater system, (2) assess the geohydrologic impacts of the site leachate on groundwater quality, and (3) assess the impact of the chemicals in the groundwater, which will, in turn, affect the Great Lakes.

In that study, 76 hazardous waste sites were sampled through test drilling and core sampling. If the water table was intercepted, a water sample was taken. If the water table was not encountered, a substrate sample was collected and analyzed. For the 80 sites which were not sampled, data was compiled and analyzed from existing sources through government agencies. Of the sites investigated, 57 were designated as having a major potential for contaminant migration.

One important finding was that a seasonal perched water table exists above the major clay unit. Where continuous, this clay unit inhibits the vertical movement of groundwater. The groundwater flow gradient may therefore flush contaminants seasonally to topographic lows and discharge them to nearby surface water bodies. The surface water systems act as a short circuit to the sluggish groundwater flow system as they accumulate the contaminants and then rapidly transport them through the surface water system to the Great Lakes.

A recently completed study (Stark and others, 1983), investigated the movement of trichloroethylene in groundwater at Wurtsmith Air Force Base in Michigan. Other contaminants found at the site were benzene and dichloroethylene. The study used a digital groundwater model to refine estimates of aquifer hydrologic parameters and calculate the rate and direction of groundwater flow. The model was also used to make decisions regarding purging of the contaminated water from the aquifer. The groundwater flow rate was calculated to be 9.1 to 24.4 centimeters (.3 to .8 feet) per day.

In the Oswego County (New York) area alone, 28 CERCLA sites have been listed. A recent study (Scrudato and others, 1980) examined the effects of groundwater contamination from chemical waste leachate eminating from Pollution Abatement Services, where over 3.8 million liters (one million gallons) of waste liquid per month were treated from 1970 to 1976. As a result, more than 32,000 (208.1 liters) barrels were landfilled within Oswego County, because it was not equipped to handle "solid" wastes. In addition, a 75,700 liter (20,000 gallon) waste oil lagoon overflowed and collapsed. Some of the chemicals handled at the site were polychlorinated biphenyl, vinyl cyanide, benezene, phenol, chromium, copper, trichloroethylene, insecticides, and toluene. The investigation also covered the sites where the barrels were believed to be shipped and stored within the country.

The contamination potential in the Silurian dolomite in Door County, Wisconsin, was investigated by M. G. Sherrill (1978). In that study, the emphasis was on discovering the hydrogeologic character of the aquifer system, and its potential for contamination. The study identified rapid flow rates of groundwater within the fractures and bedding planes of the dolomite.

Over 20 years ago, a comprehensive description of groundwater contamination in Michigan was made by Morris Deutsch (1963). In that study, Deutsch described the problems of contamination and case studied almost all imaginable cases of actual and suspected groundwater contamination. The paper described, in general terms, the types of contamination, the methods through which the system can be polluted, and the legal controls in Michigan to prevent and control contamination.

4. CONCLUDING REMARKS

The sources of contamination are both numerous and widespread throughout the Great Lakes Basin. Hazardous waste sites are well distributed throughout the Basin, with their greatest concentration in counties adjacent to the Lakes at Chicago, Cleveland and the Niagara River area. It can also be stated from a general understanding of the geohydrologic framework that permeable glacial deposits would allow infiltration of the materials to the water table.

Conversely, most till and glacial lake deposits allow very slow movement of water through them. The high permeability of the fractured bedrock can allow very rapid transport of contaminants.

The seasonal perching of infiltration by tight clay layers allows a seasonal flushing of contaminants to surface water bodies. More permeable artificial landfill material will allow more rapid contaminant transport than some natural unconsolidated deposits.

Almost 20 percent of the hazardous waste sites identified in the United States for CERCLA lie within the Great Lakes Basin. The contaminants identified in groundwater are both toxic and/or carcinogenic. In some locations, large areas have been found to be unfit for domestic use and some entire well fields have been destroyed.

Sources of contamination are present in the Basin and the geohydrology is favorable for transport of contaminants by groundwater into the Great Lakes. A better definition and quantification of the specific contamination sites are still needed. In addition, there needs to be an identification and quantification of the contaminants which seasonally are flushed into the surface water systems, especially during baseflow periods.

REFERENCES

Braun, Bruce. 1983. Bill on old dumps prompt debate. Milwaukee Journal, March 11, 1983.

Deutsch, Morris. 1983. Ground water contamination and legal controls in Michigan. U.S. Geological Survey Water-Supply Paper 1691: 77 pp.

Geological Society of America. 1959. Glacial Map of the United States East of the Rocky Mountains. Geological Society of America.

Geological Society of Canada. 1968. Glacial map of Canada. Geological Survey of Canada, Map No. 1253A.

Goldthwait, R.P., G.W. White and J.L. Forsyth. 1961. Glacial map of Ohio. U.S. Geological Survey, Miscellaneous Geological Investigation I-316.

Great Lakes Basin Commission. 1975. Great Lakes Basin Framework Study, Appendix 3 - Geology and Groundwater. Prepared by Geology and Groundwater Work Group, 152 pp.

International Joint Commission. 1976. Inventory of Land Use and Land Use Practices in the United States Great Lakes Basin. Report of the International Reference Group on Great Lakes Pollution from Land Use Activities, Vol 1: 146 pp.

Michigan Department of Natural Resources. 1982. Assessment of Ground Water Contamination: Inventory of Sites. Michigan Department of Natural Resources, 242 pp.

Miller, David W. 1980. Waste Disposal Effects on Ground Water. Premier Press, 512 pp.

Pennsylvania Department of Environmental Resources. 1981. "Hazardous Wastes DER Acts to Solve Pennsylvania Problems." Reported May 1981 by Pennsylvania Department of Environmental Resources.

Pishdadazar, H., and A. A. Moghissi. 1980. Hazardous waste sites in the United States. Nuclear and Chemical Waste Management 1 (3 & 4): 243-256.

Scrudato, R. J., H. Anderson, C. H. Ehlers, P. A. Goliber, T. S. Miller and R. H. Schneider. 1980. The Potential waste leachate in Oswego County. p. 87-105. In Proceedings of the Conference on Toxic and Hazardous Chemicals, January 9 and 10, 1980. Sponsored by the Central New York Regional Planning and Development Board.

Sherrill, M. G. 1978. Geology and ground water in Door County, Wisconsin, with emphasis on contamination potential in the Silurian Dolomite. U.S. Geological Survey Water Supply Paper 2047.

Stark, J. R., T. R. Cummings and F. T. Twenter. 1983. Ground Water contamination at Wurtsmith Air Force Base, Michigan. U.S. Geological Survey Water Resources Investigations Report 83-4002: 93 pp.

U.S. Environmental Protection Agency. 1977. Quality Criteria for Water, 1976. U.S. Environmental Protection Agency, 256 pp.
1982. Amendment to national oil and hazardous substance contingency Plan; The national priorities list. December 30, 1982, Federal Register 47 (251): 58476-58485.

Vincent, James and Arthur Franzen. 1982. Overview of Environmental Pollution in the Niagara Frontier New York. U.S. Environmental Pollution Agency, March 1982, Denver, Colorado, 219 pp.

Wisconsin Department of Natural Resources. 1983. Ground water--Wisconsin's buried treasure. Supplement to Wisconsin Natural Resources Magazine, July 1983.

Stark, J. R., T. R. Cummings and F. T. Twenter. 1983. Ground Water contamination at Wurtsmith Air Force Base, Michigan. U.S. Geological Survey Water Resources Investigations Report 83-4002: 93 pp.

U.S. Environmental Protection Agency. 1977. Quality Criteria for Water, 1976. U.S. Environmental Protection Agency, 256 pp.

1982. Amendment to National oil and hazardous substance contingency Plan; The national priorities list. December 30, 1982, Federal Register 47 (251): 58476-58485.

Vincent, James and Arthur Franzen. 1982. Overview of Environmental Pollution in the Niagara Frontier New York. U.S. Environmental Pollution Agency, March 1982, Denver, Colorado, 219 pp.

Wisconsin Department of Natural Resources. 1983. Ground water--Wisconsin's buried treasure. Supplement to Wisconsin Natural Resources Magazine, July 1983.

B. THE POTENTIAL FOR GREAT LAKES CONTAMINATION BY GROUNDWATER IN CANADA

by

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1. INTRODUCTION

The Canadian Great Lakes Basin falls entirely within the Province of Ontario and principally within southern Ontario. Rapid growth in population over the past fifty years, has resulted in southern Ontario being the most densely populated and highly industrialized region of Canada. Much of this period of rapid development (from the thirties to the early seventies) proceeded without environmental controls. Environmental legislation pertaining to waste disposal was first introduced by the Provincial Government in 1970. In addition, many practices potentially damaging to the environment were permitted to continue well into the seventies because of a lack of scientific knowledge to enable proper understanding of the consequences of waste disposal practices on the hydrogeologic regime.

The subsurface disposal of hazardous liquid wastes was also an accepted procedure at some sites until 1982. In addition, there have been, and undoubtedly will continue to be, instances of uncontrolled dumping on private land. It must also be recognized that spills, leaks and accidental discharges of toxic materials have been and will continue to be an unavoidable consequence of industrialization.

Many other recognized and approved activities exist within the Canadian Great Lakes Basin that may affect groundwater and ultimately the quality of the Great Lakes. Included among these are septic tanks, chemicals used in agriculture and the forestry industry, and waste products from the mining and milling industries.

The discharge of environmentally hazardous materials to the atmosphere and surface waters can be recognized and monitored with relative ease. With removal of the source, a rapid improvement in the quality of the receiving environment can be expected. Unfortunately, groundwater presents a much more perplexing problem. The technology associated with the identification and characterization of zones of contaminated groundwater has developed largely within the past ten to fifteen years and as a result, is presently far from being a precise or complete science. In addition, because the residence time of groundwaters can vary from a few weeks to tens of thousands of years, the consequences of poor past and present management practices may not be fully realized for several generations to come. Of the potential pathways for contaminants to reach the Great Lakes, migration through groundwater is not well understood and is inadequately documented. Misinterpretation of the existing conditions would therefore have the greatest potential for long-term consequences.

This report presents a preliminary evaluation of the potential for contaminated groundwater in the Canadian Great Lakes Basin to adversely affect the water quality of the Great Lakes. The report is based largely on documents that are available from the International Joint Commission, the Ontario Ministry of the Environment, and Environment Canada; and on discussions with personnel of these agencies and with private consulting companies in Ontario that are involved in waste-management and groundwater quality problems. The United States complement to this report was concurrently prepared by Mr. Lindsay A. Swain with the Northeastern Region Office of the U.S. Geological Survey and is found in Appendix II-A.

2. GEOLOGY

The Canadian Great Lakes Basin falls within two distinctly different geologic regimes. The Canadian Shield region extends north from an irregular line drawn approximately between Georgian Bay and Kingston. The bedrock of this area is composed almost entirely of crystalline rocks, principally Precambrian granites. Minor areas of sedimentary rocks can occur, however, particularly near the boundary between the Precambrian and Paleozoic rock types.

The unconsolidated surficial materials of the Canadian Shield are distributed very irregularly, with little or none in the upland areas, while thick deposits are confined largely to the valleys. Sand and gravel deposits are common, particularly in old river channels, outwash deposits or in kames and eskers. Extensive clay deposits are also present either as moraine or clay deposits formed during the period of the glacial lakes.

The topography of the Canadian Shield tends to be irregular to extremely rugged because of past tectonic and glacial processes.

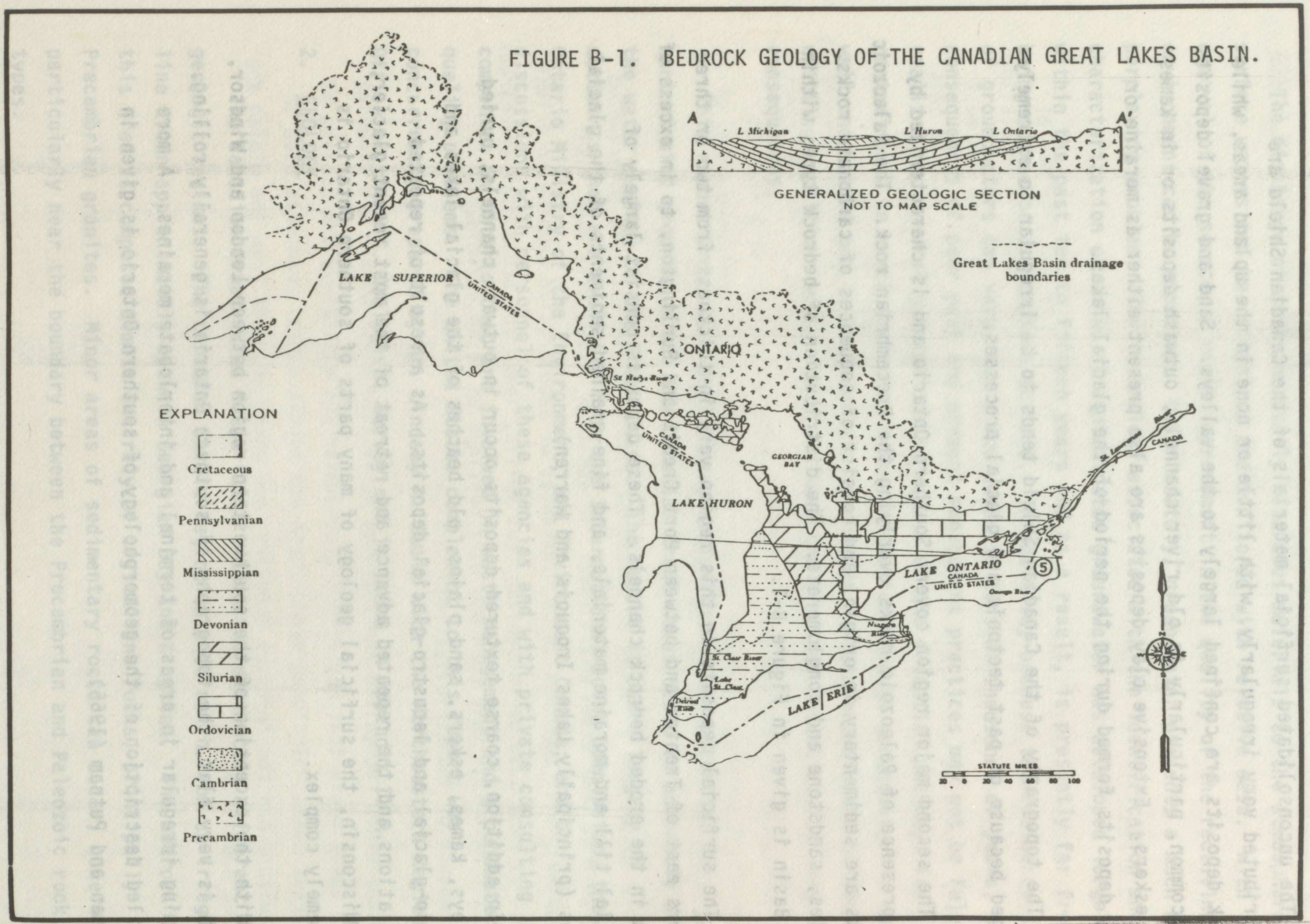
The second major region covers Southern Ontario and is characterized by the presence of Paleozoic rocks overlying the Precambrian rock. The Paleozoic rocks are sedimentary in origin, and consist of sequences of carbonate rocks, shales, sandstone and conglomerate. The distribution of bedrock types within the Basin is given in Figure B-1.

The surficial deposits in this region vary in thickness from two or three meters east of Trenton and between Port Credit and Burlington, to in excess of 200m in the eroded bedrock channels. These deposits consist largely of glacial till and moraine materials, and fine-grained sediments of the glacial lakes (principally Lakes Iroquois and Warren).

In addition, coarse textured deposits occur in outwash channels, buried valleys, kames, eskers, sand plains, old beaches of the glacial lakes and fluvio-glacial and lacustro-glacial deposits. As a result of repeated glaciations and the repeated advance and retreat of the most recent glacier, the Wisconsin, the surficial geology of many parts of southern Ontario is extremely complex.

With the exception of the southwestern region between London and Windsor, which is very flat, the topography of southern Ontario is generally rolling, becoming irregular in areas of terminal and interlobate moraines. A more detailed description of the geomorphology of southern Ontario is given in Chapman and Putnam (1966).

FIGURE B-1. BEDROCK GEOLOGY OF THE CANADIAN GREAT LAKES BASIN.



Source: International Joint Commission. December 1977, p. 8.

3. HYDROGEOLOGY

The Canadian Great Lakes Basin falls within two hydrogeologic regions according to the classification of Brown (1967). The region of Precambrian bedrock falls within the "Canadian Shield" hydrogeological region, while the more southerly zone falls within the "St. Lawrence Lowlands" hydrogeological region.

Groundwater in the bedrock of the Canadian Shield occurs primarily in fractures. The evidence suggests that the frequency and aperture of the fractures decreases with depth; thus, the major zone of groundwater circulation would be at shallow depth. Due to the low effective porosity of the rock, migration rates of contaminants could be quite high, although the hydraulic conductivity of the rock may be quite low. Migration rates could also be high in the sand and gravel deposits, but would tend to be low in the clay-till and lake-clay deposits.

Hydraulic gradients in the shallow groundwater zones tend to be high because of the irregular topography, and thus, with the exception of areas having clayey surficial deposits, relatively short groundwater residence times can be expected. As noted by Brown (1967), the surface water and groundwater chemistries are similar, suggesting further that groundwater discharge is dominated by flow systems that are relatively short and shallow.

Shallow groundwater of the Canadian Shield is generally a calcium-bicarbonate type; however, because of the low solubility of the mineral materials, the water generally has a very low concentration of total dissolved solids. In addition, because of the chemical characteristics of the mineral materials, the groundwater is generally neutral to slightly acidic. The low amount of dissolved solids in the groundwater of the Canadian Shield is generally responsible for the low buffering capacity of these waters despite being a calcium-bicarbonate type. Because of the relatively small influence of the natural controls on the groundwater chemistry, the water quality could be particularly sensitive to activities that introduce contaminants into the hydrogeologic regime.

As in the Canadian Shield, the physical hydrogeology of the bedrock formations in southern Ontario (the St. Lawrence Lowlands hydrogeologic region) is controlled largely by fracture networks; however, because of the greater variety of rock types, the conditions tend to be much more variable. Based on well yields, the most transmissive rock types are the dolomites and limestones, particularly dolomite of Middle Silurian age and the Bois Blanc and Detroit River Formations of the Devonian. These formations have well developed joint systems and bedding planes, and some reef structures. In the carbonate rock types, the waters are generally calcium and magnesium bicarbonate type and are of good quality but have relatively high concentrations of total dissolved solids. The shale formations frequently have water of poor quality as a result of the presence of evaporites such as gypsum and halite. Calcium sulfate-, sodium chloride-, and hydrogen sulfide-type waters are not uncommon.

Although bedrock aquifers are an important groundwater resource in many parts of southern Ontario, with the exception of the areas noted earlier where the bedrock is close to ground surface, the bedrock is of relatively minor importance with respect to the migration of contaminants. In particular, because of the large depth to bedrock in many areas, the bedrock forms part of large regional groundwater flow systems that have relatively low hydraulic gradients and very long travel distances and times. Conversely, because of the rolling topography, hydraulic gradients in the surficial materials tend to be higher and the flow paths shorter than in the underlying bedrock. In addition, most potential sources of groundwater contamination tend to occur at or near ground surface, suggesting further the importance of the surficial materials in the groundwater transport of contaminants to surface waters. As noted previously, the bedrock is at shallow depths in the area extending from Port Credit to Burlington and other local areas on top of the Niagara Escarpment, particularly in the Hamilton area. Contaminant transport through bedrock could be an important consideration in these areas, particularly in view of a high population density and a high degree of industrialization.

Each potential source of groundwater contamination must be treated on an individual basis because of the complexity of the surficial materials of southern Ontario. Nevertheless, some comments of a general nature are appropriate.

Generally, the most sensitive areas are those having coarse-grained sediments at or near ground surface. Although the most common unconsolidated geologic material throughout southern Ontario is till, the coarser materials provide the predominant pathways for groundwater flow. Moraine areas such as the Oak Ridges Moraine, old beaches, sand plains such as the Alliston Sand Plain and other fluvio-glacial sediments could provide important pathways for the migration of contaminants to surface waters and ultimately to the Great Lakes.

The distribution of Quaternary deposits in southern Ontario is described in detail by Champman and Putnam (1966). Coarse-grained deposits are shown to occur frequently throughout south-central Ontario and are also common, though less prevalent, in both the western and eastern regions of southern Ontario. Clay and till materials are not useful as aquifers, and consequently, the hydrogeologic characteristics of these materials have received relatively little attention. In general, because of their low hydraulic conductivity values, these deposits have been viewed as barriers to the migration of contaminants. Recent studies, however, have shown that the till and clay deposits of southern Ontario generally contain networks of fractures to depths of a few meters below ground surface (Desaulnier et al. 1981, for example). While the role of the fractures in the transport of contaminants is not fully understood, it is reasonable to expect the fractures to provide pathways of relatively rapid groundwater migration. Because of the potential for contaminants to diffuse into and out of the porous matrix between fractures, the effect of the fractures on contaminant migration is not clear. Nevertheless, one could expect the migration rates to be faster than in similar materials without fractures. Thus, even the fine-grained sediments may have a significant potential to transmit contaminants to surface waters under some circumstances.

4. HYDROLOGIC BUDGETS

Although hydrologic budgets are of great importance in evaluating the water resources of an area, by themselves, they have limited value in assessing the potential of a particular source of water to contaminate a multiple-source reservoir. The potential to cause significant contamination of the reservoir depends on both the volume discharge from the contaminated source and the concentration of contaminants in the source. An appreciation of the groundwater contribution to the hydrologic budget of the Great Lakes, nevertheless, would provide useful background information in evaluating dilution factors. Even a relatively small source of water that contains contaminants at concentrations several orders of magnitude above the acceptable limit would have the capability of contaminating a large volume of water.

Although hydrologic budgets that include a quantitative consideration of groundwater are not available for the entire Great Lakes Basin, detailed studies have been conducted on the Canadian side of the Lake Ontario Basin (Haefeli, 1972; and Ostry, 1979). Haefeli used three different methods to evaluate the discharge of groundwater directly into Lake Ontario. Calculated values of discharge ranged from 3.7×10^4 L/min to 2.0×10^5 L/min. Based on the comments by Haefeli on the various methods, a reasonable estimate of discharge would be about $1.3 \times 10^5 \pm 4.2 \times 10^4$ L/min. Flow from the upper lakes into Lake Ontario is about 3.6×10^8 L/min and other inflows to the lake (primarily surface drainage) total about 6.1×10^7 L/min. As noted by Witherspoon (1979), evaporation from the lake surface is approximately equal to precipitation on the lake surface. Assuming that the groundwater contributions on the U. S. and Canadian sides are about the same (given a total of 2.5×10^5 L/min), then groundwater discharged directly to the lake is about 0.06% of the total flow, or about 0.4% of the flow contributed to Lake Ontario from the Lake Ontario Basin.

Although these numbers suggest that groundwater is a very minor component of the hydrologic budget for Lake Ontario, they are misleading and only reflect the amount of groundwater contributed directly to the lake. Groundwater also constitutes a significant proportion of streamflow to the lake. From the analysis of runoff records from seventeen watersheds in the Lake Ontario basin, Haefeli (1972) found that baseflow (groundwater) constituted from 21 to 78% of the total stream discharge. The wide range in values reflects variations in the physiographic features of the watersheds.

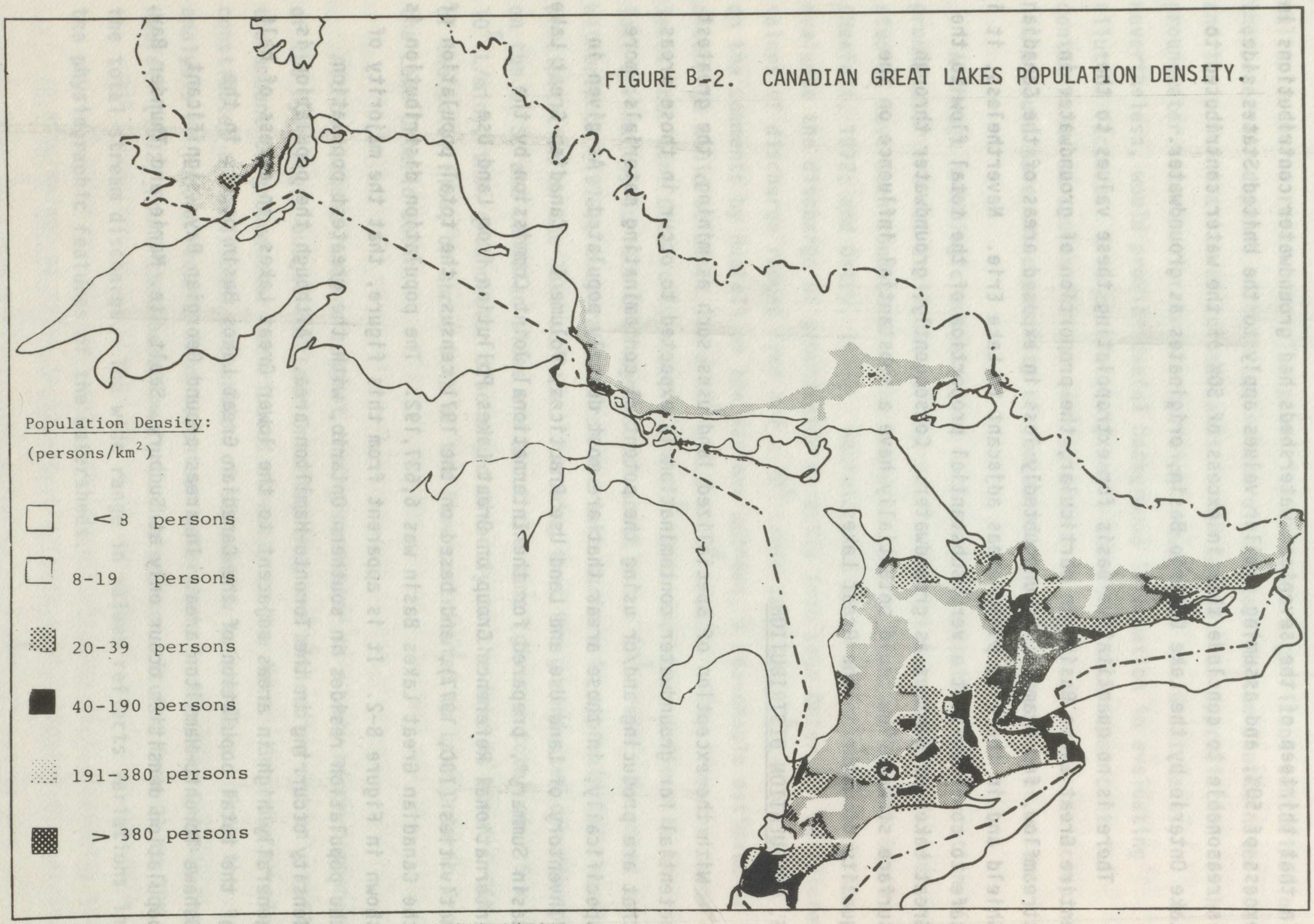
In that thirteen of the seventeen watersheds had groundwater contributions in excess of 50%, and assuming similar values apply to the United States side, it is reasonable to conclude that in excess of 50% of the water contributed to Lake Ontario by the Lake Ontario Basin, originates as groundwater.

There is no quantitative basis for extrapolating these values to the entire Great Lakes Basin; in particular, the proportion of groundwater in streamflow, for example, is undoubtedly less in exposed areas of the Canadian Shield and in the clay plain areas adjacent to Lake Erie. Nevertheless, it is safe to conclude that a very substantial proportion of the total flow to the Great Lakes originates as groundwater. Consequently, groundwater through surface stream flow could potentially have a substantial influence on the quality of water in the Great Lakes.

5. POPULATION DISTRIBUTION

With the exception of specialized land uses such as mining, the greatest potential for groundwater contamination is expected to occur in those areas that are producing and/or using the potential contaminating materials; more specifically, in those areas that are most densely populated. As given in "Inventory of Land Use and Land Use Practices, Volume I - Canadian Great Lakes Basin Summary", prepared for the International Joint Commission by the International Reference Group on Great Lakes Pollution from Land Use Activities (IJC, 1977), and based on the 1971 census, the total population of the Canadian Great Lakes Basin was 6,637,192. The population distribution is shown in Figure B-2. It is apparent from this figure, that the majority of the population resides in southern Ontario, with the greatest population density occurring in the Toronto-Hamilton area. Although the population is generally high in areas adjacent to the lower Great Lakes, in excess of half of the total population of the Canadian Great Lakes Basin occurs in the Oshawa-Toronto-Hamilton area. In areas around Georgian Bay, significant population densities occur only at Sudbury, Sault Ste. Marie and Thunder Bay.

FIGURE B-2. CANADIAN GREAT LAKES POPULATION DENSITY.



Source: International Joint Commission. December 1977, p. 22.

Since a relatively small number of people or a small industrial operation has the potential to cause serious groundwater contamination, no portion of the Basin can be overlooked. In terms of priorities, the urbanized and industrialized regions of southern Ontario, in particular, appear to offer the greatest potential for serious groundwater contamination.

6. POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

6.1 DIFFUSE SOURCES

Diffuse sources of groundwater contamination are those that are applied more-or-less uniformly over large land areas. These represent a serious source of contamination in that large volumes of water can be affected; however, in most cases the potential contaminants are either not highly toxic or are present at relatively low concentrations. The most common example of a diffuse source of potential groundwater contamination is fertilizer spread over agricultural land. The application of pesticides and herbicides onto agricultural and forested lands, acid rain, and atmospheric fallout are other examples.

(i) Fertilizer

The contribution of nitrogen and phosphorus to the Great Lakes as a result of agricultural activites, was investigated in detail as part of the PLUARG studies and will not be dealt with in detail here. As indicated in the Final Summary Report to the International Joint Commission - "Agricultural Watershed Studies in the Canadian Great Lakes Basin" (IJC, 1978) - agricultural activities tend to increase the concentration of nitrate in streams through nitrate transport in overland flow and in groundwater. Although the results demonstrate the potential for a solute to be transported through the groundwater to adjacent streams and ultimately to the Great Lakes, nitrate is not a parameter of concern with respect to Great Lakes quality.

The report also showed that agricultural activity could increase the phosphorus concentration in streams. The main loading, however, was in sediments from surface and bank erosion. Groundwater is not expected to play a significant role in the transport of phosphorus to the Great Lakes because of the geochemical characteristics of phosphorus.

(ii) Pesticides

Insecticides, fungicides and herbicides are used extensively in agricultural areas, and to some extent in forested areas. It is estimated that the agricultural use of herbicides, fungicides, and insecticides will increase at rates, respectively, of about 32.4%, 166.5% and 51.9% from 1971 to the year 2020 (International Joint Commission, 1977). In that the drinking water criteria for these materials are generally within the nanogram per liter to a few tens of micrograms per liter range, it is apparent that relatively small quantities have the potential to contaminate large volumes of water.

Water quality tests conducted by the Ontario Ministry of the Environment have shown isolated instances of domestic groundwater supplies being contaminated by pesticides. However, in all instances the contamination was traced to very local situations such as spills or washing of equipment. Their data, though not extensive, did not suggest widespread contamination of groundwater by pesticides. Similarly, though detailed surveys have not been conducted, data collected by the Ontario Ministry of Agriculture and Food suggest that in Ontario, there is no widespread contamination of groundwater by pesticides.

Due to the decreased persistence of the pesticides that are currently being used, existing evidence suggests that the migration of pesticides in groundwater from agricultural land will not pose a significant threat to the future quality of water in the Great Lakes although local problems may occur. This viewpoint, however, may be subject to change following the completion of more detailed surveys currently underway by the Ontario Ministry of the Environment..

(iii) Atmospheric Fallout

In industrialized areas, a wide range of chemicals can be distributed over a broad area as dry fallout or as dissolved constituents of rainwater. As reported in IJC (1978), the PCB concentration of precipitation in the six watersheds of southern Ontario that were studied ranged from <2 to 100 ng/L. It is reasonable to expect that many other organic compounds that are toxic in very low concentrations will also occur in precipitation. The biodegradability and the mobility of the halogenated hydrocarbons in geologic materials is highly variable. Conceivably, those that are not readily biodegradable and are relatively mobile, could be leached into the groundwater zone and then discharged at a later time to surface waters draining into the Great Lakes.

IJC (1978) identified the fallout of industrial organic contaminants as a serious threat to the water quality of the Great Lakes and recommended the continued monitoring and surveillance of these materials. This surveillance should include the groundwater pathway.

(iv) Acid Rain

Increasing industrialization, accompanied by an increase in the consumption of fossil fuels, has resulted in increased discharges of oxides of sulfur and nitrogen to the atmosphere. This has resulted in the gradual lowering of precipitation pH. Because of the buffering capacity of the carbonate minerals in soils of southern Ontario, acid rain should not have an effect on the groundwater quality of this region for the foreseeable future. However, the Canadian Shield area, which is largely devoid of carbonate rocks, is highly susceptible to the effects of acid rain.

In addition to the ecological consequences caused by lowering the pH of surface waters, many trace metals tend to be more mobile at lower pH values. It is suggested that over time the pH of groundwaters could decline, causing an increase in the concentrations of trace metals and thus a decreased quality of groundwater discharge.

Acid rain has become a major area of research in Ontario within the past five years. Although the effects on surface waters are becoming reasonably well documented, there is little reported information concerning the effects on groundwater as yet. There is some indication, however, (pers. comm. Dr. Laura Johnson, National Hydrology Research Institute, Environment Canada) that acid rain entering geological materials of the Canadian Shield is buffered to the natural pH of the soil. As a result, groundwater that is currently being discharged to surface waters tends to maintain the pH of the surface water somewhat higher than would be the case in the absence of the groundwater discharge. Over time, the acid neutralization capacity of the soils could be exhausted, in which case, the rate of decline in the pH of the surface water could accelerate. Conversely, data collected by the Ontario Ministry of the Environment suggests that acid rain is not having a noticeable effect on groundwater chemistry. The effect of acid rain on groundwater quality warrants further consideration as more data become available.

In that acid rain is recognized by both the Canadian and U.S. governments as a serious environmental problem, once cooperative efforts are initiated to investigate and resolve the problem, there is reason to expect that acid rain will not represent a long-term threat to Great Lakes quality.

6.2 POINT SOURCES

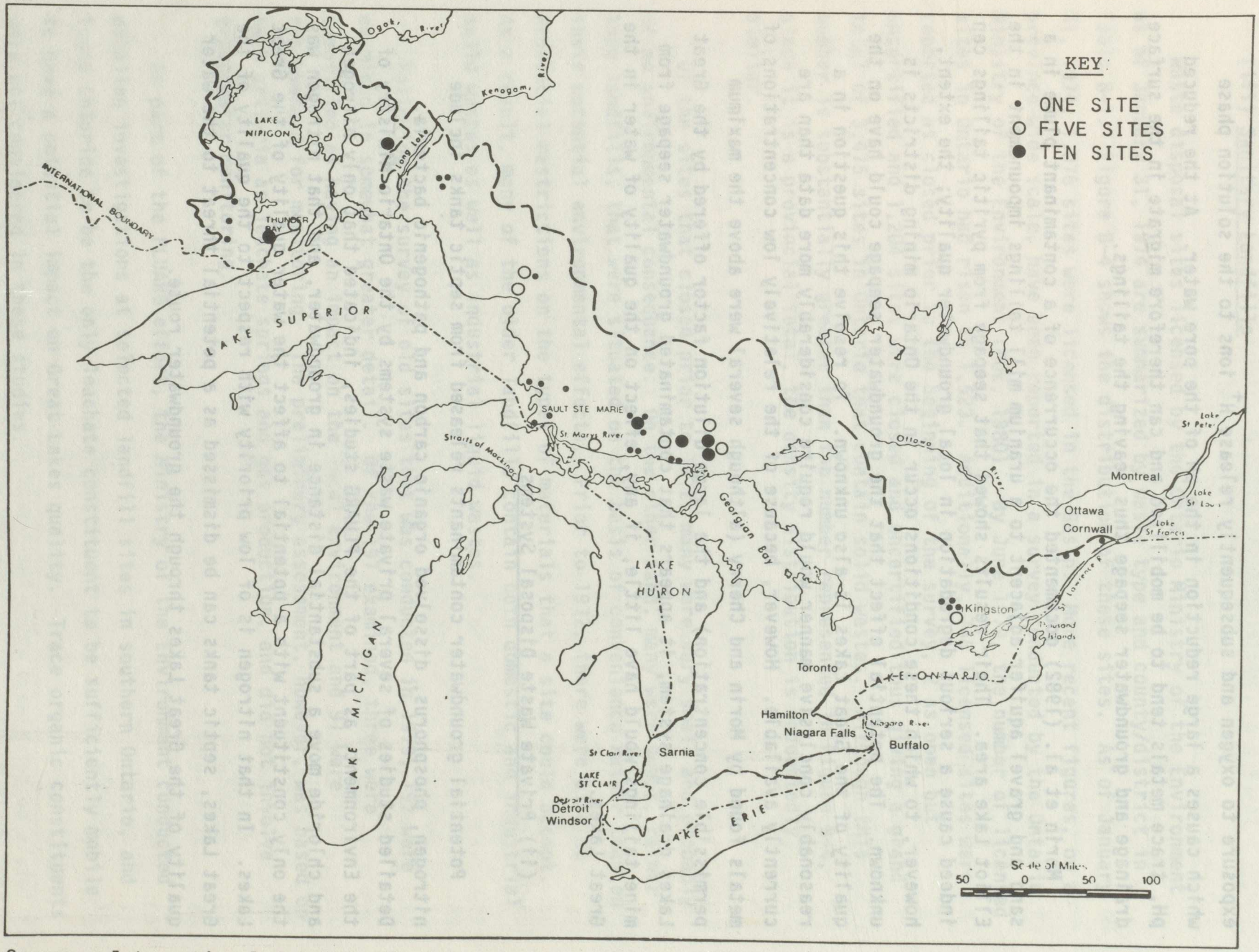
Unlike distributed sources of contamination, a point source would tend to contaminate a relatively small volume of groundwater; however, the concentrations of contaminants could be much higher than normally expected from a distributed source. The types of point sources are indeed varied. The most common include waste disposal sites such as private waste disposal systems (septic tanks), dumps, sanitary landfills, private industrial waste-disposal sites and waste lagoons. Others include accidental spills, leakage from storage containers, mine tailings, etc.

(i) Mine Tailings

As reported in IJC (1977), there were 149 mine tailings disposal sites in the Canadian Great Lakes Basin, 37 of which were active. No attempt was made to update these figures for the present report. The distribution of the tailings sites is given in Figure B-3. As indicated, the majority of sites is in Northern Ontario, with the greatest concentration of sites being in the Sudbury area.

As a result of the mining and refining processes, mine tailings are far from their natural conditions and are in chemical disequilibrium with their environment. Consequently, they tend to weather thereby giving rise to the possible release of toxic materials, mainly heavy metals. Since most ores of Northern Ontario are sulfide ores, the majority of the sulfide minerals (pyrite for example) that are being discharged into the tailings, oxidize on

FIGURE B-3. MINE TAILINGS DISPOSAL SITES IN THE CANADIAN GREAT LAKES BASIN.



Source: International Joint Commission. December 1977, p. 34.

exposure to oxygen and subsequently release H^+ ions to the solution phase which causes a large reduction in the pH of the pore water. At the reduced pH, trace metals tend to be mobilized and can therefore migrate in the surface drainage and groundwater seepage thus leaving the tailings.

Morin et al. (1982) documented the occurrence of a contaminant plume in a sand and gravel aquifer adjacent to a uranium mill tailings impoundment in the Elliot Lake area. Their results showed that seepage from pyritic tailings can indeed cause a serious degradation in local groundwater quality; the extent, however, to which these conditions occur in the Ontario mining districts is unknown. The potential effect that the groundwater seepage could have on the quality of the Great Lakes is also unknown. To resolve this question in a reasonably conclusive manner would require considerably more data than are currently available. However, because of the relatively low concentrations of metals found by Morin and Cherry (although several were above the maximum permissible concentration) and the large dilution factor offered by the Great Lakes drainage system, it appears that contaminated groundwater seepage from mine tailings would have little, if any, effect on the quality of water in the Great Lakes.

(ii) Private Waste Disposal Systems

Potential groundwater contaminants released from septic tanks include nitrogen, phosphorus, dissolved organic carbon and pathogenic bacteria. Detailed studies of several private waste systems by the Ontario Ministry of the Environment, as part of the PLUARG studies, indicated that only nitrogen and chloride move a substantial distance in groundwater, and that nitrogen was the only constituent with a potential to affect the water quality of the Great Lakes. In that nitrogen is of low priority with respect to the quality of the Great Lakes, septic tanks can be dismissed as a potential threat to the water quality of the Great Lakes through the groundwater route.

(iii) Sanitary Landfills

Waste disposal sites licensed by the Ontario Ministry of the Environment as of January 31, 1974 are summarized by waste type and county/district in Table B-1. Figure B-4 shows the distribution of these sites. As of January 31, 1974, 1,076 sites were licensed in the Basin. More recent figures, on a province-wide scale, have been reported in a survey conducted by the Ontario Ministry of the Environment (MOE, 1980). By June 1979, the number of licensed sites in Ontario had risen to 1,523. Additionally, 746 licensed sites were reported as closed prior to the beginning of the survey, 2 as open but uncertified and 1,204 sites were closed and uncertified thus giving a grand total of 3,475 sites in Ontario that contain solid wastes. Although this number is substantially greater than the number represented in Figure B-4, since it is a provincial total, the density distribution is undoubtedly similar.

Of the sites that closed prior to 1972, many were very small and probably of no environmental consequence. On the other hand, many were dumps, rather than landfills, that were situated on the basis of convenience rather than on their potential environmental effects. Prior to 1972, there were also no Provincial restrictions on the types of materials that a site could accept. As a result, many of the older landfills contain both domestic and industrial solid wastes as well as industrial liquid wastes.

Following the survey of old sites that was conducted in 1979, 197 were examined in somewhat greater detail. Of the 197 examined, three were identified as having an impact on the local environment and 91 were recommended for monitoring. The preliminary assessment, however, was based on such criteria as leachate springs and gas production, and did not involve groundwater monitoring.

As part of the PLUARG effort, the Ministry of the Environment conducted detailed investigations at selected landfill sites in southern Ontario, and found chloride to be the only leachate constituent to be sufficiently mobile to have a potential impact on Great Lakes quality. Trace organic constituents were not considered in these studies.

TABLE B-4. WASTE DISPOSAL SITES BY COUNTY/DISTRICT WITHIN THE CANADIAN GREAT LAKES BASIN (As of January 31, 1974)

County/District		Waste Disposal Site Type				
No.	Name	Unknown	Solid	Liquid	Hazardous	Totals*
1.	Algoma	–	35	–	–	35
2.	Brant	–	7	3	1	7
3.	Bruce	6	31	1	1	37
4.	Dufferin	–	12	–	–	12
5.	Elgin	3	7	1	–	10
6.	Essex	1	7	4	–	9
7.	Frontenac	3	20	1	–	24
8.	Grey	7	23	–	–	30
9.	Haldimand Norfolk	4	28	1	–	32
10.	Haliburton	–	37	–	–	37
11.	Halton	–	15	3	2	17
12.	Hastings	4	39	2	–	44
13.	Huron	2	23	3	1	25
14.	Kent	3	19	2	–	22
15.	Lambton	2	26	5	2	31
16.	Leeds & Grenville	2	10	–	–	12
17.	Lennox & Addington	3	19	1	–	23
18.	Niagara	2	22	2	1	26
19.	Manitonlin	–	19	8	–	19
20.	Middlesex	5	22	1	–	27
21.	Muskoka	1	47	1	–	48
22.	Nipissing	–	29	1	–	29
23-24.	Northuberland and Durham	4	43	10	–	53
25.	Oxford	1	15	–	–	16
26.	Parry Sound	3	67	–	–	70
27.	Peel	–	7	2	3	11
28.	Perth	–	15	1	–	15
29.	Peterborough	3	38	1	–	42
30.	Prince Edward	–	13	2	–	15
31.	Simcoe	1	36	–	–	37
32-33.	Sudbury	4	74	5	–	78
34.	Thunder Bay	1	80	2	1	81
35.	Timiskaming	–	–	–	–	–
36.	Victoria	7	18	1	1	25
37.	Waterloo	–	12	3	–	12
38.	Wellington	–	15	1	–	15
39.	Wentworth	–	11	–	–	11
40.	York	–	11	2	–	11
41.	Toronto	1	2	–	–	3
42.	Ontario	3	20	2	–	25**
		76	974	72	13	1076**

* Totals do not always equal the sum of the various waste disposal site types. Some waste disposal sites received more than one waste type.

**Total number of sites was initially reported incorrectly by 20 sites and subsequently revised in January 1984.

Source - International Reference Group on Great Lakes Pollution from Land Use Activities, December 1977: Inventory of Land Use and Land Use Practices in the Canadian Great Lakes Basin, International Joint Commission, Windsor.

a) Volume II - Canadian Lake Superior Basin
b) Volume III - Canadian Lake Huron Basin
c) Volume IV - Canadian Lake Erie Basin
d) Volume V - Canadian Lake Ontario Basin

More recently, and with the growing awareness of the potential environmental risk posed by the industrial organic compounds, the University of Waterloo undertook detailed groundwater monitoring at two sanitary landfills in southern Ontario. Both sites were in operation prior to 1972 and probably accepted liquid industrial wastes prior to that time. These sites are situated in sandy geological materials. Chloride was found to be the only inorganic leachate consitutent to move a significant distance from the landfills; however, halogenated hydrocarbons, well in excess of drinking water limits, were detected in groundwaters at appreciable distances from the disposal sites (Reinhard et al., 1984).

The two sites referred to above, were selected for study because they were situated in granular geologic materials and not because of their history of having received liquid industrial wastes. There is good reason to suspect that many landfills that were in operation prior to 1972 in industrialized portions of the Canadian Great Lakes Basin, and that are situated in permeable geologic materials, will have plumes of organic-contaminated groundwater associated with them. Current investigations by the Ministry of the Environment on a landfill site in Tiny Township, indicate the presence of elevated concentrations of chlorinated hydrocarbons in groundwater associated with the site. This provides further support for the above claim.

There are insufficient data to evaluate the potential effect of these sites on the water quality of the Great Lakes. Further monitoring at other landfill sites that have accepted industrial liquid wastes should be undertaken.

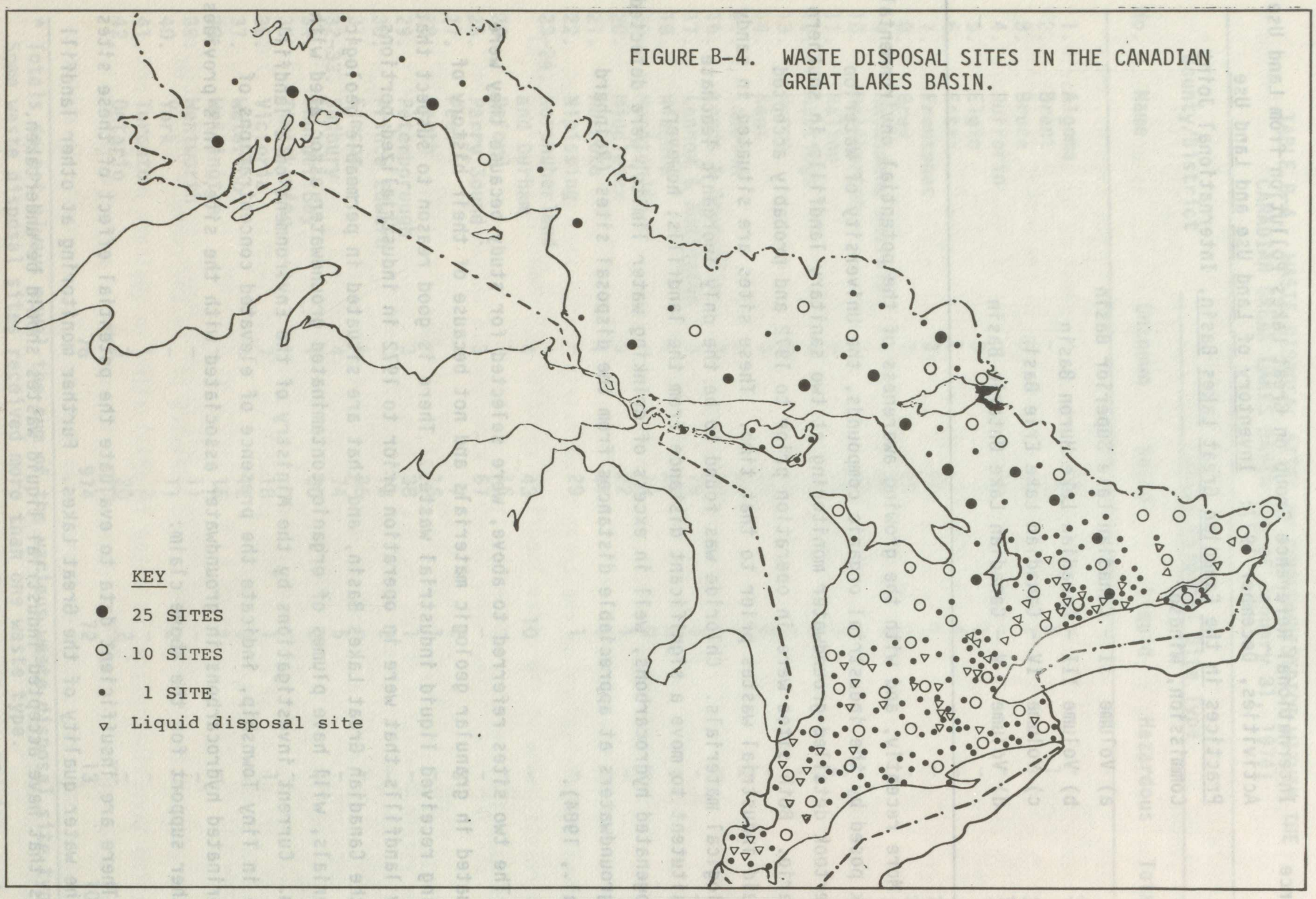


FIGURE B-4. WASTE DISPOSAL SITES IN THE CANADIAN GREAT LAKES BASIN.

Source: International Joint Commission. December 1977, p. 35.

(iv) Liquid Industrial Wastes

As noted above, liquid industrial wastes could be accepted by landfills up to 1972 and it is quite likely that a substantial proportion of the liquid wastes were disposed of in this manner. Following 1972, selected sites were licensed to accept liquid wastes. In particular, as given in IJC (1977), in 1975, 72 sites were licensed to receive liquid wastes, and 13 were licensed for hazardous wastes. Presently there are six sites licensed to accept liquid industrial wastes in the Province; however, none of these can accept hazardous wastes. The subsurface disposal of hazardous liquid wastes is no longer an acceptable and licensed procedure in Ontario although the practice was continued on a limited scale as recently as 1982.

In addition to hazardous wastes that have been put into sanitary landfills, or more recently into licensed hazardous waste sites, it is quite likely that significant volumes of hazardous wastes have been disposed of by industries on industry-owned land. This practice was legal prior to 1972, after which time it required licensing, and currently is not an accepted practice. As a supplement to the 1979 survey of disposal sites referred to above, MOE personnel compiled a list of privately-owned chemical disposal facilities. The results of the compilation are given in MOE (1981). Sixty-five sites were identified, although this is probably an underestimate of the actual numbers found in Ontario, of which 11 had an impact on the environment and 27 were recommended for further study. Those sites that were considered to be potential problems are currently under investigation.

There are at least two well-publicized occurrences which indicate a need for continued vigilence on the Canadian side of the Basin. One site (Toronto Globe and Mail, Sepember 20, 1983) located in Elmira, Ontario near the Conestoga River, a sub-basin of the Grand River watershed, concerns the sub-surface disposal on company property of large volumes of liquid wastes generated during the production of agricultural chemicals and defoliants. These wastes are reported to contain a variety of halogenated hydrocarbons including dioxin. In the absence of effective remedial action, it appears inevitable that some portion of the wastes will reach the adjacent surface waters and will ultimately be discharged to the Great Lakes. This site is presently under investigation by the Ministry of the Environment.

A second potentially troublesome area occurs near Sarnia in Lambton County, as a result of deepwell injection of liquid industrial wastes. There were approximately 19 wells used in the county for this purpose, with the greatest concentration of wells (9) occurring south of Sarnia, near the St. Clair River. It is acknowledged that large volumes of wastes were injected and in many cases contained hazardous constituents. Initially, wastes were injected under pressure into a fractured dolomite formation (the Detroit River formation) situated at a depth of approximately 183 to 213 meters (600 to 700 feet) below ground surface. To avoid fracturing of the overlying confining beds, injection under pressure was ceased in 1972. A hydrogeologic investigation of the region by Environment Canada revealed high chloride concentrations in some wells at shallow depths (Vandenberg et al. 1977). The previous disposal practices were cited as a possible cause of the anomalies. Further investigations of the anomalies are underway.

Although it is well documented that many trace organics are relatively mobile in groundwaters, it is currently difficult to evaluate the potential effects of the groundwater pathway on the quality of the Great Lakes. However, because of the smaller population in the Canadian Basin and the lower degree of industrialization, the magnitude of the problem will not be as great as on the U.S. side. It must nevertheless be acknowledged that large volumes of liquid industrial wastes have been disposed of at either controlled or uncontrolled sites while the fate of these materials are largely unknown. Increased monitoring will be required in order to evaluate the potential effects on Great Lakes quality.

(v) Storage Tanks and Manufacturing Facilities

In populated and industrialized areas, there are numerous storage tanks and manufacturing facilities that contain highly toxic substances. Organic solvents are a common industrial example. There are also numerous documented cases of local groundwater contamination as a result of leakage from these facilities; however, no serious consideration has been given to the potential effect of these occurrences on Great Lakes quality.

At least one hydrogeologic consultant with considerable experience in southern Ontario is of the opinion that leaks and spills at manufacturing sites may pose a more serious threat to the groundwater environment.

In that hydrogeologic conditions are seldom if ever a factor in the siting of storage tanks, it is reasonable to expect that many are located in conditions that would allow for the rapid migration of the discharged fluids into groundwater.

In light of their number and the high toxicity of several of the constituents, gasoline storage tanks should be viewed as a serious threat to local groundwater quality and possibly to the quality of the Great Lakes. Three of the important toxic constituents of gasoline include benzene, toluene and xylene (BTX). Benzene, because of its high solubility in water and high toxicity, probably has the greatest potential for widespread groundwater contamination.

7. LEGISLATIVE CONTROLS

The first legislatave controls on waste disposal in Ontario were introduced by the Waste Management Act of 1970. This Act has been revised on several occasions as technology advanced or as the need arose, resulting in reasonably comprehensive controls on waste disposal. More recently, the Ministry of the Environment introduced the "Blueprint for Waste Management in Ontario" (June, 1983). This document expresses a strong commitment on the part of the government to recycling, reusing and reprocessing waste materials and proposes increasingly stringent controls on waste disposal. Of particular importance, provision is made for bringing selected private waste disposal sites under legislative control; a condition that is absent in the existing legislation. Though currently a document for discussion, implementation of the "Blueprint" should substantially reduce the volume of wastes for disposal, and provide the necessary legal framework to ensure that wastes are managed in an environmentally sound manner. However, a serious shortcoming of the "Blueprint" may be its failure to provide cost sharing and therefore stimulate capital work projects dealing with alternate waste management systems (The Windsor Star, October 6, 1983).

Though the legal framework may be put into place, not withstanding the strong commitment expressed in the "Blueprint," the extent to which it can be enforced remains a serious question. In particular, the identification and control of small discharges and spills on private property will continue to be a difficult task.

8. CONCLUDING REMARKS

Toxic organics appear to have the greatest potential to adversely affect the water quality of the Great Lakes because of their high toxicity, and in many cases high mobility in hydrogeologic environments. Only recently have organics been recognized as a serious threat to the environment. Considerable research is required on the migration characteristics of these materials in hydrogeologic regimes.

Distributed sources of inorganic contamination in the Canadian Great Lakes Basin, such as agricultural fertilizers and acid rain, warrant continued surveillance but appear to have little potential to adversely affect the quality of the Great Lakes. There is also no evidence to suggest that organic herbicides and pesticides used in agriculture or the forestry industry are causing widespread contamination of groundwater in the Basin. Investigations on long-term effects of fallout of industrial organics also do not exist. Further monitoring of both potential sources of contamination is warranted.

Since most heavy metals and other potential inorganic contaminants are relatively immobile in groundwaters, it appears unlikely that the migration of these materials through groundwater from landfills, mine tailings or other point sources will adversely affect the water quality of the Great Lakes. However, there are sufficient waste disposal sites with acknowledged zones of groundwater contamination by trace organics to suggest that disposal sites within the Basin could have a potentially significant effect on Great Lakes quality. Although a very small proportion of the landfills in Ontario have been identified as having adverse effects on the environment, this evaluation has generally been made with little knowledge and/or monitoring of the groundwater conditions, and in most cases, with no consideration of trace organics. Further monitoring of disposal sites should be undertaken in order to evaluate the discharge of toxic organic constituents to the local groundwater and their potential effects on Great Lakes quality.

Increased efforts should be directed at identifying private disposal sites that have accepted liquid industrial wastes and where warranted, groundwater investigations should be initiated.

Industries that produce or use significant quantities of halogenated hydrocarbons or petroleum products should be identified and the potential for spills, leaks or other accidental releases should be evaluated. Where warranted, groundwater investigations should be undertaken. Previous plant sites as well as operating sites should be considered.

Finally, investigations of groundwater quality in the Canadian Basin have generally been undertaken within the context of the local environment and local water supplies. The direct application of the results of these studies to the potential effects on Great Lakes quality has seldom been considered. Site-specific studies, or regional studies designed within the context of Great Lakes quality may be required in order to quantify the potential effects of groundwater contamination on the Great Lakes.

REFERENCES

Brown, I. C. [ed.] 1967. Groundwater in Canada. Geol. Surv. Can., Econ. Geol. Dept. No. 24.

Chapman and Putnam. 1966. The Physiography of Southern Ontario. 2nd ed. University of Toronto Press.

Desaulnier, D. E., J. A. Cherry, and P. Fritz. 1981. Origin, age and movement of pore water in argillaceous Quaternary deposits at four sites in Southwestern Ontario. Journal of Hydrology 50:231-257.

Haefeli, C. J. 1972. Groundwater inflow into Lake Ontario from the Canadian side. Inland Waters Branch, Canadian Department of the Environment, Scientific Series No. 9.

International Joint Commission. 1978. Agricultural Watershed Studies in the Canadian Great Lakes Basin. Final Summary Report. Report of the International Reference Group on Great Lakes Pollution from Land Use Activities.

International Joint Commission. 1977. Inventory of Land Use and Land Use Practices, Volume I, Canadian Great Lakes Basin Summary. Report of the International Reference Group on Great Lakes Pollution from Land Use Activities.

Morin, K., J. A. Cherry, T. P. Lim, and A. Vivyurka. 1982. Contaminant migration in a sand aquifer near an inactive uranium tailings impoundment, Elliot Lake, Ontario. Canadian Geotechnical Journal 19:49-62.

Ontario Ministry of the Environment. 1980. Site Inventory Study.

Ontario Ministry of the Environment. 1981. Industrial Waste Site Identification Study, Preliminary Field Investigations.

Ostry, R.C. 1979. The Hydrogeology of the IFYGL Forty-Mile and Oakville Creeks Study Areas. Ontario Ministry of the Environment, Water Resources Report 5b.

Reinhard, M., N. L. Goodwin, and J. F. Barker. 1984. Occurrence and distribution of organic chemicals in two landfill leachate plumes. Environ. Sci. and Tech. 18:953-961.

Vandenberg, A., D. W. Lawson, J. E. Charrin, and B. Novakovic. 1977. Subsurface waste disposal in Lambton County, Ontario. Inland Waters Directorate, Water Resources Branch, Fisheries and Environment Canada, Technical Bulletin No. 90.

Witherspoon, D. F. 1979. Hydrology of Lake Ontario. p. 276-279. In Proceedings of the IFYGL Symposium, March 1979. National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Ann Arbor, Michigan 48104.

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