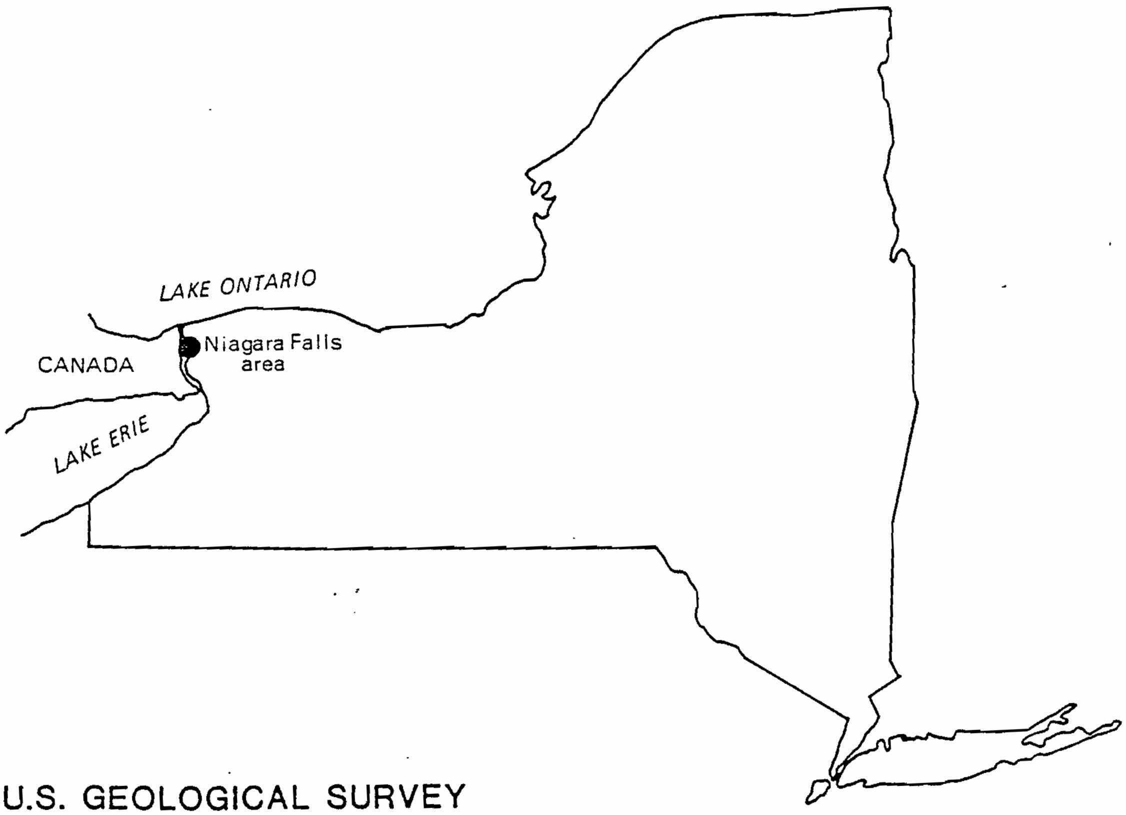
Effect of Niagara Power Project on Ground-Water Flow in the Upper Part of the Lockport Dolomite Niagara Falls Area, New York



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
Report 86-4130

Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY
NEW YORK STATE DEPARTMENT OF
ENVIRONMENTAL CONSERVATION

EFFECT OF NIAGARA POWER PROJECT ON GROUND-WATER FLOW IN THE UPPER PART OF THE LOCKPORT DOLOMITE, NIAGARA FALLS AREA, NEW YORK

By Todd S. Miller and William M. Kappel

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Ithaca, New York

1987

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by the following factors:

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	Volume	
acre-feet	1,233	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3.785	cubic meter (m^3)
	Flow	
million gallons per day (Mgal/d)	3785	cubic meters per day (m^3/d)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.01093	cubic meter per second (m^3/s)
	Mass	
pound (lb)	453.6	grams (g)
ton	907.2	kilograms (kg)
	Slope	
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Other Units	
	kilowatt (kw)	

Effect of Niagara Power Project on Ground Water Flow in the Upper Part of the Lockport Dolomite, Niagara Falls Area, New York

By Todd S. Miller and William M. Kappel

ABSTRACT

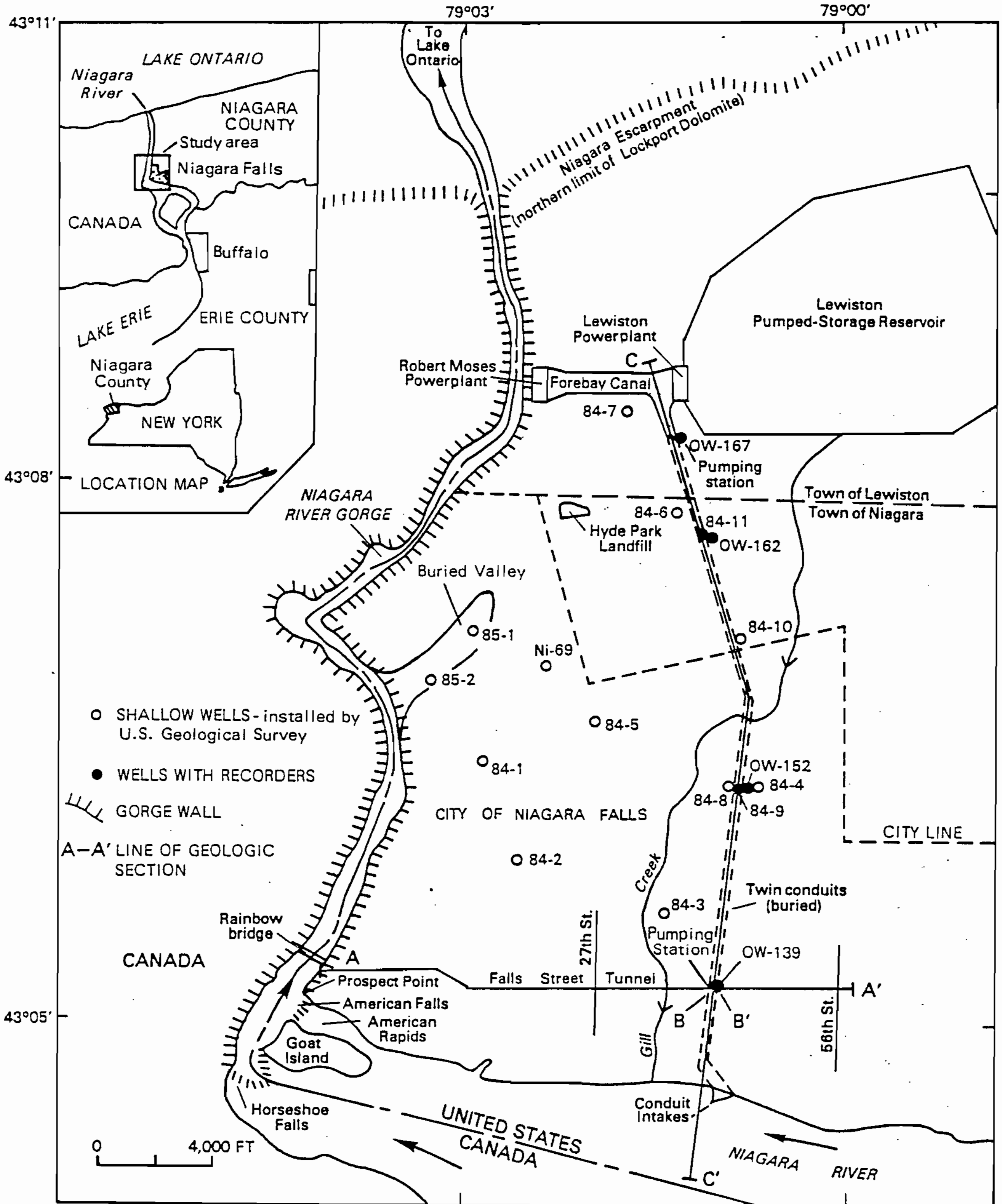
The Niagara River Power Project near Niagara Falls, N.Y., has created recharge and discharge areas that have modified the direction of ground-water flow east and northeast of the falls. Before construction of the power project in 1962, the configuration of the potentiometric surface in the upper part of the Silurian Lockport Dolomite generally paralleled the buried upper surface of the bedrock. Ground water in the central and east parts of the city of Niagara Falls flowed south and southwestward toward the upper Niagara River (above the falls), and ground water in the western part flowed westward into the Niagara River gorge.

The power project consists of two hydroelectric powerplants separated by a forebay canal that receives water from the upper Niagara River through two 4-mile-long, parallel, buried conduits. During periods of nonpeak power demand, some water in the forebay canal is pumped to a storage reservoir for later release to generate electricity during peak-demand periods.

Since the power project began operation in 1962, ground water within 0.5 mile of the buried conduits has seeped into the drain system that surrounds the conduits, then flows both south from the forebay canal and north from the Niagara River toward the Falls Street tunnel--a former sewer that crosses the conduits 0.65 mile north of the upper Niagara River. Approximately 6 million gallons of ground water a day leaks into the Falls Street tunnel, which carries it 2.3 miles westward to the Niagara River gorge below the falls.

Daily water-level fluctuations in the forebay canal affect water levels in the drain system that surrounds the conduits, and this, in turn, affects the potentiometric surface in the Lockport Dolomite within 0.5 mile of the conduits. The resulting water-level fluctuations in the drains and Lockport Dolomite diminish with distance from the forebay canal. The drains transmit changes in pressure head near the forebay canal southward at least as far as the Falls Street tunnel area and possibly to the upper Niagara River. High water levels in the forebay canal decrease the gradient of the potentiometric surface toward the conduit drains, and low water levels in the forebay canal increase the gradient.

Some water in the pumped-storage reservoir recharges ground water in the Lockport Dolomite by seepage through bedding joints, which are exposed in the unlined reservoir bottom, and through the grout curtain beneath the reservoir's dike. Water-level fluctuations in the reservoir cause slight ground-water fluctuations near the reservoir.



Base from U.S. Geological Survey
Lewiston, 1965, and Niagara Falls, 1965, 1:24,000

Figure 1.--Major features of Niagara Power Project and location of wells installed or monitored by the U.S. Geological Survey during 1984-85.

INTRODUCTION

The Niagara Falls area has many industrial and chemical-processing plants because electric power there is relatively inexpensive and because water for industrial processing is readily available. The Niagara Falls area contains 31 hazardous-waste-disposal sites that have significant potential for ground-water contamination (Koszalka and others, 1985). The possibility of chemical migration from these sites to the ground water in the underlying Lockport Dolomite and from there to the Niagara River, which provides fishing and other recreation below the falls and a public water supply above the falls, has created a need for information on ground-water recharge, discharge, direction of flow, and any effects the Niagara Power Project may have on the ground-water flow system.

The Niagara Power Project (fig. 1) was built in 1962 by the Power Authority of the State of New York, now called the New York Power Authority (NYPA), and is one of the largest hydroelectric facilities in the United States. Major components of the facility are the twin buried conduits, the forebay canal, the Lewiston and Robert Moses powerplants, and the Lewiston pumped-storage reservoir (fig. 1).

The two buried conduits are 4 mi long and constructed of concrete in trenches excavated 100 to 160 ft deep in the Silurian Lockport Dolomite. The conduits divert between 50,000 and 75,000 ft^3/s of water from the upper Niagara River north to the forebay canal, a 4,000-ft-long basin between the Lewiston and Robert Moses powerplants (fig. 1). The pumped-storage reservoir stores surplus water pumped from the forebay canal during periods of low power demand (usually at night) and releases it to generate electricity during periods of high power demand (during the day) through the Lewiston powerplant back into the forebay canal. Water from the forebay canal eventually flows through the Robert Moses powerplant and is discharged into the Niagara River gorge about 5 mi below Niagara Falls. Surrounding each conduit is a drain system designed to reduce hydrostatic pressure on the outer conduit walls should the interior of the conduits need to be drained. Two pumping stations--one just south of the forebay canal and the other at Royal Avenue, 0.65 mi north of the upper Niagara River--are the only locations at which water in the drain system can be removed.

The Falls Street tunnel crosses the twin buried conduits 0.65 mi north of the upper Niagara River. This unlined tunnel, excavated in the early 1900's, extends east-west 3.3 mi from 56th Street to the Niagara River gorge and was designed to carry sewage from the southern part of the city to a treatment plant below the Falls. A new interceptor sewer now carries the sewage, but the Falls Street tunnel still carries storm-water runoff to the Niagara gorge.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation, studied the hydrogeology of the Niagara Falls area during 1984-85. The purpose of the study was to define the effects of the Niagara Power Project on ground-water flow and to refine and extend knowledge of ground-water movement in the upper part of the Lockport Dolomite in the central part of Niagara Falls. The study addressed mainly the upper 10 to 25 ft of the Lockport Dolomite, which is the most weathered and permeable zone and therefore the most vulnerable to contamination from surface sources. This information provides a basis for the development of plans for remedial action at toxic-waste sites in the Niagara Falls area.

This report describes the geohydrology of the upper part of the Lockport Dolomite and the effect of power-project facilities and other alterations of the natural flow system in the Niagara Falls area. Plate 1 depicts the bedrock-surface altitude and the potentiometric-surface altitude in the upper part of the Lockport Dolomite; other maps herein show the direction of ground-water flow before and after construction of the Niagara Power Project in the Niagara Falls area. Also included are hydrographs showing the effects of water-level fluctuations in the forebay canal on water levels adjacent to the buried conduits, and vertical sections showing geologic units and construction details of the buried conduits.

Approach

The study was done in several stages:

1) Eleven observation wells were installed in the central part of the study area where no data were available to define ground-water levels and movement.

2) Four test wells were installed in the backfill above the buried conduits to identify the backfill material and obtain water-level measurements to determine whether the backfill is a discharge area and significant pathway for ground-water (and contaminant) movement. Geophysical surveys were used to locate the buried bedrock trenches that contain the conduits.

3) Water-level measurements were made in 104 wells on October 23 and 24, 1984, a period of low water levels, and on March 26 and 27, 1985, a period of high water levels, to delineate the directions of regional ground-water movement.

4) Water-level recorders were installed at six wells near the buried conduits to determine effects of water-level fluctuations in the forebay canal and pumped-storage reservoir on water levels in the upper part of the Lockport Dolomite in that area.

5) Seismic surveys were used to delineate a buried valley in the northwestern part of the study area (fig. 1).

Previous Investigations

Johnston (1964) described the hydrologic conditions of the Niagara Falls area with emphasis on water-bearing characteristics of the Lockport Dolomite. Maslia and Johnston (1982) developed a two-dimensional cross-sectional ground-water model of the Hyde Park landfill area in the northern part of the study area (fig. 1). Koszalka, Paschal, Miller, and Duran (1985) summarized results of studies by the New York State Department of Environmental Conservation, private consultants, and by the U.S. Geological Survey to describe ground-water conditions at many waste-disposal sites in the Niagara Falls area.

Acknowledgments

The New York Power Authority provided construction details of the power-project facilities, water-level data from the forebay canal and pumped-storage reservoir, and assistance in measuring water levels in NYPA wells in the vicinity of the pumped-storage reservoir. The New York State Department of Environmental Conservation coordinated the water-level measurements at industrial sites. Several industries, including Occidental Petroleum and E.I. Dupont De Nemours and Company, provided water-level data. The City of Niagara Falls provided construction details on many sewer and building projects and assisted in obtaining permits and permission to drill observation wells within the city.

GEOHYDROLOGY OF THE LOCKPORT DOLOMITE

Stratigraphy and Lithology

Unconsolidated glacial deposits of till and lacustrine silt and clay, generally 5 to 15 ft thick but ranging to 48 ft thick, overlie the 80- to 158-ft-thick Lockport Dolomite of Middle Silurian age within the Niagara Falls area (Tesmer, 1981). The thickest unconsolidated deposits (up to 48 ft) are in a shallow buried valley in the western part of the city (pl. 1B).

Underlying the Lockport Dolomite is a 87-ft-thick sequence of Middle Silurian shale, limestone, and dolomite in the lower part of the Clinton Group, which is underlain by a 113-ft-thick sequence of Lower Silurian sandstone and shale that is in turn underlain by 1,200-ft-thick Upper Ordovician shale. These rocks are exposed only in the Niagara River gorge and are shown in the stratigraphic column in figure 2. The strata are gently folded and dip slightly to the south-southwest at about 30 ft/mi (Fisher and Brett, 1981).

The Lockport Dolomite is a fine to coarse crystalline, thin to massive bedded dolomite, limestone, and shaly dolomite, with vugs containing gypsum (calcium sulfate) and calcite (calcium carbonate). Other minor minerals disseminated throughout the formation are sphalerite (zinc sulfide), pyrite (iron sulfide), and galena (lead sulfide) (Tesmer, 1981).

Hydraulic Conductivity

The Lockport can be divided into two zones on the basis of water-transmitting properties. The upper 10 to 25 ft of rock is a moderately permeable zone that contains relatively abundant bedding planes and vertical joints enlarged by dissolution of dolomite and abundant solution cavities left by dissolution of gypsum; the remainder of the formation contains low to moderately permeable bedding planes of which as many as seven may be major water-bearing zones that are surrounded by fine-grained crystalline dolomite of low permeability. Hydraulic-conductivity values obtained from model simulations and limited aquifer-test data (Maslia and Johnston, 1982) range from 5 to 15 ft/d in the upper part and from 1 to 2 ft/d in the lower part. Well yields commonly range from 10 to 100 gal/min.

System and series		Group	Formation	Thickness (feet)	Description
Silurian	Middle	Lockport	Lockport Dolomite	158	Dark-gray to brown, massive to thin-bedded dolomite locally containing algal reefs and small, irregularly shaped masses of gypsum. Near the base are light-gray coarse-grained limestone (Gasport Limestone Member, dark-gray shaley dolomite)
		Clinton	Rochester Shale	60	Dark-gray calcareous shale weathering light-gray to olive.
			Irondequoit Limestone	12	Light-gray to pinkish-white coarse-grained limestone.
			Reynales Limestone	10	White to yellowish-gray shaly limestone and dolomite.
			Neahga Shale	5	Greenish-gray soft fissile shale.
	Lower	Medina	Thorold Sandstone	8	Greenish-gray shaly sandstone.
			Grimsby Sandstone	45	Reddish-brown to greenish-gray cross-bedded sandstone interbedded with red to greenish-gray shale.
			Power Glen Shale	40	Gray to greenish-gray shale interbedded with light-gray sandstone.
			Whirlpool Sandstone	20	White, quartzitic sandstone
Ordovician	Upper	Richmond	Queenston Shale	1,200	Brick-red sandy to argillaceous shale.

Figure 2.--Stratigraphy of the Niagara Falls area. (Modified from Fisher, 1959.)

Ground Water

Occurrence

The Lockport Dolomite is the principal source of ground water in the Niagara Falls area. Although the effective primary porosity is negligible, significant ground-water movement occurs through secondary openings such as bedding joints (planes), vertical joints (fractures), and solution cavities, described below. The upper 25 ft of the Lockport has a greater potential for movement of ground water (and contaminants) than the deeper parts because it has more interconnected vertical and horizontal joints that have been widened by solutioning, which allows direct entry of contaminants from surface sources.

Bedding planes.--The bedding planes, which transmit most of the water in the Lockport (Johnston, 1964), are relatively continuous fracture planes parallel to the natural layering of the rock. These openings were caused by crustal movements and the expansion of the rock during removal of weight by erosion of overlying rock units and by retreat of the glaciers. Johnston (1964) identified seven water-bearing zones, which consist either of a single open-bedding plane or an interval of rock layers containing several open planes. The top 10 to 25 ft of rock may contain one or two significant bedding planes; these are probably connected by vertical joints, which are abundant in the upper part of the formation.

The lower part of the Lockport Dolomite contains fewer water-bearing bedding planes that are interconnected by vertical joints. These deeper water-bearing zones are underlain and overlain by essentially impermeable rock. Each water-bearing bedding plane can be considered a separate and distinct artesian aquifer (Johnston, 1964). The hydraulic head within each water-bearing zone is lower than that in the zone above it; this indicates a downward component of ground-water flow.

Vertical joints.--Vertical joints in the Lockport Dolomite are not significant water-bearing openings except (1) in the upper 10 to 25 ft of rock, (2) within about 200 ft of the Niagara River Gorge, and (3) in the vicinity of the buried conduits. Physical and chemical weathering have increased the number, continuity, and size of vertical fractures in the upper part of the Lockport. The major joints, oriented N 70°E to N 80°E, are generally straight, spaced 10 to 80 ft apart, and penetrate 10 to 25 ft (American Falls International Board, 1974). Intersecting the major joint set are less extensive high-angle joints that are confined to particular beds. Vertical joints become narrower, less numerous, and less connected with depth.

In addition to the major regional fractures, extensive tension-release fractures were formed near the gorge wall by the erosion and removal of the supporting rock mass in the gorge; openings up to 0.3 ft wide have been observed (American Falls International Board, 1974). Less developed tension-release joints and blasting-originated joints are common along the twin conduits. These fractures probably extend less than 100 ft from the trench walls.

Solution cavities.--Solution cavities are formed by the dissolution of gypsum pockets and stringers by percolating ground water. These cavities range in diameter from 1/16 in to 5 in; they are most abundant in the upper 10 to 15 ft of rock but occur also along water-bearing bedding zones throughout the Lockport. The solution cavities become less continuous with depth and therefore have little effect on the water-transmitting ability of the lower parts of the formation.

Recharge

Most of the recharge to the Lockport Dolomite results from infiltration of rainfall and snowmelt through the soil to the water table. Precipitation in the Niagara Falls area averages 30 in/yr and is fairly evenly distributed throughout the year (Dethier, 1966). Snow usually accumulates from mid-December to mid-March, during which time several thaws may reduce or entirely melt the snow pack. Seven 14-month hydrographs of U.S. Geological Survey wells installed in the upper part of the Lockport (fig. 3) and a 10-year hydrograph of a long-term observation well, Ni-69 (fig. 4) indicate that most recharge occurs from late fall through winter (November to April), when evapotranspiration is low. Generally, water levels fluctuate less than 6 ft annually.

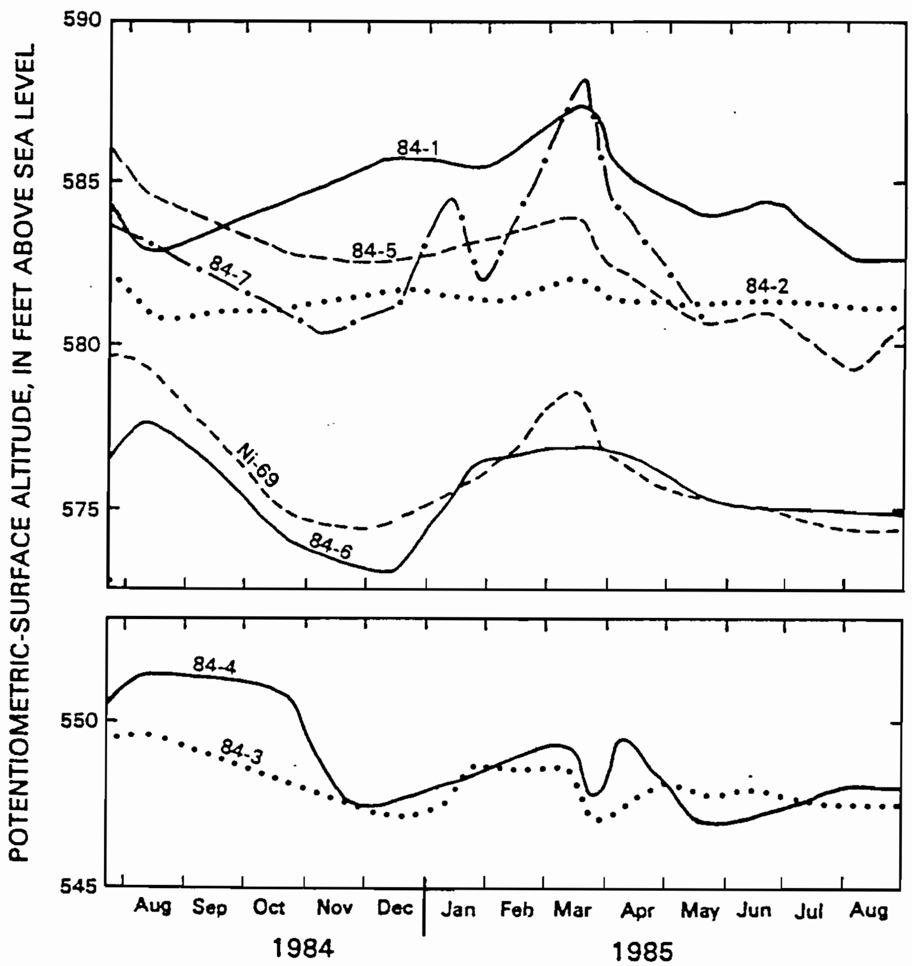


Figure 3.--Hydrographs of wells 84-1 through 84-7 in and near the City of Niagara Falls.

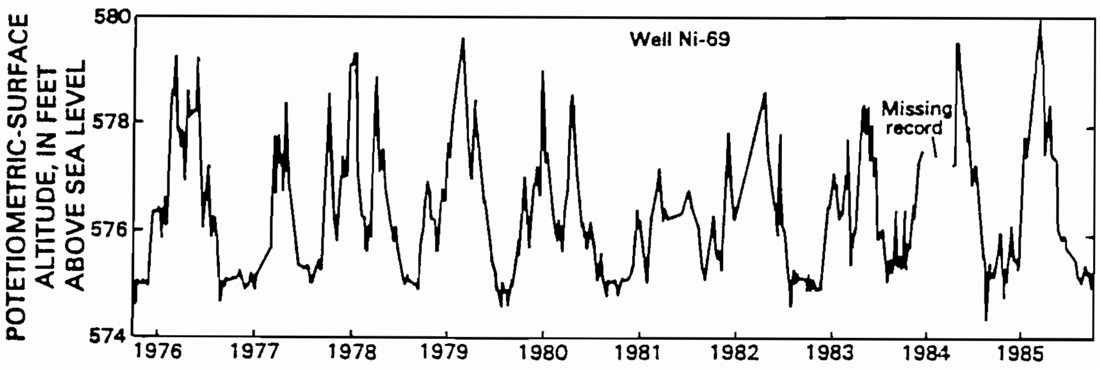


Figure 4.--Hydrograph of well Ni-69 in northern part of the city of Niagara Falls.

The rate and amount of recharge to a formation from precipitation depends on the permeability of the overlying lacustrine fine sand, silt, clay, and till, which in the Niagara Falls area is relatively low, with hydraulic conductivity ranging from 0.0014 to 0.27 ft/d. The average annual recharge from precipitation is estimated to be 5 to 6 in/yr (LaSala, 1967) but is probably greater in several small areas where the Lockport, whose hydraulic conductivity ranges from 5 to 15 ft/d, crops out at land surface.

Movement and Discharge

Before construction of Niagara Power project and Falls Street tunnel.--Little information is available on ground-water levels in the Niagara Falls area before 1960; therefore, interpretation of ground-water movement in the upper part of the Lockport Dolomite before that time is based largely on fundamental assumptions governing ground-water flow. These assumptions are that (1) ground-water divides coincide with topographic highs; thus the major divides in the region were at the Niagara Escarpment, north of the study area (fig. 1), and in the central part of the City of Niagara Falls (pl. 1A); (2) regional flow of ground water followed the south-southwestward slope of the land surface and the southwestward dip of major bedding planes, (3) local ground-water movement followed the configuration of the buried bedrock surface; and (4) ground water in the central and southern parts of the city discharged to the upper Niagara River, while water in the western part discharged to the lower Niagara River in the gorge. The general inferred directions of ground-water movement in the upper part of the Lockport Dolomite before any major construction or industrial pumping is shown in figure 5.

Effect of Falls Street tunnel.--In the early 1900's, the Falls Street tunnel was excavated through the upper part of the Lockport Dolomite from 56th Street to the Niagara gorge (fig. 6). This 3.5-mi-long unlined tunnel trends

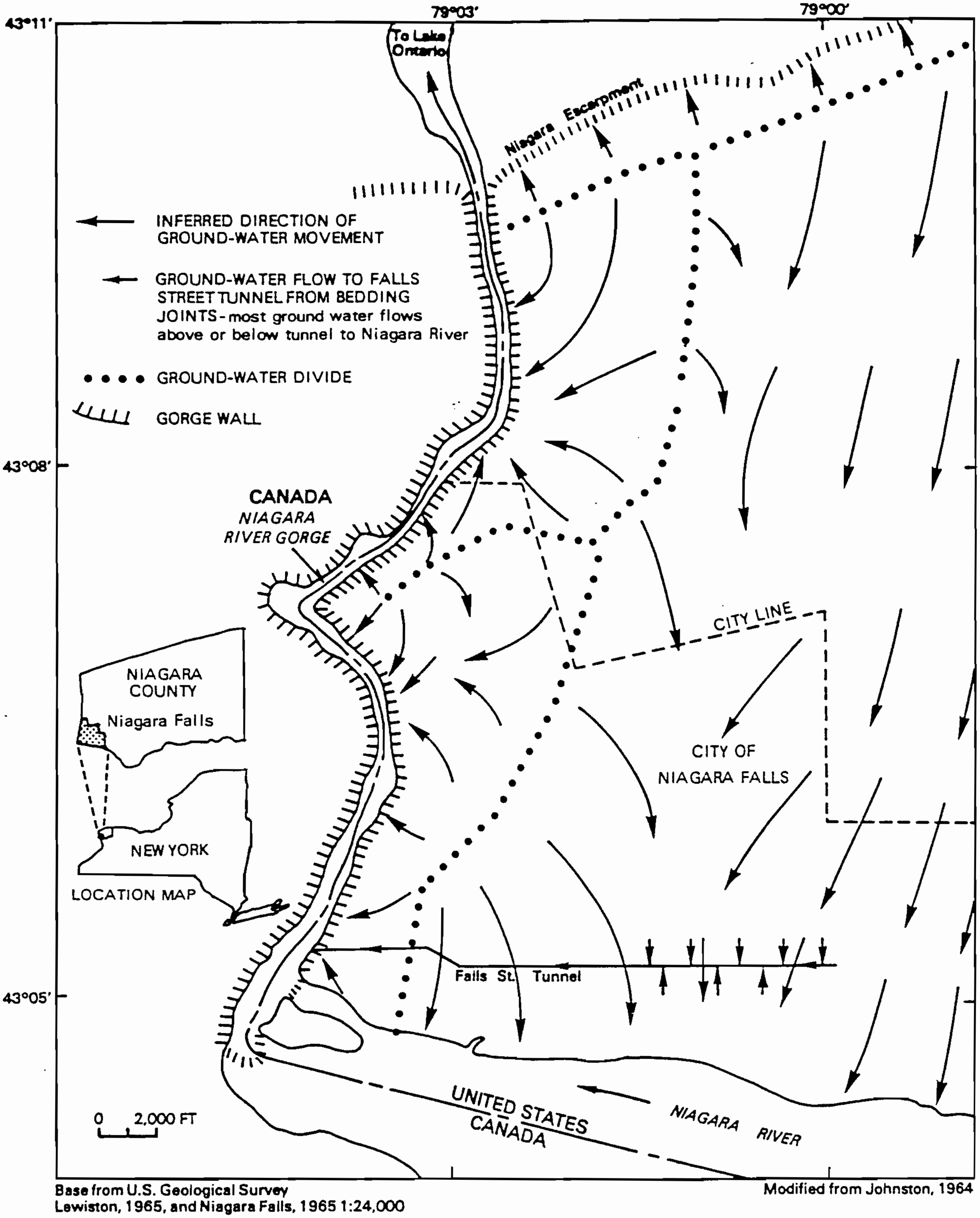


Figure 5.--Inferred directions of ground-water movement in the upper part of the Lockport Dolomite in the Niagara Falls area before any major construction.

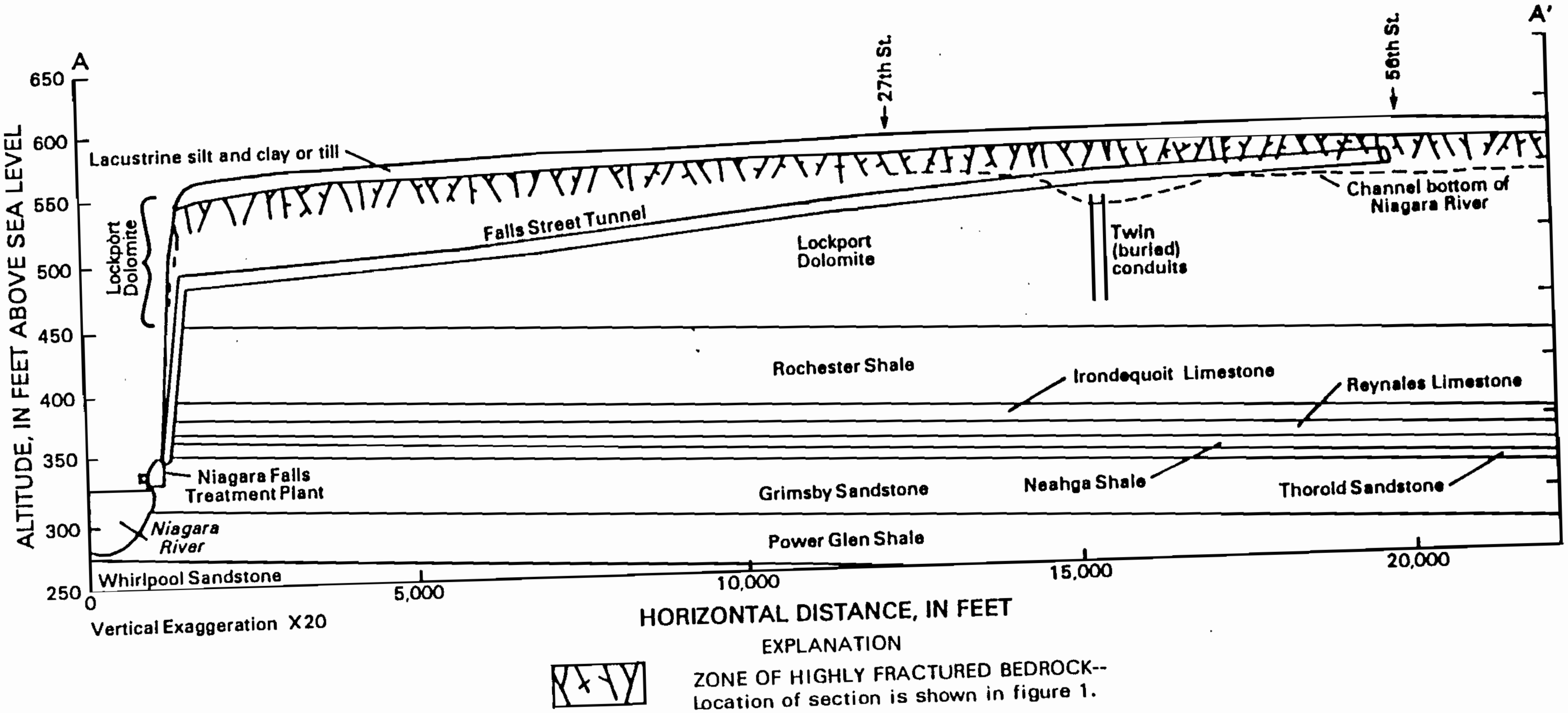


Figure 6.--Vertical section A-A' at Falls Street tunnel.
(Location is shown in fig. 1.)

east-west and slopes 20 ft/mi beneath the southern part of the city approximately 0.65 mi north of the upper Niagara River (fig. 1). Runoff and ground water that drained into the tunnel flowed west with sewage to a treatment plant in the Niagara River gorge below the Falls.

The bottom of the Falls Street tunnel slopes westward from 549 ft above sea level at 56th Street to 533 ft at 27th Street (fig. 6), which places the tunnel at or above the altitude of the lowest part of the Niagara River channel in this reach. Thus, in the reach from 56th Street to 27th Street, water from the Niagara River (surface altitude about 560 ft) probably moves through the upper part of the Lockport northward toward the tunnel through the relatively permeable upper 15 to 20 ft of the Lockport. A shallow bedrock valley in this area (pl. 1B) may be a major zone of infiltration to the tunnel because the depth of weathering would be deepest under this channel. Ground water north and south of the tunnel probably drains into the tunnel also, but the size of the area affected by the tunnel is unknown.

The Falls Street tunnel from 24th Street west to the Niagara gorge is 25 ft or more below the relatively permeable upper zone of the Lockport. Thus, the tunnel in this area is overlain by less fractured, less permeable beds that limit downward flow. A study of ground-water infiltration into the tunnel (Camp, Dresser and McKee, 1982) found only minimal seepage to the Falls Street tunnel between 24th Street and the gorge. Although the amount of water that drained into the tunnel before construction of the conduits is unknown, the Falls Street tunnel east of 27th Street probably altered ground-water movement by creating a local ground-water low as water drained into the tunnel from the upper 25 ft of bedrock and possibly from the Niagara River.

During the 1930's and 1940's, several companies drilled and pumped water from an industrialized area within 2,000 ft of the Niagara River near Gill Creek (fig. 1); yields from these wells were as high as 1,800 gal/min. Johnston 1964) and Woodward-Clyde Consultants (1983) reported that most of the pumped water was induced recharge from the Niagara River that moves predominantly through the upper part of the Lockport Dolomite. The induced recharge from the Niagara River by industrial pumping and possibly some infiltration to the Falls Street tunnel are the only known changes in natural ground-water flow patterns in this part of the city before the construction of the Niagara Power Project.

HYDROLOGIC EFFECTS OF NIAGARA POWER PROJECT

The Niagara Power Project, constructed by New York Power Authority during 1958-62, has an electrical production capacity of 1,950,000 kw. Part of the flow of the upper Niagara River 2.5 mi above the Falls is diverted 4 mi north through the twin buried conduits to the L-shaped forebay canal, which is between the Robert Moses powerplant and the Lewiston powerplant (fig. 1). The conduits can divert 50,000 to 75,000 ft^3/s of water, which is at least 25 percent of the river's flow.

Seasonal Diversions

A seasonal operating schedule determines the quantity of water diverted from the river to the forebay canal (table 1). During the tourist season (April 1 to October 31), at least 100,000 ft^3/s must flow over the falls during daylight hours, and at least 50,000 ft^3/s must flow over the falls at night. During the rest of the year, a minimum of 50,000 ft^3/s must flow over the falls at all times. The remainder of the flow, usually between 100,000 and 150,000 ft^3/s, is divided between the NYPA project and the Canadian Ontario Hydropower project. Average flow in the Niagara River at Buffalo, N.Y., 12 mi upstream from the falls, is 204,000 ft^3/s (U.S. Geological Survey, 1984).

The water level in the forebay canal also is regulated by a daily schedule, depending on the amount of water needed for power generation at the Robert Moses and Lewiston powerplants. During periods of peak power demand, generally weekdays from 8:00 a.m. to 4:00 p.m., water is discharged from the pumped-storage reservoir to the forebay canal through the Lewiston powerplant, which supplements flow from the twin conduits; the combined flow is then discharged through the Robert Moses powerplant. The combined discharge of water from the reservoir and conduits raises the water level in the forebay canal (fig. 7). During periods of low power demand, generally weeknights from 8:00 p.m. to 4:00 a.m. and during weekends, the Lewiston powerplant turbines are used as pumps to lift water from the forebay canal up into the reservoir; this generally lowers water level in the forebay canal. During the weekend, the water is pumped from the forebay canal to the Lewiston Reservoir until Monday morning, when it reaches its peak level, about 650 ft above sea level (fig. 8). This power-generation schedule causes water levels in the forebay canal to fluctuate 4 to 20 ft a day (fig. 7) and those in the reservoir to fluctuate by as much as 10 ft a day. The reservoir's water level is highest on Monday morning and slowly decreases through the week.

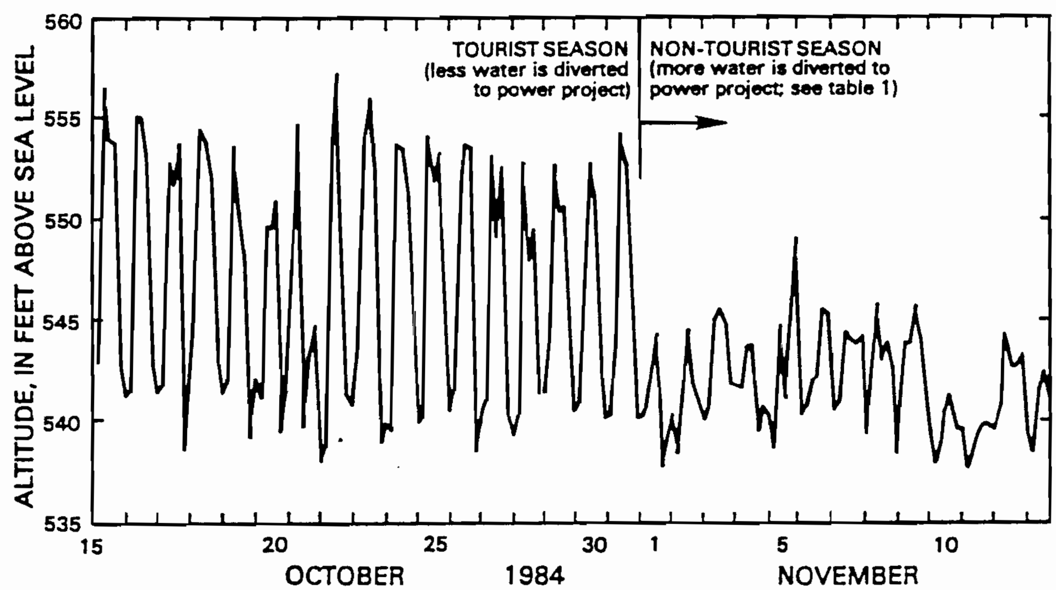


Figure 7.--Daily water-level fluctuation in the forebay canal during late October and early November 1985, showing effect of change in annual diversion schedule.

Table 1.--Flow of Niagara River over Horseshoe and American Falls.[1]

Season	Dates	Hours		Minimum flow over falls (ft^3/s)
Tourist season	Apr. 1 to Sept. 15	Day:	8:00 am to 10:00 pm	100,000
		Night:	10:00 pm to 8:00 am	50,000
	Sept. 1 to Oct. 31	Day:	8:00 am to 8:00 pm	100,000
		Night:	8:00 pm to 8:00 am	50,000
Non-tourist season	Nov. 1 to Mar. 30		12:00 am to 12:00 am	50,000

[1] The diverted water (average total flow of river, 204,000 ft^3/s, minus flow over falls) is divided between Canada and United States.

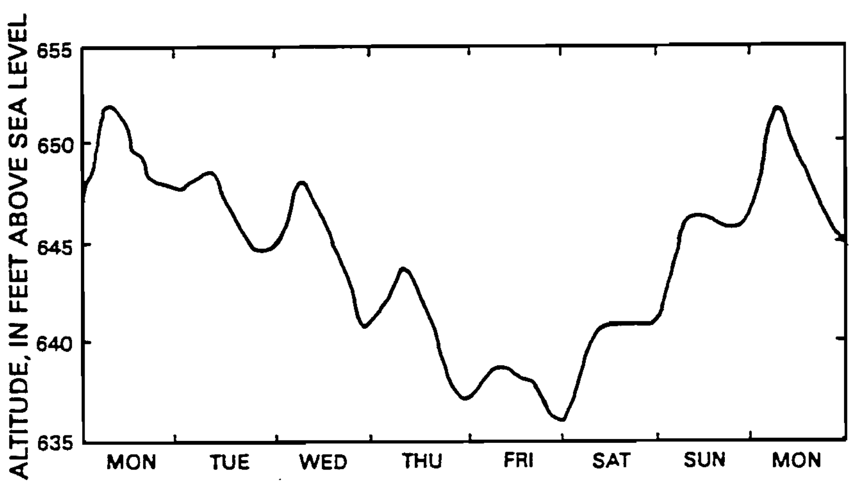


Figure 8.

Typical Lewiston Reservoir water levels during a weekly pumped-storage/release cycle.

Ground-Water Flow and Water Levels

Construction of the twin buried conduits, the forebay canal, and the pumped-storage reservoir has modified hydrologic conditions within the Niagara Falls area. The daily and seasonal regulation of water levels in the reservoir and forebay canal have changed the natural flow patterns and water levels in the upper part of the Lockport Dolomite. To determine the effect of the power project on ground-water movement, water levels in the upper part of the Lockport Dolomite were measured at 104 wells on October 23-24, 1984 and on March 26-27, 1985 (values are given in table 2, at end of report). The difference between water levels in October and those in March were relatively small (generally within 3 to 5 ft); therefore, only the water levels measured in March were used to construct a potentiometric-surface map (pl. 1A), which includes arrows showing the directions of ground-water flow.

Effect of Twin Buried Conduits

The twin buried conduits were constructed in two separate parallel bedrock trenches approximately 4 mi long. Each trench is 52 ft wide and penetrates 100 to 160 ft into the Lockport Dolomite; at the north end they

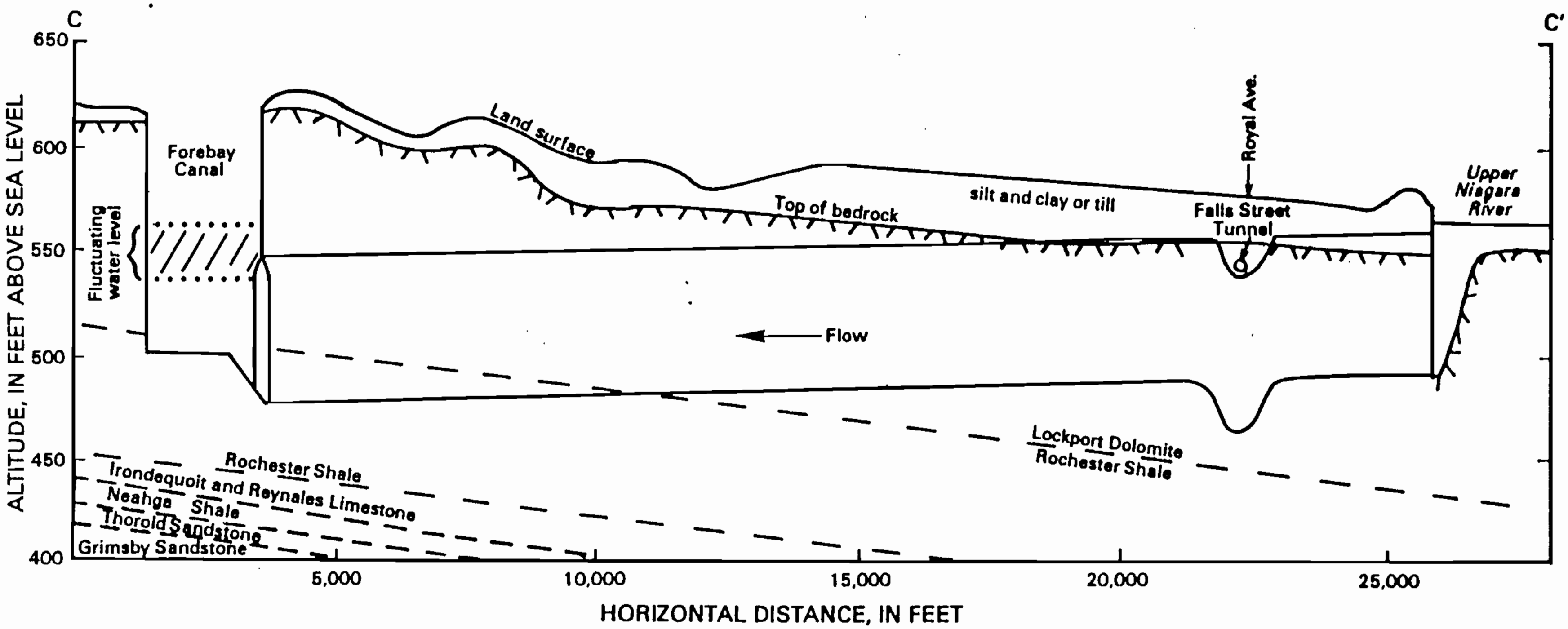


Figure 9.--Vertical section C-C' along twin buried conduits. (Location is shown in fig. 1.)

penetrate the Lockport and upper part of the underlying Rochester Shale (fig. 9). The top of the conduits averages more than 40 ft below land surface. General construction details for the conduits are shown in figure 10.

Along the conduits are two dewatering stations--one at the intersection of the Falls Street tunnel at Royal Avenue, the other just south of the forebay canal (fig. 1). Each pumping station has direct access to water in both conduits and to water in the drain system that surrounds the conduits, which is in hydraulic contact with the surrounding bedrock. The pumping stations were designed to drain water from the bedrock surrounding each conduit through the drain system to reduce hydrostatic pressure, which could collapse the conduits should they need to be dewatered.

The drain system surrounding the conduits consists of formed, vertical 6-in-diameter drains placed every 10 ft along both sides of each conduit (fig. 11A), and two semicircular (2-ft radius) floor drains beneath the full length of the conduits at the bottom of each trench. The wall and floor drains are connected to continuous concrete-formed side drains in the lower corners of each bedrock trench (fig. 11A). All drains were formed into the concrete-conduit structure and are open to the bedrock walls and floor of conduit trenches but are not open directly to the river or forebay canal.

The only locations where water in the drain system can mix with water inside the conduits is at the two pumping stations. Each station has three sumps (fig. 11B)--a central sump connected to the conduit drain system that surrounds both conduits, and the two outer sumps, each of which is connected to the adjacent conduit. Both pumping stations have a pair of balancing weirs; one is near the Falls Street tunnel and operates at an altitude of 560 ft; the other is at the conduit outlet on the forebay canal and operates at an altitude of 550 ft. When the water level in the drain system exceeds the altitude of the balancing weir, water from the drains flows through the weir to the outer sumps and into the conduits, which discharge into the forebay canal.

Ground-water discharge into the backfill.--Backfill on top of the conduits was found to be relatively permeable where the Falls Street tunnel and conduits intersect (Koszalka and others, 1985, p. 56); however, no description of the backfill materials elsewhere along the conduits could be found. To determine whether the backfill is permeable elsewhere and forms a major pathway for ground-water movement, four wells were drilled during this study, three over the east conduit (wells 84-9, 84-10, and 84-11) and one over the west conduit (84-8, fig. 1). Drill cuttings indicated that the backfill consists of 2 to 5 ft of topsoil overlying 30 to 75 ft of shotrock (cobble- to boulder-size clasts of Lockport Dolomite that was blasted and removed during trench excavation), which overlies 5 to 15 ft of sandy, clayey silt fill of low permeability that overlies the conduits. The shotrock is permeable but unsaturated; only the lower part of the sandy, clayey silt was saturated. Water-level recorders installed on two wells in the sandy clayey silt (84-9 and 84-11, location shown in fig. 1) indicated that the water levels took several months to recover to a static level after the wells were pumped dry (fig. 12), which indicates that the sandy, clayey silt backfill has very low permeability and therefore transmits little ground water. Well 84-9 did not respond to fluctuations of water levels in the forebay canal, and water levels in well 84-11 fluctuated only when water levels in the forebay rose to altitudes greater

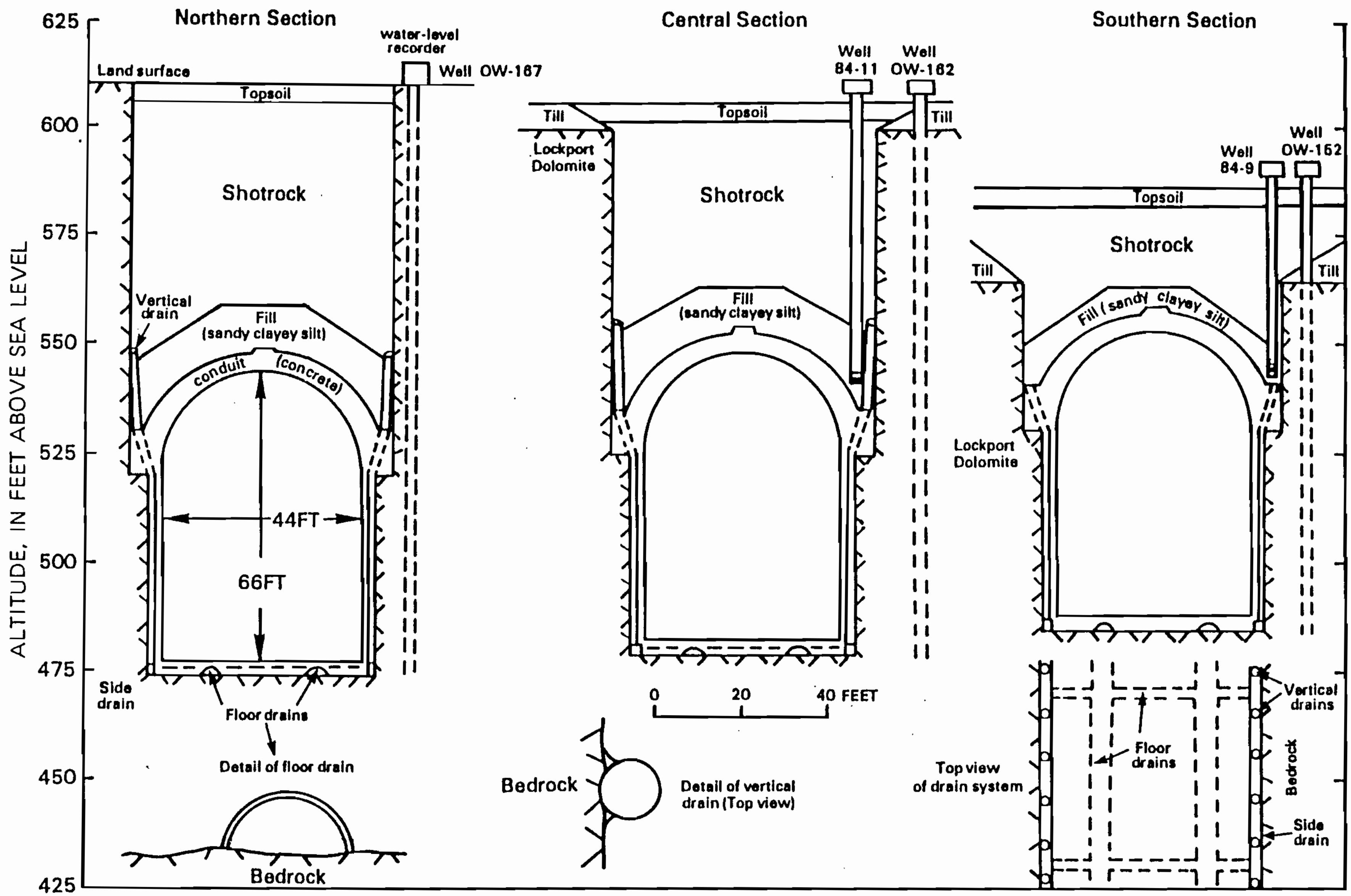
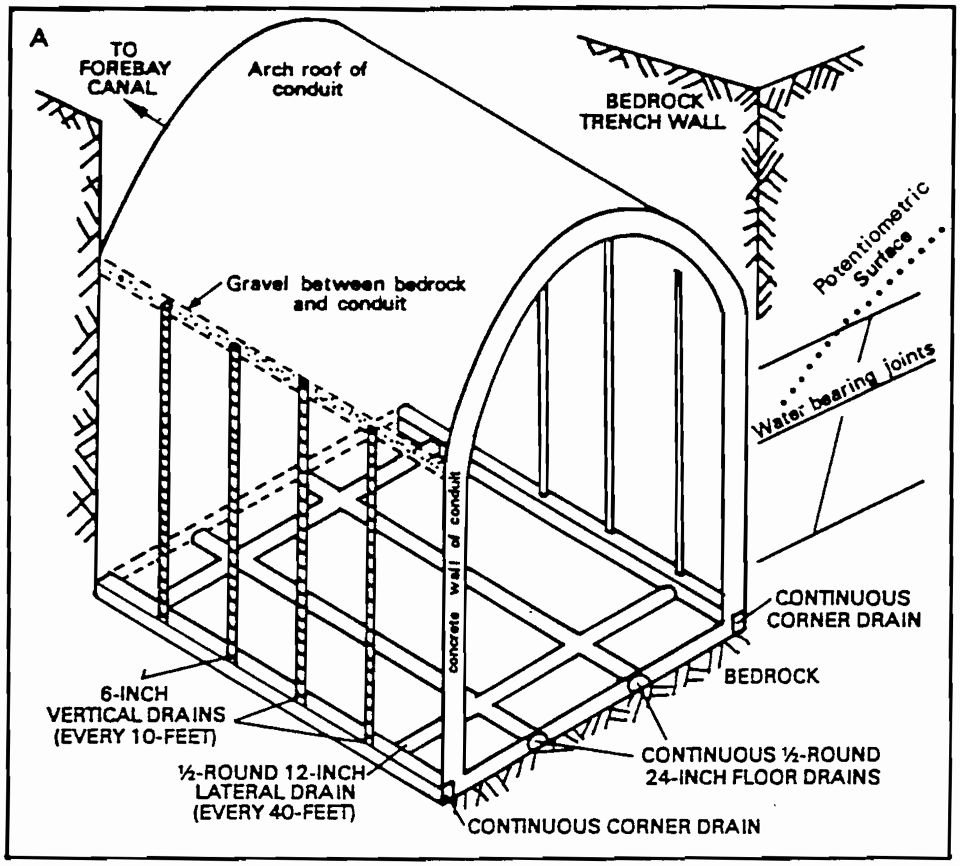


Figure 10.--General construction details of the Niagara Falls conduits at the northern, central, and southern parts of the conduit system. (Modified from Uhl, Hall and Rich, 1961.)



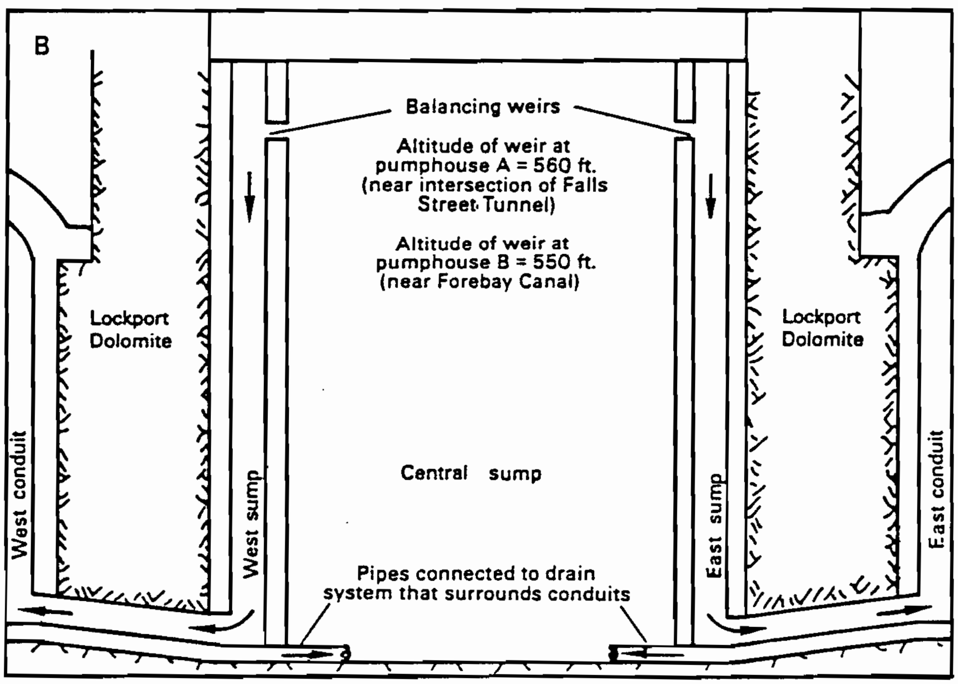


Figure 11.--General details of conduit construction: A. Exterior drain system. B. Pumphouse.

than 560 ft, which occurred at the end of January and beginning of February 1985, when NYPA raised the water level in the forebay canal to clear a large accumulation of pack ice from the conduit intakes along the upper Niagara River. When this occurred, the water level in well 84-11 rose 10 ft to an altitude of 556.11 ft, then began a slow, steady decline (fig. 12). Water-level altitudes greater than 560 ft at well 84-11 would have caused the lower zone of the permeable shotrock fill to become saturated. Water probably entered the well relatively rapidly by leakage down the side of the casing, which could explain the rapid rise of the water level in the well; normally this should not have occurred because the well was installed in relatively impermeable sediment. Well 84-11 does not respond to water-level fluctuations in the bedrock or forebay canal below this altitude.

The relatively impermeable, sandy, clayey silt in the saturated part of the backfill prevents significant ground-water movement in the backfill. An exception may be at the intersection of the Falls Street tunnel and the conduits, where more permeable backfill was found. The method of backfilling there may have been different from that used elsewhere along the conduits because the conduits dip where they pass under the Falls Street sewer (fig. 9).

Ground-water discharge into drains surrounding the conduits.--The drain system that surrounds the conduits has lowered ground-water levels near the conduit trenches, which causes ground water in the Lockport Dolomite to flow toward the conduits (pl. 1A). Ground water within 0.5 mi of the conduits that previously flowed southward now flows toward the conduits and discharges into the drain system. To determine the direction of flow in the drains, water levels were measured in the central chamber in the pumping stations and in several NYPA open-hole wells installed in the bedrock 5 to 10 ft from the vertical wall drains. Because the drain system is in direct hydraulic contact

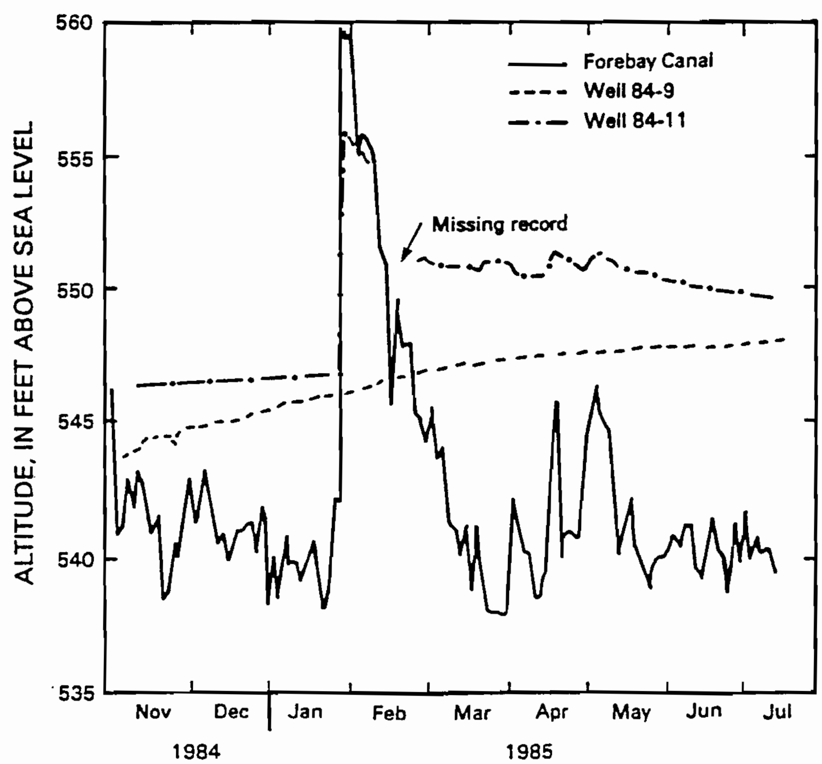


Figure 12.

Average daily water-level fluctuations in the forebay canal and recovery of water levels in wells 84-9 and 84-11 (installed in backfill atop conduits) after evacuation of water from the casing, November 1984 through July 1986.

with ground water in the Lockport Dolomite, the hydraulic heads measured in the NYPA wells are the same or nearly the same as water levels in the drains that surround the conduits (fig. 10). Water levels in wells adjacent to the conduits indicate that, most of the time, water from the vicinity of the forebay canal that enters the drains flows southward to where the Falls Street tunnel crosses the conduits (pl. 1A), whereas water from the upper Niagara River that enters the drains flows northward to the tunnel. The drain system acts as the path of least resistance to ground-water flow in and near the conduit trenches.

The major discharge point for water in the conduit drains is the Falls Street tunnel where it crosses the conduits (fig. 9). The method of construction at the conduit/tunnel intersection probably created this discharge zone. During construction of the conduit trenches, a 400-ft section of the Falls Street tunnel was rebuilt with precast concrete pipe sections, and the conduit trenches were then excavated beneath the Falls Street pipeline. After backfill was placed over the conduits and around the Falls Street tunnel pipe section, ground-water levels in the backfill fluctuated at or above the top of the rebuilt section of the Falls Street tunnel (fig. 13). Apparently the seals between the concrete pipe sections failed, and water from the drains began to leak into the Falls Street tunnel.

In 1982, the Falls Street tunnel was inspected for ground-water infiltration, and a large amount of inflow, estimated at approximately 6 Mgal/d, was found to leak into the Falls Street tunnel through joints in the concrete pipe where the tunnel passes over the conduits (Camp, Dresser and McKee, 1982). Most of this leakage is probably water from the conduit drain system, which drains ground water from 0.5 mi on both sides of the 4-mi-long trenches. The Lockport Dolomite is too impermeable to supply the quantity of water that

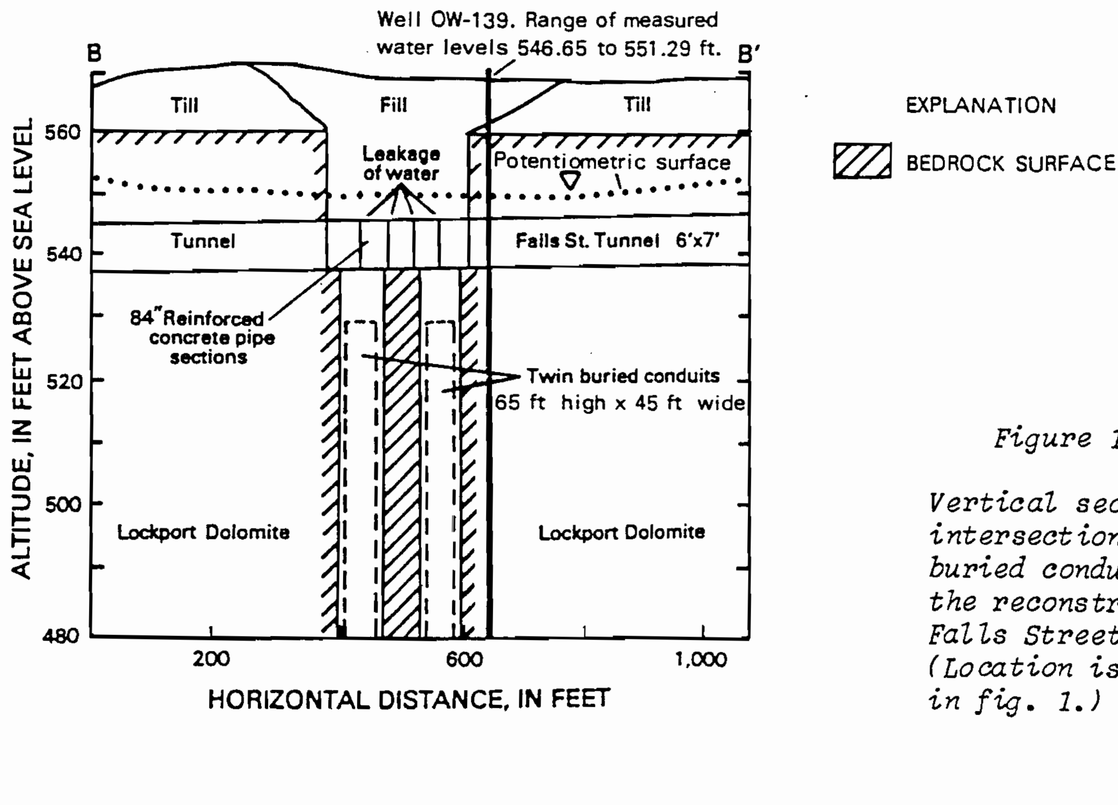


Figure 13.

Vertical section of intersection of twin buried conduits and the reconstructed Falls Street tunnel. (Location is shown in fig. 1.)

leaks into the tunnel. Estimation of how much water enters the Falls Street tunnel from either the north (powerplant) or south (river) side of the tunnel was beyond the scope of this project, however.

Effect of Forebay Canal

The forebay canal is an L-shaped excavation that penetrates the Lockport Dolomite and upper part of the Rochester Shale at the north end (outlet) of the twin conduits (fig. 1). It is 4,000 ft long, 500 ft wide, and 110 ft deep. The walls and floor are unlined. Water that enters the forebay canal from the conduits is routed to the Robert Moses powerplant, and some is pumped up to the Lewiston Reservoir, depending on the daily power-demand schedule.

The daily range of water-level fluctuations in the canal is dependent on the seasonal diversion schedule, the demand for power generation, and the flow of the Niagara River. During the summer and early fall, when the flow in the Niagara River is generally lower, daily fluctuations in the canal are greatest, as much as 25 ft. The water level in the forebay canal is increased by the release of water from the Lewiston Reservoir, which supplements the flow entering from the conduits. This combined flow into the forebay canal increases the hydraulic head in the canal to drive the Robert Moses powerplant turbines more efficiently. During high-flow periods (generally during spring) or when allowable diversions from the Niagara River are higher (table 1), daily water-level fluctuations in the forebay are less, usually ranging from 5 to 10 ft even during peak power-demand periods (fig. 7).

Ground-water discharge into the forebay canal.--The walls and floor of the forebay canal consist of bedrock. Observations of ground-water seepage from bedding planes in the forebay canal walls to the forebay canal (Lockport Dolomite) and higher water levels in nearby wells than in the forebay (pl. 1A and table 2) indicate that ground water generally discharges into the forebay canal. Little, if any, water enters the forebay canal from the underlying Rochester Shale, which has low permeability.

Effects of water-level fluctuations in the forebay canal.--The daily water-level fluctuations in the forebay canal, which can range to as much as 25 ft (fig. 7), cause instantaneous water-level fluctuations in wells along the conduits to as least 3.4 mi south of the forebay canal. The water-level fluctuations in the forebay canal also cause hydraulic-pressure changes in the drain system that surrounds the conduits. Instantaneous head responses in wells adjacent to the twin conduits to water-level fluctuations in the forebay canal suggest a direct hydraulic connection between the forebay canal and the drains. Water probably moves from the canal to the drains through gently southward dipping water-bearing bedding planes that are exposed in the walls of the forebay canal and is intercepted by the drain system that surrounds the conduits.

Water levels were recorded at four NYPA observation wells adjacent to the conduits at various distances south of the forebay canal; well OW-167 is at the outlet of the conduits, and wells OW-162, OW-152, and OW-139 are 0.8, 2.2, and 3.4 mi south of the forebay canal, respectively (fig. 1). Comparison of water levels in these wells with those in the forebay canal shows an immediate response (fig. 14). The magnitude of water-level fluctuations in the drains decreases with distance south of the forebay canal. Well OW-167, closest to the forebay canal, fluctuates daily as much as 12 ft, whereas well OW-139, 3.4 mi from the forebay canal, fluctuates less than 2.5 ft.

Water levels in the NYPA observation wells are nearly always higher than those in the forebay canal. Rising water levels in the forebay canal raises the water level in the drains and adjacent Lockport Dolomite, which reduces the water-table gradient toward the drains and therefore reduces the amount of flow to the drains. Declining water levels in the forebay canal cause the water level in the drains to decline, which increases the water-table gradient toward the drains and increases the amount of ground-water flow from the Lockport Dolomite to the drains.

Most of the time the potentiometric surface, as determined from wells adjacent to the conduits, slopes southward, which indicates that water in the drains usually flows southward (pl. 1A), parallel to the conduits, from the forebay canal to at least where the Falls Street tunnel crosses the conduits. Sometimes, however, when water levels in the forebay canal are low, the water-level gradient in the drains may reverse between wells OW-152 and OW-167 for several hours, which indicates that water in the drains flows northward toward

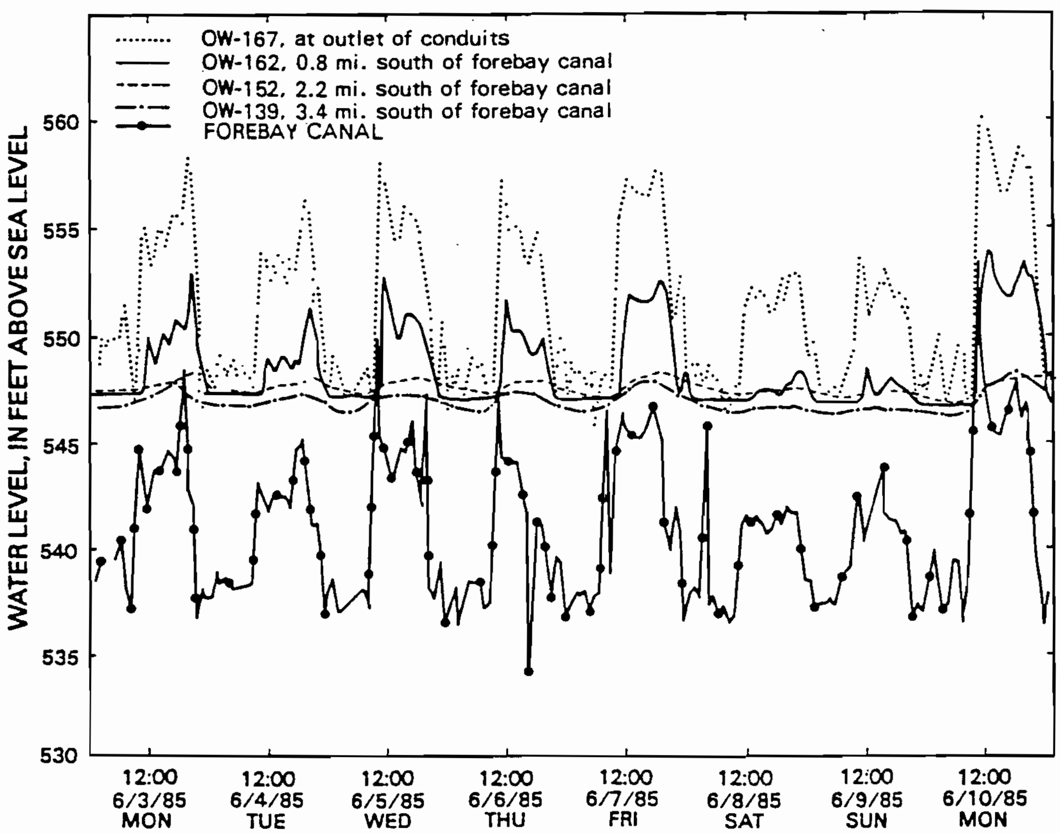


Figure 14.--Water-level response of selected New York Power Authority observation wells adjacent to the conduits to water-level fluctuations in the forebay canal from June 3 through June 10, 1985.

intervals. The water level in well OW-139 is always lower than in the other wells, probably because this well is in the cone of depression formed by the leakage of water into the Falls Street tunnel where it crosses the conduits.

Fluctuation of water levels in the drains can affect the ground-water levels to 0.5 mi on either side of the conduits (pl. 1A). From late December 1960 through early January 1961, the exterior conduit drain pumps at the pumping stations were shut off as the conduits were flooded. Ground-water levels in wells 10 ft, 75 ft, and 450 ft from the conduits rose 50 to 60 ft, but a well 2,400 ft away was not affected (fig. 15). Water levels in these wells show that the flooding of the conduits affected the ground-water levels to at least 450 ft to either side, but probably not beyond 2,400 ft.

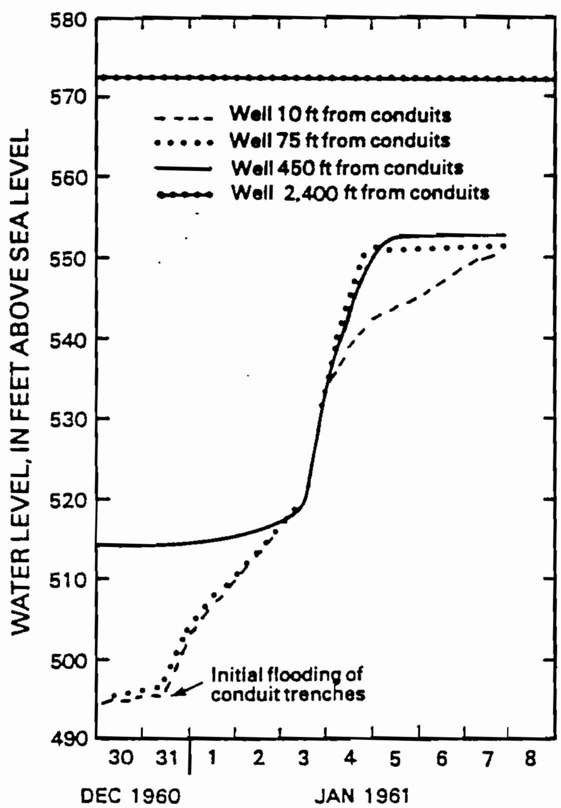


Figure 15.

Effects of 1960-61 flooding of the conduit trenches on water levels in wells 10, 75, 450, and 2,500 feet from the buried conduits.

Effect of Pumped-Storage Reservoir

The 2.97-mi^2 Lewiston pumped-storage reservoir is confined by a 55-ft-high, 6.5-mi-long dike that can contain as much as 60,000 acre-feet of water. The dike consists of a compacted-clay core capped by crushed rock fill and topsoil. The bedrock directly beneath the dike has been sealed with a grout wall (holes drilled at 15-ft intervals into the Lockport to a depth of approximately 70 ft with grout pumped in under pressure) to minimize leakage from the reservoir; the bedrock floor of the reservoir is not sealed. Water levels in the reservoir fluctuate daily; they range between 620 and 650 ft above sea level and average 640 ft (fig. 9).

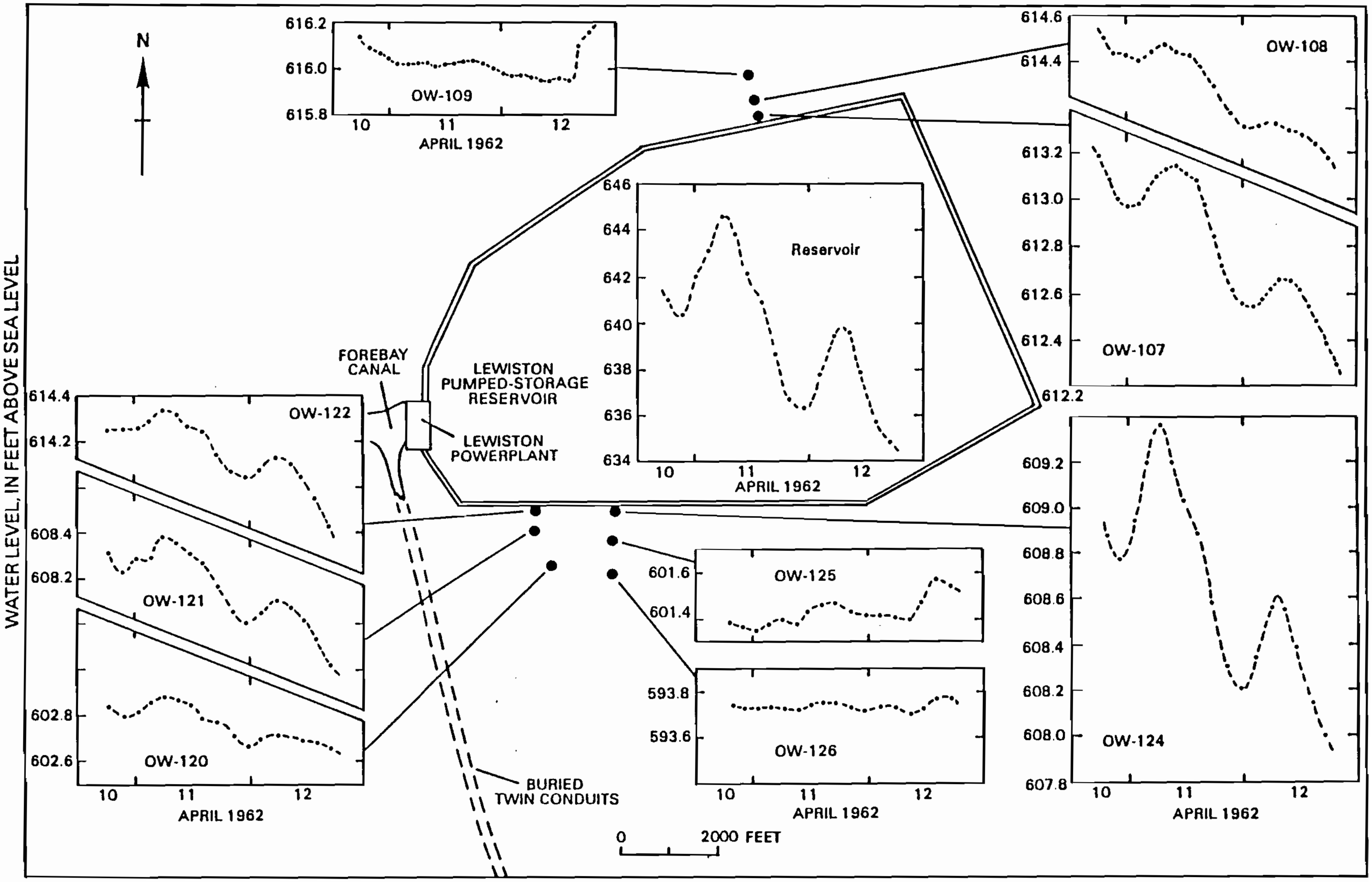


Figure 16.--Response of ground-water levels in vicinity of Lewiston pumped-storage reservoir to water-level fluctuations in reservoir. (Modified from Johnston, 1964.)

Ground-water recharge from the reservoir.--Within 3 weeks after the reservoir was first filled in October 1961, water levels in nearby wells that tap the upper parts of the Lockport Dolomite rose between 1.6 and 17.0 ft, and several wells near the southwest corner of the reservoir started to flow (Johnston, 1964). Johnston attributes the artesian flow and water-level rise to seepage through joints exposed on the floor of the reservoir that intersect the open-hole wells south of the reservoir. Apparently the grout wall beneath the dike did not completely seal off flow beneath the dike. Heads measured elsewhere along the south side of the reservoir reflected the increased reservoir water level, but to a much lesser degree.

Effects of water-level fluctuations.--Ground-water levels in some areas near the reservoir are affected by water-level fluctuations in the reservoir. The degree of fluctuation is dependent on a well's location, the effectiveness of the grout curtain upgradient from the well, and whether the well intersects bedding planes or fractures that extend back to the ungrouted reservoir floor (Johnston, 1964, p. 61-62). Water-level fluctuations in the reservoir affect ground-water levels to the southwest and, to a lesser degree, to the south, but the fluctuations are generally minor (fig. 16), ranging from 0.1 to 1.0 ft (Johnston, 1964). Water-level measurements taken in October 1984 and March 1985 at wells on the south side of the reservoir (table 2, at end of report) indicate that the same range of fluctuation still occurs.

SUMMARY

The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation, studied the hydrogeology of the Niagara Falls area during 1984-85 to extend knowledge of ground-water movement in the upper part of the Lockport Dolomite in the area and define the hydraulic effects of the Niagara Power Project. The power project has created recharge and discharge zones that have modified the direction of ground-water flow in the Niagara Falls area. Before construction of the power project in 1958-62, ground water in the upper part of the Lockport Dolomite generally flowed southward, parallel to the buried surface of the Lockport Dolomite. Ground water in the central and eastern parts of the city flowed south and southwestward toward the upper Niagara River, and ground water in the western part of the city flowed westward to the Niagara River gorge.

Since completion of the power project, ground water within 0.5 mi of both sides of the buried twin conduits flows toward the conduits and into the drain system that surrounds them. Water in the drains flows southward from the forebay canal to Royal Avenue, where it leaks into the Falls Street tunnel. In addition, water from the upper Niagara River flows northward in the drains to Royal Avenue, where it also leaks into the Falls Street tunnel. Approximately 6 Mgal/d leaks into the Falls Street tunnel where it crosses the conduits. Water in the tunnel flows westward to the Niagara River gorge below the falls.

Water-level fluctuations in the forebay canal, which connects the Lewiston pumped-storage reservoir with the Robert Moses powerplant, affects

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Table 2.--Records of selected wells in Niagara Falls, New York.

NUMBERING AND ARRANGEMENT OF WELLS

All wells are identified by latitude and longitude to the nearest second, as measured from 7 1/2-minute topographic maps, scale 1:24,000. The location of each well was plotted on these maps by U.S. Geological Survey staff during a visit to the site, from large-scale engineering drawings, or from consultant reports. All measuring points have been leveled to National Geodetic Vertical Datum (sea level) unless otherwise noted.

The location of each well is shown on plate 1A. Data are arranged in 1-minute strips of latitude. Each table begins with the southernmost strip followed by other strips successively farther north.

FOOTNOTES AND ABBREVIATIONS

Owner

NYPA - New York Power Authority
USGS - U.S. Geological Survey
CNF - City of Niagara Falls

Date Drilled

Year in which well was drilled. NYPA wells drilled between 1958 and 1960.

Well Depth

Total depth of well from land surface unless noted: PKR indicates level of packer in borehole.

Screen Interval

Screen located at bottom of well unless noted:
OH - open hole
OE - open end

Aquifer Type

Lock. Dol. - Lockport Dolomite
Roch. Sh. - Rochester Shale
Backfill - Well screened in backfill (sandy-silt) on top of NYPA conduits.

Measuring Point

(e) indicates estimated measuring point.

Geologic Log

Geologic log available at U.S. Geological Survey, Ithaca, N.Y.

Table 2.--Records of selected wells in Niagara Falls, New York.

(Dashes indicate no data.)

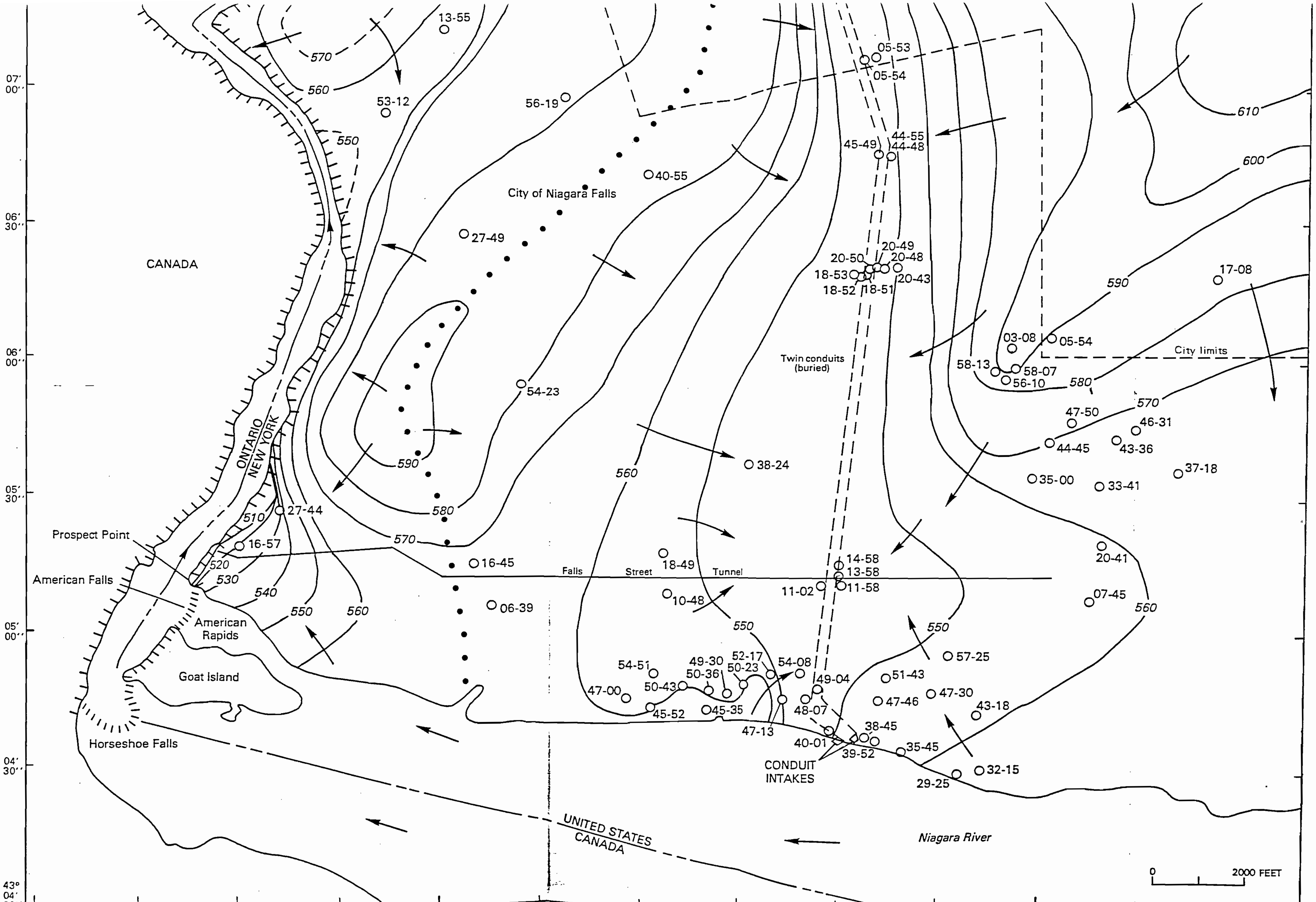
Location lati-tude	Location long-itude	Local well no.	Owner	Date drilled	Well depth (ft)	Casing depth (ft)	Screen interval (ft)	Depth to bedrock (ft)	Aquifer type	Measuring point (ft above sea level)	Water level (ft above sea level) Oct. 23-24, 1984	Water level (ft above sea level) Mar. 26-27 1985	Geologic log
4304 29	7900 25	SP8	Occidental	1979	44	39	5	35	Lock.Dol.	570.10	562.09	561.29	yes
4304 32	7900 15	16	Occidental	1979	36	31	5	31	Lock.Dol.	570.4	562.11	561.43	yes
4304 35	7900 45	SP6	Occidental	1979	31	26	5	26	Lock.Dol.	568.0	554.18	551.46	yes
4304 36	7900 36	10	Occidental	1979	30.5	20.5	10	20.5	Lock.Dol.	569.7	560.46	559.37	yes
4304 38	7900 45	SP5	Occidental	1979	40.0	35.0	5	30	Lock.Dol.	569.1	553.92	550.91	yes
4304 39	7900 52	OW130	NYPA	1958	90.5	30	OH	30	Lock.Dol.	570.80	554.58	552.10	no
4304 40	7901 01	OW133	NYPA	1958	91.2	30	OH	30	Lock.Dol.	570.65	552.34	549.16	no
4304 43	7901 18	20	Occidental	1979	31	26	5	26	Lock.Dol.	572.2	560.49	559.30	yes
4304 43	7901 35	RMP-3	USGS	1982	30.5	27.5	3.0	21.5	Lock.Dol.	576.(e)	562.16	562.66	yes
4304 43	7901 43	RMP-4	USGS	1982	25.0	22.0	3.0	19.5	Lock.Dol.	577.(e)	---	565.90	yes
4304 43	7901 54	RMP-5	USGS	1982	30.0	27.0	3.0	20.0	Lock.Dol.	583.(e)	---	562.78	yes
4304 43	7902 03	RMP-6	USGS	1982	25.5	22.5	3.0	20.5	Lock.Dol.	583.(e)	---	563.38	yes
4304 44	7901 13	RMP-1	USGS	1982	27.0	24.0	3.0	--	Clay	588.(e)	565.33	565.45	yes
4304 44	7901 22	RMP-2	USGS	1982	27.0	24.0	3.0	21.0	Lock.Dol.	583.(e)	562.96	562.96	yes
4304 45	7901 35	1B	Dupont	1983	29	16	OH	12.2	Lock.Dol.	571.61	561.34	561.34	yes
4304 45	7901 52	4C	Dupont	1983	46	30	OH	13.5	Lock.Dol.	569.98	559.40	559.33	yes
4304 47	7900 30	40	Occidental	1979	27	22	5	22	Lock.Dol.	572.1	553.69	551.88	yes
4304 47	7900 46	27	Occidental	1979	28	23	5	23	Lock.Dol.	572.3	554.00	551.13	yes
4304 47	7901 13	8B	Dupont	1983	28.6	14	OH	12	Lock.Dol.	568.02	562.01	562.18	yes
4304 47	7902 00	5B	Dupont	1983	26	17	OH	13	Lock.Dol.	572.82	557.00	557.47	yes
4304 48	7901 07	7C	Dupont	1983	45	30	OH	16	Lock.Dol.	571.17	550.06	549.01	yes
4304 49	7901 04	OW137	NYPA	1958	86.9	20	OH	20	Lock.Dol.	568.10	552.14	548.89	no
4304 49	7901 30	12B	Dupont	1983	27.0	14	OH	11	Lock.Dol.	572.14	559.74	560.20	yes
4304 50	7901 23	10C	Dupont	1983	19.5	19.0	OE	7.5	Lock.Dol.	570.58	557.76	557.76	yes
4304 50	7901 36	14C	Dupont	1983	70.0	25.0	OH	8.0	Lock.Dol.	572.10	554.63	552.72	yes
4304 50	7901 43	15C	Dupont	1983	31.0	22.5	OH	6.0	Lock.Dol.	571.30	556.36	556.58	yes
4304 51	7900 43	26	Occidental	1979	25	20	5	19.5	Lock.Dol.	571.2	551.41	--	yes
4304 52	7900 17	18C	Dupont	1983	35.9	21.3	OH	13.0	Lock.Dol.	570.67	560.46	560.35	yes
4304 54	7901 08	23B	Dupont	1983	--	--	--	--	Lock.Dol.	569.63	549.66	548.05	no
4304 54	7901 51	19B	Dupont	1983	23.1	13.5	OH	10.5	Lock.Dol.	573.26	554.79	553.43	yes
4304 57	7900 25	41	Occidental	1979	29	19	10	19	Lock.Dol.	571.8	551.03	549.16	yes
4305 06	7902 39	82-4	USGS	1982	25	23	2	10.5	Lock.Dol.	575.10	564.08	568.20	yes
4305 07	7859 45	82-8	USGS	1982	25	23	2	21.0	Lock.Dol.	571.60	560.00	559.70	yes
4305 10	7901 48	82-5	USGS	1982	21	19	2	10.5	Lock.Dol.	570.28	553.85	554.18	yes
4305 11	7900 58	82-9	USGS	1982	38	35	3	none	Backfill	569.62	549.92	546.72	yes

Table 2.--Records of selected wells in Niagara Falls, New York (continued).

Location: latitude	Location: longitude	Local well no.	Owner	Date drilled	Well depth (ft)	Casing depth (ft)	Screen interval (ft)	Depth to bedrock (ft)	Aquifer type	Measuring point (ft above sea level)	Water level (ft above sea level): Oct. 23-24, 1984	Water level (ft above sea level): Mar. 26-27 1985	Geologic log
4305 11	7901 02	82-11	USGS	1982	38	36	2	19.0	Lock.Dol.	569.43	548.09	545.13	yes
4305 13	7900 58	OW139	NYPA	1958	--	9.5	OH	9.5	Lock.Dol.	569.44	551.29	547.70	no
4305 14	7900 58	82-10	USGS	1982	38	35	3	17.0	Lock.Dol.	569.77	550.60	547.02	yes
4305 16	7902 45	82-3	USGS	1982	23	21	2	7.0	Lock.Dol.	580.71	567.04	567.81	yes
4305 16	7903 57	82-1	USGS	1982	113.7	109.2	4.5	23.0	Roch.Sh.	554.13	504.73	514.73	yes
4305 18	7901 49	82-6	USGS	1982	22.0	20	2.0	10.5	Lock.Dol.	571.81	556.88	557.51	yes
4305 20	7859 41	82-7	USGS	1982	24.0	22	2.0	18.0	Lock.Dol.	572.78	558.46	558.68	yes
4305 27	7903 44	82-2	USGS	1982	124.2	118.5	5.7	18.5	Roch.Sh.	570.46	501.72	504.06	yes
4305 33	7859 41	51	CECOS	--	--	--	--	--	---	574.11	--	568.44	no
4305 35	7900 00	83	CECOS	--	--	--	--	--	---	577.63	--	566.38	no
4305 37	7859 18	81	CECOS	1980	50.0	35	--	20.0	Lock.Dol.	577.26	--	564.39	yes
4305 38	7901 24	84-3	USGS	1984	29.5	24.5	5	13.5	Lock.Dol.	573.15	548.18	546.90	yes
4305 43	7859 36	VH129C	Dupont	1983	42.2	31.0	OH	24.5	Lock.Dol.	586.13	570.37	568.95	yes
4305 44	7859 55	VH116C	Dupont	1983	30	22.2	OH	12.2	Lock.Dol.	584.15	569.82	571.09	yes
4305 46	7859 31	VH117C	Dupont	1983	42	31.5	OH	21.5	Lock.Dol.	580.78	565.41	566.30	no
4305 47	7859 50	VH115C	Dupont	--	36.5	30.0	OH	20.0	Lock.Dol.	594.41	572.03	573.62	yes
4305 54	7902 23	84-2	USGS	1984	29.7	24.7	5	8.5	Lock.Dol.	592.48	581.23	581.58	yes
4305 56	7900 10	14	Reichold	1984	--	--	--	--	Lock.Dol.	595.60	585.10	579.90	no
4305 58	7900 06	18	Reichold	1984	--	--	--	--	Lock.Dol.	595.98	583.99	589.65	no
4305 58	7900 07	16	Reichold	1984	--	--	--	--	Lock.Dol.	596.10	582.08	588.88	no
4305 58	7900 13	12	Reichold	1984	--	--	--	--	Lock.Dol.	597.34	586.79	585.56	no
4306 03	7900 08	9	Reichold	1984	--	--	--	--	Lock.Dol.	598.89	588.38	594.48	no
4306 05	7859 54	76	CECOS	--	--	--	--	--	Lock.Dol.	602.50	---	589.75	no
4306 17	7859 08	29	CECOS	--	--	--	--	--	Lock.Dol.	595.91	---	583.24	no
4306 18	7900 51	OW151	NYPA	1958	106.6	22.5	--	22.5	Lock.Dol.	587.47	551.14	545.29	no
4306 18	7900 52	84-8	USGS	1984	47.0	43.0	2.0	none	Backfill	588.03	---	541.35	yes
4306 18	7900 53	OW150	NYPA	1960	107.4	23.0	OH	23.0	Lock.Dol.	588.03	551.57	547.51	no
4306 20	7900 43	84-4	USGS	1984	46.0	41.0	5.0	29.0	Lock.Dol.	586.66	550.85	547.64	yes
4306 20	7900 48	OW152	NYPA	1958	111.6	26.0	OH	26.0	Lock.Dol.	586.83	549.99	543.90	no
4306 20	7900 49	84-9	USGS	1984	47.0	45.0	2.0	none	Backfill	590.45	---	547.41	yes
4306 20	7900 50	OW153	NYPA	1958	104.2	27.0	OH	27.0	Lock.Dol.	587.45	551.22	545.81	no
4306 27	7902 49	84-1(a&b)	USGS	1984	40.3	35.3	5.0	19.0	Lock.Dol.	598.16	582.64	585.76	yes
4306 40	7901 55	84-5	USGS	1984	41.8	36.8	5.0	18.5	Lock.Dol.	600.22	582.71	582.67	yes
4306 44	7900 45	OW154	NYPA	1958	114.6	18.0	OH	18.0	Lock.Dol.	586.24	551.50	550.96	no
4306 44	7900 48	OW157	NYPA	1958	110.2	17.5	OH	17.5	Lock.Dol.	592.75	551.78	544.20	no

Table 2.--Records of selected wells in Niagara Falls, New York (continued).

Location: lati-tude	Location: long-itude	Local well no.	Owner	Date drilled	Well depth (ft)	Casing depth (ft)	Screen interval (ft)	Depth to bedrock (ft)	Aquifer type	Measuring point (ft above sea level)	Water level (ft above sea level): Oct. 23-24, 1984	Water level (ft above sea level): Mar. 26-27 1985	Geologic log
4306 45	7900 49	OW155	NYPA	1958	121.5	20.0	OH	20.0	Lock.Dol.	591.02	551.28	---	no
4306 53	7903 12	85-1	USGS	1985	60.0	55.0	5.0	42.5	Lock.Dol.	588.10	---	---	yes
4306 56	7902 19	NI-69	CNF	1958	36.0	17.0	OH	17.0	Lock.Dol.	598.98	574.77	576.88	no
4307 05	7902 53	84-10	USGS	1984	54.0	52.0	2.0	none	Backfill	595.69	---	549.00	yes
4307 05	7900 54	OW160	NYPA	1958	113.6	23.5	OH	23.5	Lock.Dol.	595.18	551.45	---	no
4307 13	7902 55	85-2	USGS	1985	65.0	63	2.0	45.0	Lock.Dol.	589.66	---	---	yes
4307 31	7900 38	OW105	NYPA	1958	73.8	18	OH	18	Lock.Dol.	593.38	574.75	580.02	no
4307 34	7901 03	OW162	NYPA	1958	131.8	17.8	OH	17.8	Lock.Dol.	605.88	552.58	543.76	no
4307 34	7901 04	84-11	USGS	1984	67.0	65.0	2.0	none	Backfill	611.26	---	550.48	yes
4307 34	7901 05	OW164	NYPA	1958	94.5	18.5	OH	18.5	Lock.Dol.	608.64	552.52	544.13	no
4307 34	7901 06	OW166	NYPA	1958	130.6	18.3	OH	18.3	Lock.Dol.	608.23	555.77	544.24	no
4307 38	7900 56	OW101	NYPA	1958	73.5	19.2	OH	19.2	Lock.Dol.	597.92	---	580.53	no
4307 40	7900 33	OW102	NYPA	1958	48.7	10.5	OH	10.5	Lock.Dol.	600.74	577.37	583.26	no
4307 46	7901 58	24	Occidental	1980	23.0	18	5.0	6.0	Lock.Dol.	616.74	602.20	610.18	yes
4307 47	7901 18	84-6	USGS	1984	50.0	47.5	2.5	9	Lock.Dol.	618.32	573.85	577.07	yes
4307 50	7901 55	7	Occidental	1979	20.8	18.8	2	6.2	Lock.Dol.	613.80	599.48	604.84	yes
4307 52	7902 22	18	Occidental	1979	85.5	80.5	5	35.6	Lock.Dol.	599.14	551.27	554.91	yes
4307 53	7859 58	OW119	NYPA	1958	39.4PKR	11.6	OH	11.6	Lock.Dol.	615.60	603.63	610.54	no
4307 59	7900 23	OW126	NYPA	1958	20.2PKR	8.3	OH	8.3	Lock.Dol.	601.42	597.01	598.30	no
4307 59	7901 16	OW169	NYPA	1958	149.2	9.2	OH	9.2	Lock.Dol.	624.13	553.47	542.35	no
4307 59	7901 17	OW170	NYPA	1958	121.0	10.5	OH	10.5	Lock.Dol.	625.15	554.44	542.53	no
4307 59	7901 18	OW171	NYPA	1958	132.0	10.5	OH	10.5	Lock.Dol.	625.20	554.31	542.12	no
4308 02	7859 58	OW106	NYPA	1958	33.9PKR	18.7	OH	18.7	Lock.Dol.	618.20	601.22	604.33	no
4308 03	7902 16	22	Occidental	1980	43.4	38.4	5.0	23.4	Lock.Dol.	591.75	549.70	---	yes
4308 04	7859 18	OW129	NYPA	1958	35.1PKR	15.0	OH	15.0	Lock.Dol.	614.84	604.47	609.16	no
4308 06	7859 58	OW118	NYPA	1958	38.5PKR	16.4	OH	16.4	Lock.Dol.	613.89	602.19	603.28	no
4308 07	7859 18	OW128	NYPA	1958	33.0PKR	11.5	OH	11.5	Lock.Dol.	613.13	604.83	609.10	no
4308 07	7900 24	OW125	NYPA	1958	34.9PKR	9.0	OH	9.0	Lock.Dol.	612.45	600.85	603.24	no
4308 08	7901 22	OW168	NYPA	1958	136.1	7.5	OH	7.5	Lock.Dol.	610.39	559.77	548.41	no
4308 09	7901 18	OW167	NYPA	1958	135.4	7.5	OH	7.5	Lock.Dol.	609.30	559.31	545.40	no
4308 11	7859 58	OW104	NYPA	1958	64.6	11.9	OH	11.9	Lock.Dol.	609.34	595.25	596.03	no
4308 11	7900 23	OW124	NYPA	1958	35.2PKR	11.5	OH	11.5	Lock.Dol.	613.58	596.62	597.30	no
4308 15	7901 12	OW185	NYPA	1958	60.0	10.0	OH	10.0	Lock.Dol.	619.25	596.61	599.28	no
4308 15	7901 35	84-7	USGS	1984	46.2	41.2	5.0	13.5	Lock.Dol.	613.95	580.87	584.68	yes

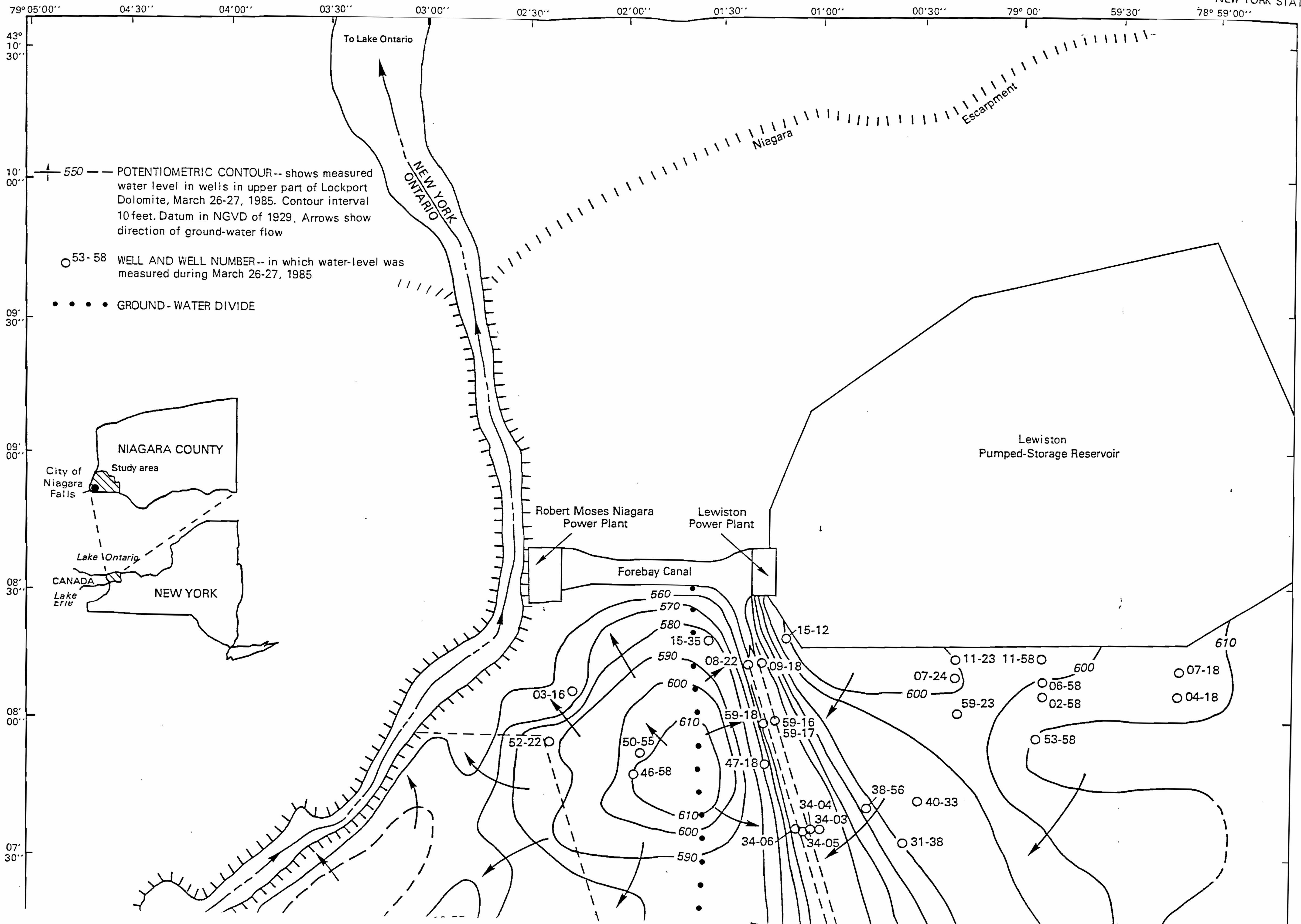


Base from U.S. Geological Survey
Lewiston, 1965, and Niagara Falls, 1965, 1:24,000

PLATE 1A- POTENTIOMETRIC-SURFACE ALTITUDE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

UNITED STATES DEPARTMENT OF ENV...
NEW YORK STATE DEPARTMENT OF ...



EPARED IN COOPERATION WITH THE
ENT OF ENVIRONMENTAL PROTECTION AGENCY AND THE
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

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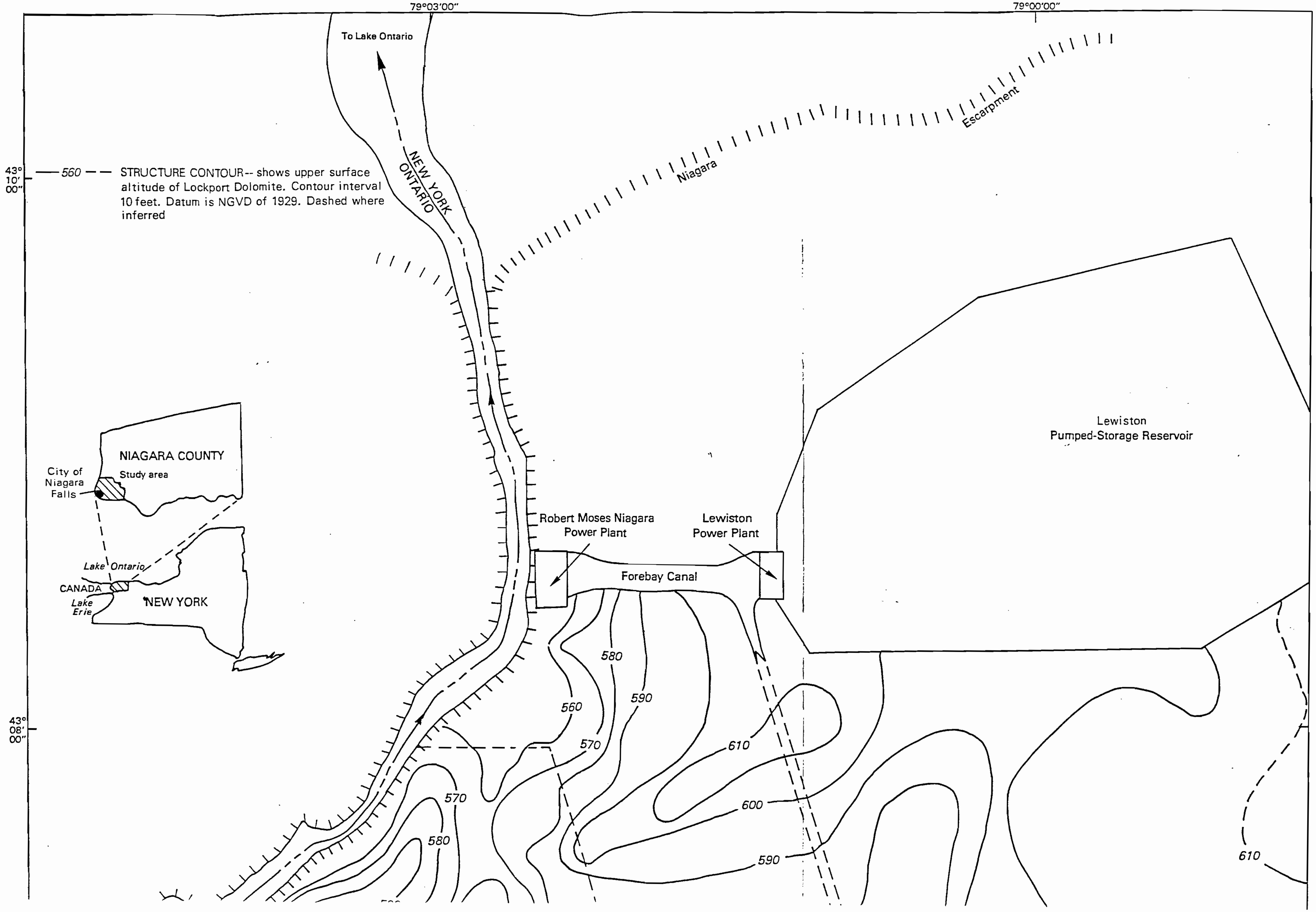
PLATE 1



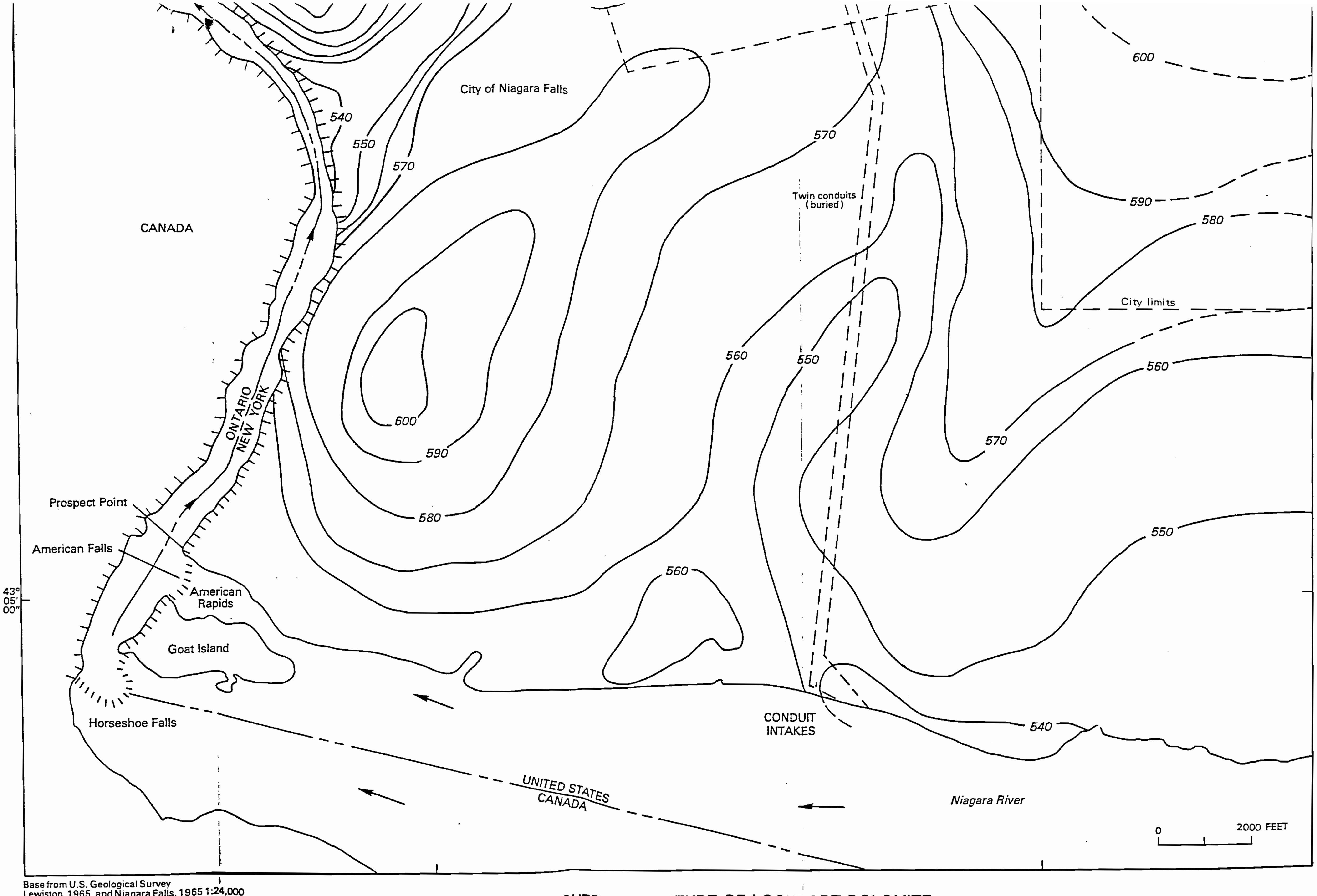


PLATE 1B–UPPER SURFACE ALTITUDE OF LOCKPORT DOLOMITE

V IN THE UPPER PART OF THE LOCKPORT DOLOMITE, NIAGARA FALLS AREA, NEW YORK

By