NIAGARA POWER PROJECT

RELICENSING

GROUNDWATER FLOW INVESTIGATIONS IN THE VICINITY OF THE NIAGARA POWER PROJECT

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EXECUTIVE SUMMARY

As part of the FERC (Federal Energy Regulatory Commission) relicensing of the New York Power Authority's Niagara Power Project, Lewiston, New York, a number of environmental and engineering investigations are being conducted. Among these is the present investigation, a study of the potential Project effects on groundwater flow in the investigation area. This study, conducted during the summer of 2002, represents the initial gathering of data from already established water level monitoring points. Based on an analysis of these data, additional field investigations and groundwater modeling efforts were undertaken in the spring of 2003.

The overall objective of the present investigation is to determine the ongoing effects, if any, of the Project on local groundwater flow patterns. Since the Project is unlikely to have an effect below the geological unit known as the Lockport Group, the investigation focused on groundwater flow in this approximately 150-foot-thick bedrock unit that directly underlies the area's glacial overburden and is the principal aquifer in the area.

The source of nearly all groundwater in the Niagara Falls area is precipitation, which infiltrates the ground surface. Water percolating downward into the Lockport Group enters several types of openings in the rock, such as: (1) horizontal (bedding) fracture zones, which include nine important water-bearing flow zones; (2) vertical joints, observed primarily in the upper bedrock; and (3) small cavities from which gypsum has been dissolved. The level of groundwater measured in wells monitoring these openings is used to determine the direction of groundwater flow. Short-term fluctuation in the level of groundwater occurs naturally as a result of changes in atmospheric pressure, and longer-term fluctuations as a result of seasonal changes in precipitation and temperature.

Groundwater in the Project vicinity fluctuates in response to both natural and manmade influences. Manmade influences include regulation of flow over Niagara Falls, mandated by international treaty, for scenic and power production purposes (by both U.S. and Canadian hydropower operators). They also include withdrawals of groundwater by local industry for process, dewatering, or remediation

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purposes. Project-related factors that have the potential to affect the groundwater regime include high-volume withdrawals of water from the Niagara River upstream of Niagara Falls, with resulting fluctuation of surface water levels there, and the daily and weekly cycles of water level fluctuations in the forebay and Lewiston Reservoir that are an integral part of the power production process. The Project may affect the long-term raising or lowering of the groundwater surface. Near the Lewiston Reservoir, the bedrock appears to be recharged and groundwater levels are higher, whereas near the conduits and forebay, groundwater seems to discharge and groundwater levels are lower.

The URS Team, during the summer of 2002, conducted a study to gather data on these potential effects. The Team collected data from staff gauges in the Niagara River, from wells on the lands of the Tuscarora Nation, from wells owned by NYPA or belonging to government agencies, and from privately owned industrial wells. An attempt was made to correlate changes in surface water levels attributable to the Project with changes in groundwater elevation. As part of this overall effort, observations were made within one of the conduit pump stations.

The ongoing effects of the Project are exhibited by the fluctuation of groundwater levels and the raising or lowering of the local piezometric surface. In general, the magnitude of observed effects is directly related to the specific horizontal bedrock fracture zone(s) intersected by a particular well, and inversely related (albeit weakly) to distance from the Project. Local hydrogeologic variation may cause deviations from these observed effects.

An important observation made during this investigation is that Niagara River water appears to be exiting the conduits through the gravity-driven conduit drainage system. At Pump Stations A and B, located along the conduits, groundwater from the external drains around the conduits can flow over weirs and enter the conduits and be conveyed to the forebay. The purpose of this design is to relieve excess hydrostatic pressure on the conduit walls. The observed flow pattern, from the conduits to the drainage system containing groundwater, indicates that a small volume of conduit water is passing over the weir into the drainage system and potentially entering the regional aquifer. The observed flow, however, represents a small fraction of the water in the conduits and is likely to occur only intermittently. It has been reported that the Falls Street Tunnel, a large rock-cut stormwater tunnel that crosses over the

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conduits, receives regional groundwater via fractures in the rock, including groundwater in the vicinity of the conduit drains. It has also been reported that the point where the conduits cross the Falls Street Tunnel lies within a highly fractured zone of bedrock through which water could readily move from the upper Niagara River.

Other observations include the predominant influence of the forebay on hydrogeologic flow zones intercepted by the conduits (presumably via the conduit drainage system), the short time-lag response in groundwater levels to fluctuations of the forebay and the apparent reversal of hydraulic gradients (from toward to away from the conduit drainage system and forebay) when the water elevation in the forebay is high.

Given the limitations on the location and the number of wells available for monitoring and the relatively short time-frame, additional investigations are recommended to further understand the effects of the Project and the flow of groundwater near the Falls Street Tunnel, Lewiston Reservoir, Tuscarora Nation, and other locations within the investigation area The present study is not regarded as definitive.

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1.0 INTRODUCTION

As part of the investigatory effort related to the FERC (Federal Energy Regulatory Commission) relicensing of the Niagara Power Project (Project), Lewiston, New York, the URS Team was requested by the New York Power Authority (NYPA) to evaluate groundwater flow patterns in the vicinity of the Niagara Power Project and to determine their relation to the Project. This report presents the results of that effort.

1.1 Investigation Area

The investigation area is bounded to the north by the Niagara escarpment, to the east by the Tuscarora Nation eastern boundary/Cayuga Creek, to the south by the upper Niagara River, and to the west by the lower Niagara River. (Figure 1).

1.2 Previous Investigations

The geology and hydrogeology of the Niagara Falls area have been described in a number of reports over the years. The baseline hydrogeologic study used for this evaluation was Johnston 1964, conducted during the installation of the conduits in the late 1950s. Johnston described the geology of the area in detail, with a significant discussion of regional hydrogeology prior to construction of the Niagara Power Project. Subsequent reports have included: Miller and Kappel 1987, Dupont et al. 1992, Yager 1996, and Yager and Kappel 1998.

1.3 Objective of Present Investigation

The overall objective of the present investigation is to determine the ongoing effects, if any, of the Project on local groundwater flow patterns. Specific ongoing Project effects of interest include:

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- High-volume withdrawals of water from the Niagara River upstream of Niagara Falls, with resulting fluctuation of surface water levels there,

- Daily and weekly cycles of surface water level fluctuation in the Lewiston Reservoir,

- Daily cycles of water level fluctuation in the forebay.:

- The conduits (including the intakes, pump stations, weirs, and external drainage system) that transport water from the upper river to the forebay, (see Figure 1).

Specific issues of concern include the effects of the Project on flow of groundwater to groundwater users, to area surface water bodies, and to manmade features. Since the Project is unlikely to have an effect below the geological unit known as the Lockport Group (see Section 2.0 below), the investigation focused on groundwater within this geological unit only.

2.0 LOCAL GROUNDWATER FLOW

To properly assess the ongoing effects of the Niagara Power Project on local groundwater flow it is necessary to have an understanding not only of manmade structures that might affect such flow, but also of the topography, geology, and hydrogeology of the region.

2.1 Topography and Geology

Except for the Niagara escarpment, the Falls, and the Niagara River gorge, the area around the Project is of relatively low relief. All surface water bodies in the investigation area drain northward to Lake Ontario directly, or indirectly via the Niagara River. The Niagara escarpment intersects the river on a generally east-west axis downstream of Niagara Falls, with its greatest relief (200 to 250 feet) at the river. Surface elevations are lower to the north of the escarpment than to the south.

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Due to extensive rock exposures in the Niagara River gorge and the many rock borings that have been completed for local environmental investigations, the regional geology is well understood. Throughout the region, a relatively thin layer of unconsolidated overburden overlies generally horizontal layers of sedimentary bedrock (Figure 2). The overburden layer in the investigation area is 5 to 15 feet thick, although in some places (southeast of the investigation area, along Tonawanda Creek) it reaches 80 feet. Three types of unconsolidated deposits comprise the overburden: (1) glacial till; (2) layers of lacustrine, or lake-deposited, clays, silts, and fine sands; and (3) lenses of sand and gravel (Johnston 1964). The till, which typically overlies bedrock directly, consists of an unsorted mix of boulders, clay, and sand deposited by the glacial ice sheet. The lacustrine deposits, which typically overlie the till, were deposited by the temporary lakes formed at the terminus of the glacier as it melted. Sand and gravel lenses are found wherever the lacustrine and till deposits were reworked at the margins of temporary lakes. They are uncommon in the investigation area.

Bedrock consists of nearly horizontal sedimentary rocks, deposited in a layered system with a surface slope (dip) approximately parallel to the land surface. The topmost section of bedrock is stratigraphically identified as the Lockport Group (Figure 2). The thickness of the Lockport Group over most of the investigation area is approximately 150 feet, although along the Niagara escarpment its thickness decreases to about 20 feet. Current stratigraphic correlations identify four units within the Lockport Group. From top to bottom they are the Guelph Dolomite (formerly known as the Oak Orchard Member), typically a medium to dark gray oolitic (composed of accretionary spheres of calcium carbonate) dolomite averaging 33 feet in thickness; the Eramosa Dolomite, typically a thick- to thin-bedded dark brownish-gray dolomite averaging 52 feet in thickness; the Goat Island Dolomite, typically a light olive to brownish-gray vuggy (porous) dolomite averaging 41 feet in thickness; and the Gasport Dolomite, typically a light pinkish-gray to dark olive-gray fossil-rich dolomite averaging 33 feet in thickness (Brett et al. 1995). In general, the thickness of the Lockport Group gradually decreases from south to north, and consequently the upper units are not present in the northern portions of the investigation area. The Lockport Group is continuous over the investigation area, outcropping along the Niagara gorge (all four units) and the Niagara escarpment (principally the Goat Island and Gasport units). In the Grand Island area (south of the investigation area), the Lockport Group is overlain by the Salina Group. The Lockport Group is underlain throughout the region by the Clinton Group, which contains the DeCew Dolomite (in contact with the bottom of the Gasport Dolomite) and the Rochester Shale as its two

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top units. It should be noted that the DeCew Dolomite was previously included in the stratigraphy of the Lockport Group (Johnston 1964).

2.2 Regional Hydrogeology

The presence of significant volumes of clay and silt in overburden soils in the investigation area, with inherent low hydraulic conductivities, prevents the overburden from being an economically important source of groundwater. Given this slow rate of water movement, overburden deposits in the area are considered a confining unit, limiting the recharge, or amount of surface water entering the underlying bedrock. Overburden groundwater flow is locally controlled, with minor horizontal flow along the more permeable, albeit infrequently occurring, seams. In some instances, bedding for underground utility lines, or former stream channels that cut into the surficial soil, may act as preferential pathways for horizontal flow. Despite this, direction of groundwater flow in the overburden, although limited in volume, is predominantly downward, recharging the underlying bedrock aquifer through infiltration of rainfall and snowmelt. Preferential localized recharge of the bedrock aquifer occurs where natural soils have been disturbed, as by landfilling or by excavation for structural foundations. Where such activities have disturbed or removed the confining overburden layer, direct vertical groundwater migration pathways have been created between the surface and the underlying bedrock.

Bedrock of the Lockport Group comprises the only regionally extensive aquifer system in the Niagara Falls area. From the top of the underlying bedrock to a depth of approximately 45 feet, the Lockport is fractured both horizontally and vertically. With increasing depth, the degree of fracturing decreases significantly, vertical fractures becoming especially infrequent. When fractures are concentrated in the same area, the water-bearing capacity of the bedrock is substantially increased.

Johnston (1964) identified an area of high groundwater yield in the Lockport Group bedrock near the north shore of the upper Niagara River approximately two miles upstream of the Falls. The area is approximately 2,000 feet wide and trends to the northeast from the shoreline for approximately 2 miles. The point where the Falls Street Tunnel (see Section 2.5.2) crosses over the two conduits lies within this more highly fractured zone.

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In the upper 15 feet of the top of bedrock, the Lockport is also more highly fractured as a result of weathering processes, and the water-bearing openings are typically widened by solution. This zone, therefore, referred to as the "weathered bedrock zone," has a higher permeability, and groundwater predominantly occurs as artesian water confined by the overlying, lower-permeability overburden soils.

Beneath the weathered bedrock zone, groundwater is transmitted principally along horizontal, more permeable bedding planes surrounded by lower-permeability rock (Figure 3). Within the Project area, 9 extensive horizontal water-bearing zones have been defined within the Lockport Group (Yager 1996). These bedding planes, or zones, are approximately parallel to one another, but slope southward with the geologic dip of the rock at about 30 feet per mile. As a result, as the Lockport is eroded and thins to the north (Section 2.1), the number of horizontal water-bearing zones is reduced as the shallower bedding zones are progressively eroded at the bedrock surface. (Figure 3). In the deeper water-bearing zones, groundwater conditions are exclusively artesian, with the individual horizontal zones generally forming separate artesian aquifers (Johnston 1964).

In contrast to the water-bearing Lockport Group, the underlying Rochester Shale has low enough permeability overall to be considered an aquitard (rock unit with insufficient pore openings to vertically transmit groundwater). The 55- to 60-foot thick Rochester Shale unit is exposed at the Niagara River gorge and along the face of the Niagara escarpment, but does not outcrop at the surface in the Niagara Falls area (Figure 3).

2.3 Groundwater Regime in the Investigation Area

2.3.1 Flow Patterns in the Upper Lockport

Regional groundwater flow in the Lockport Group generally radiates from topographic highs near the Niagara escarpment outward toward the Niagara gorge and Niagara River. A generalized map of groundwater flow for the region south of the Niagara Power Project and bounded by the Niagara River is shown in Figure 4. This map is based on June 1990 data from the uppermost bedrock aquifer zone presented in DuPont et al. 1992. As shown in Figure 4 and as described below, several manmade features

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appear to alter the natural pattern of bedrock groundwater flow in the area. (Note: Unless otherwise noted, all elevations are given in United States Lake Survey Datum 1935.)

2.3.2 Groundwater Recharge and Discharge

2.3.2.1 Recharge

Groundwater recharge occurs in the investigation area via both natural and manmade features. Natural recharge occurs throughout the investigation area in areas devoid of buildings or pavement, where precipitation infiltrates downward through the overburden into bedrock. Hydrologic zones within the lower bedrock units are recharged through horizontal bedding planes capable of transmitting groundwater, or through vertical fracture zones and joints that intersect the overburden/bedrock surface (Yager 1996). Natural recharge also occurs upstream of the Falls, where swift river currents scour the river bottom and have exposed the bedrock surface.

Recharge as a result of manmade features appears to occur in a few places (Miller and Kappel 1987). One of them is the Lewiston Reservoir (although leakage from the reservoir is retarded by an extensive grout curtain wall constructed beneath the reservoir dike). Recharge also appears likely throughout the area due to leakage from the City of Niagara Falls municipal water supply system and from unlined storm sewers that approach or intersect the underlying bedrock.

2.3.2.2 Discharge

A groundwater divide occurs between the Lewiston Reservoir and the Niagara escarpment, parallel to the escarpment. (Johnston 1964). The only source of groundwater from the divide northward appears to be natural recharge through infiltration. The escarpment serves as a discharge area for groundwater infiltrating north of the divide. From the western portion of the area lying south of the divide, the groundwater generally flows either towards the lower Niagara or towards the forebay. Shallow groundwater in the upper fractured rock and overlying unconsolidated deposits, however, moves

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toward and is captured by Fish Creek, which discharges into the lower Niagara River (Figure 4). Groundwater from the eastern part of the region between the divide and the reservoir flows around the eastern boundary of the reservoir, turns southwest and discharges either to the conduit excavation, the upper Niagara River, or the Redland Quarry (see Figures 4 and 5).

Discharge to the river occurs directly from point sources (e.g., via the Falls Street Tunnel, a known wet-weather discharge point [see Section 2.5.2]) or nonpoint sources (such as general seepage of groundwater from the face of the Niagara escarpment). It also occurs indirectly, from Niagara River tributaries (themselves recipients of groundwater flow from overburden deposits). The Niagara River is the principal receptor of groundwater discharge in the investigation area (Johnston 1964).

Any of several manmade structures may alter groundwater flow in the investigation area. The most significant of these are the NYPA conduits, the forebay, the Lewiston Reservoir, the Falls Street Tunnel (FST), local industrial groundwater remediation systems, and the Redland Quarry (Figures 4 and 5). Groundwater is extracted from remediation wells for treatment and subsequent (permitted) discharge to local sewers. It is extracted from the Redland Quarry to enable the continuance of quarry operations. These structures act as regional *point* drains, while the FST, conduits, and forebay act more as regional *linear* drains. (The Lewiston Reservoir, with a water level about 40 feet above natural land surface, is an area not of groundwater drainage, or discharge, but of artificial recharge (Yager 1996).) All these structures tend to alter the natural pre-industrial flow regime.

The Redland Quarry and local groundwater remediation systems remove a relatively small, but nonetheless significant, volume of groundwater from the investigation area. This removed water is discharged largely to surface waters, whether through local sewers or directly (as, for example, discharge of groundwater seeping into the Redland Quarry to a tributary of Cayuga Creek). It is unknown to what extent regional recharge from precipitation compensates for discharge.

As appears from Figures 4 and 5, the NYPA conduits seem to provide a preferential flow pathway for groundwater, whether via the excavation or through the conduit drainage system (see Section 2.5.1). The FST, an unlined storm sewer constructed in the Lockport Dolomite, provides a potential

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groundwater "sink" through which groundwater can discharge to the Niagara gorge (via the Niagara Falls wastewater treatment plant in dry weather, or directly to the river in wet weather) (Miller and Kappel 1987). Other sewers, such as the John Avenue Tunnel, may also act as sinks (Figure 4). It has been reported that the greatest discharge of groundwater to the FST occurs near the corner of 40th Street and Royal Avenue in the City of Niagara Falls, immediately west of where the FST crosses over the NYPA conduits (CDM 1982). Attempts to reduce infiltration to the FST were made in 1989 and 2000 (See Section 2.5.2).

Much has been made of this juxtaposition of the FST to the conduits. Some investigators have conjectured that groundwater discharge at this intersection is caused in part by the conduit drainage system, from which groundwater allegedly enters the FST to be discharged (in dry weather through the treatment plant) to the river. This hypothesis is supported by Miller and Kappel (1987), who suggest that infiltration to the FST at the conduit crossing results in a lower hydraulic head, which in turn causes groundwater in the conduit drains to flow south from the area of the forebay (depending upon water levels in the forebay) and north from the Niagara River to the FST. It is also supported by Yager and Kappel (1998), who suggest that Niagara River water seeps into the conduit drainage system through bedrock at the intakes, and flows northward to the area of the FST, into which, due to hydraulic head at that point, it discharges. DuPont et al. (1992), on the other hand, suggest that flow in the conduit drains is discharged primarily to the forebay. In addition, Johnston (1964) reported that the area where the conduits cross the FST lies within a highly fractured bedrock zone through which water could readily move from the upper Niagara River to directly infiltrate the FST. The present investigation was designed in part to provide further information on this issue.

2.4 Hydraulic Boundaries

2.4.1 Upper Niagara River and Chippawa-Grass Island Pool

The upper Niagara River, including the Chippawa-Grass Island Pool, forms the southern hydraulic boundary of the investigation area. (The Chippawa-Grass Island Pool is the 3-mile long river reach between Grand Island and the Upper Rapids, from which Niagara River water enters the conduits

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for gravity flow to the forebay [Figure 1]). Flow at the river's head averages 212,300 cubic feet per second (cfs). By the terms of the Niagara River Water Diversion Treaty of 1950 between the U.S. and Canada, flow over Niagara Falls must be at least 100,000 cfs during tourist season daylight hours, and at least 50,000 cfs at all other times, with remaining flow to be divided equally for power production purposes between the Niagara Power Project on the U.S. side and the Sir Adam Beck plants on the Canadian side (Figure 1). Flow over Niagara Falls is controlled primarily by the International Niagara Control Structure, a linear array of 18 sluice gates projecting halfway across the Niagara River from the Canadian shore, approximately 4,500 feet upstream of Niagara Falls. This structure also helps regulate water surface elevation in the Chippawa-Grass Island Pool. According to further international agreement (International Niagara Board of Control Directive, 1993), the change in surface elevation of the Chippawa-Grass Island Pool may not exceed 1.5 feet over a 24-hour period, as measured at the Material Dock staff gauge (location ID GO-MATERIAL) (Figure 1). Such daily fluctuation must remain within a stipulated three-foot range, although under abnormal flow or ice conditions that range may be extended to four feet.

2.4.2 Niagara Escarpment

The Niagara escarpment forms the northern topographical boundary of the area investigated. As described in Section 2.1, it is a generally east-west-trending cliff, with its greatest elevation differential, 200-250 feet, at the river (Figure 1). Groundwater is discharged from the face of the escarpment through a number of seeps and springs. The groundwater divide referenced in Section 2.3.2.2, located south of the escarpment, is the northern hydraulic boundary, separating northward groundwater flow (i.e., toward the escarpment) from southward flow within the investigation area..

2.4.3 Cayuga Creek

South of the Tuscarora Nation, Cayuga Creek demarcates the eastern boundary of the investigation area. Based on its classification as a groundwater drain in the model developed by Yager (2000), the creek is assumed to be a hydraulic boundary for the upper 45 feet of the Lockport Group, and therefore a logical eastern limit of the hydrogeologic investigation area. Cayuga Creek flows to the south

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(roughly parallel to Gill Creek, and about 15,000 feet to the east). It discharges into the upper Niagara (via the Little River) at Cayuga Island (Figure 1).

2.5 Hydraulic Influences in the Investigation Area

2.5.1 NYPA Conduits

NYPA's two parallel low-head conduits, which carry water below ground for approximately 4 miles from the upper river to the forebay (Section 2.5.3), convey an average of 70,000 cfs on an annual basis to the forebay. The conduit intakes are located on the river approximately 2,000 feet upstream of the mouth of Gill Creek (Figure 1). The conduits pass beneath the FST about 3,000 feet north of the intakes. Constructed of reinforced concrete, the conduits are installed in 100- to 160-foot-deep trenches excavated in the Lockport Dolomite. They are each horseshoe-shaped in cross-section, (flat on the bottom, arched on top), 46 feet wide at the base by 66.5 feet high (Figures 6 and 7).

The conduits are equipped with a network of gravity drains outside the walls and beneath the floor. These drains, hydraulically connected to two pump stations, one near each end of the conduit system, were designed to relieve hydrostatic pressure from groundwater on the exterior of the conduits in the event that the conduits ever had to be dewatered (Figure 8). Pump Station A is located north of the conduit intakes, and Pump Station B just upstream of the forebay (Figure 1). Hydrostatic pressure relief is needed only when the conduits are dewatered; pumping is not required at either pump station during normal operations. In 1974, to protect pumps and electrical equipment from corrosion damage, all such items were removed from both stations. The gravity drainage system remains hydraulically connected to both conduits (via sumps and weirs) and to the surrounding bedrock (Figures 7 and 8), which has been shown to be connected to both the Niagara River and the forebay (Miller and Kappel 1987; and Yager and Kappel 1998).

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2.5.2 Falls Street Tunnel

The FST, a 17,000-foot-long unlined rock tunnel, was hand-excavated through the Lockport Dolomite in the early 1900s (Figure 1). On its upstream (eastern) end it measures approximately 6 feet by 7 feet, and on its downstream (western) end, approximately 8 feet by 8 feet. The purpose of this and other tunnels was the transport of wastewater discharging from combined sewers throughout the city. The FST discharges directly to the Niagara River below the Falls. In 1938, a wastewater treatment plant (primary treatment only) was constructed at the foot of Ashland Avenue, about one mile downstream of the Falls (Figure 1). Wastewater was routed to this plant via the 3.3-mile-long Gorge Interceptor (GI) tunnel, which extended from the area of Devil's Hole southward along the river (Figure 1). In the late 1960s, a new 48-mgd treatment plant (on line by 1977) was constructed on Buffalo Avenue (above the Falls), and the Ashland Avenue plant was converted to the 20-mgd Gorge Pumping Station (GPS), designed to pump wastewater from the GI to the new plant via a new Gorge Forcemain. As part of this overall effort, the Southside Interceptor (SSI) tunnel was completed, paralleling the FST (Figure 1). Depending on wastewater volume, flow may be diverted to either the SSI or the FST. During wet weather, a portion of FST flow is conveyed to the plant and the remainder is discharged to the river. During normal (i.e., dry weather) conditions, 100% of FST flow is conveyed to the plant (Figure 1).

The NYPA conduits pass beneath the FST at Royal Avenue (Figures 1 and 6). Since the conduits pass below the FST, the FST had to be bisected at that point to bed the conduits. The 300-foot section of tunnel intersected by conduit construction was afterwards reconstructed as a 7-foot diameter concrete pipe contained within a concrete vault. Two 100-foot sections of pipe were direct-buried immediately east and west of the vaulted section, as a transition from concrete pipe to the open-rock tunnel.

Because of the volume of stormwater flow brought from the FST into the city's wastewater treatment plant, leakage of groundwater into the FST has proven to be a significant problem for the City of Niagara Falls. As mentioned in Section 2.3.2.2, the greatest volume of groundwater inflow has been noted at the FST's crossover of the NYPA conduits (CDM 1982). In 1989, in an effort to decrease dry weather flow and increase wet weather capacity at the plant, the City of Niagara Falls initiated a number of measures to reduce groundwater flow into the FST or to divert it. These efforts have included:

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- dewatering the vault and injecting grout sealant into vault cracks;
- installing external seals around pipe joints within the vault;
- installing new internal end seals where the pipe exits the vault;
- injecting grout through the pipe in the direct-burial sections;
- adding a diversion dam.

These efforts reduced inflow within the piped section to zero but diverted groundwater to the upstream and downstream rock sections, ultimately reducing inflow by only about one-half. In 1994, it was reported that 6-7 mgd (about 20 percent of average treatment plant flow) was infiltrating a 200-foot section of the FST immediately downstream (west) of the NYPA conduits. In 2000, a grouting project was completed along this section of tunnel, reducing the inflow to about 1.6 mgd (about 5 percent of average treatment plant flow). Additional flow reduction projects are being evaluated.

2.5.3 Forebay

The forebay is located at the northern, or downstream, terminus of the conduits, between the Robert Moses Niagara Power Plant and the Lewiston Pump Generating Plant (Figure 1). It lies on an east-west axis. Niagara River water flows from the conduits into the forebay, where it becomes available for passage through the Robert Moses Plant or for pumping into the Lewiston Reservoir. The forebay is approximately 4,200 feet long, 500 feet wide, and 110 feet deep. The walls and base of the forebay are bedrock. Near the conduit outlet, the forebay penetrates the bottom of the Lockport Group into the Rochester Shale (Figure 6). During typical operations in 2002, forebay surface levels fluctuated between 6 and 19 feet (Figure 9).

2.5.4 Lewiston Reservoir

The Lewiston Reservoir occupies approximately 3 square miles of land east of the forebay and the Lewiston Pump Generating Plant (Figure 1). It is surrounded by a 6.5-mile-long, 55-foot-high earth- and rock-filled dike containing a clay core. Releases from the 1,900-acre reservoir are used to supply extra power during peak usage periods (daytime weekdays and at periods during the weekend), with

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reservoir water being passed through the Lewiston Pump Generating Plant while water from the forebay is being passed through the Robert Moses Plant. Reservoir water is replenished by pumping from the forebay during non-peak-usage periods (nighttime weekdays, and throughout the weekend). Since water withdrawn for power generation during the week cannot be replenished as quickly as it is used, a net water loss occurs from Monday through Friday. The reservoir exhibited a maximum net draw down of approximately 36 feet over that period in 2002 (NYPA 2002). Normal Monday morning levels are restored by pumping from the forebay over the weekend. In addition to a weekly cycle, reservoir surface water elevations exhibit a daily cycle over a 24-hour period Monday through Friday (NYPA 2002) (Figure 9).

2.5.5 Gill Creek

Gill Creek, which flows southward across the investigation area, discharges into the upper Niagara River downstream (west) of the NYPA intakes (Figure 1). The headwaters of Gill Creek at one time flowed through what is now the southeast corner of the Lewiston Reservoir. When the reservoir was constructed, Gill Creek was rerouted around the dike at the reservoir's southeast corner. During periods of low precipitation NYPA augments Gill Creek flow by release of water from the Lewiston Reservoir (up to 3 cubic feet per second).

2.5.6 Redland Quarry

The Redland Quarry is an operating limestone mine with a reported maximum depth of 140 feet below ground surface (approximately El. 484 feet). It is located approximately 7,500 feet southeast of the Lewiston Reservoir (Figure 1). In order to maintain a dewatered (i.e., operational) state within the mine, groundwater is extracted from sumps in the mine and discharged to a tributary of Cayuga Creek. The extraction and discharge of groundwater at the mine is regulated by State Pollutant Discharge Elimination System (SPDES) permit #NY0025267. As reported by the New York State Public Notice for SPDES Renewal dated September 25, 2002, the mine is permitted to discharge a maximum of 432,000 gallons of water per day (300 gallons per minute) to Cayuga Creek.

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2.5.7 Other Influences

A number of additional structures and activities may alter the natural flow of groundwater in the investigation area. Potential flow-altering influences in the area include: (1) industrial site remediation pumping systems (for control of groundwater flow); (2) remediation system grout curtains (vertical sections of grouting of bedrock to limit horizontal flow of groundwater); (3) capped landfills (which may reduce surface area that provides natural groundwater recharge); and (4) municipal sewers and tunnels (whose excavations introduce preferential pathways for groundwater flow).

Three operational extraction wells that exhibit sufficient drawdown to alter regional groundwater flow are plotted on Figure 4 (DuPont et al. 1992). The status of present-day remediation systems and their current effect on the regional groundwater flow regime are unknown and were beyond the scope of this study. However, the remediation systems would be expected to produce a confined aquifer response as portrayed in Yager's model results (Yager 1996).

3.0 INVESTIGATION ACTIVITIES

Field investigations were conducted to assess the ongoing effects of the Project on groundwater direction, gradients and fluctuations. Data obtained from these investigations were used primarily to evaluate:

- temporal and spatial effects of Project-induced changes in groundwater level on groundwater flow patterns and discharge to downgradient groundwater users; and
- the question of discharge to or from the conduit drains at Pump Stations A and B.

Prior to the commencement of field monitoring efforts, the identification of existing groundwater and surface water monitoring wells and staff gauges was necessary. Wells were identified through a review of well lists in public documents maintained by the New York State Department of Environmental Conservation (NYSDEC), NYPA, and in other public document repositories. From the reports, data were collected on more than 500 wells that might potentially be used to conduct the groundwater study. These were NYPA-owned, industry-owned, and government-owned. On the basis of well age, location,

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construction details, and accessibility, a subset of candidate wells was selected for field verification. The location of each well to which access was granted in the subset was field-verified as to physical condition and usability. From the field-verified wells, approximately 40 NYPA-owned and 25 privately owned and government-owned wells were identified to be potentially usable for the investigation. Due to problems of physical accessibility or denial of access to property by landowners, only 30 of these 65 wells proved usable in the investigation. A list of staff gauges and wells used to collect data within this investigation area is presented on Table 1.

Surface water and groundwater elevations were monitored throughout the investigation area. This monitoring extended to: (1) the Niagara River, including Niagara Falls and the Chippawa-Grass Island Pool; and (2) Lockport Group groundwater monitoring wells generally screened in the upper 45 feet of bedrock and accessible to investigators, especially in the investigation area of the Project (i.e., conduits, forebay, and Lewiston Reservoir). Surface water levels were monitored by means of staff gauges owned by NYPA and the National Oceanic and Atmospheric Administration (NOAA). Groundwater monitoring was carried out in wells owned by NYPA, various government agencies, residents of the Tuscarora Nation, and local industry. Groundwater monitoring was accomplished by means of electronic dataloggers (Troll 4000® or MiniTroll Pro®, by In-Situ, Inc.®) set to record water pressure and temperature. Datalogger pressure readings were converted by the internal datalogger software from pounds per square inch (psi) to feet of water column using standard mathematical conversions (with internal barometric compensation accomplished via an integral tube in the cable). Water column values were then correlated to water elevations using corresponding manually measured water levels from surveyed measuring points at each well. Complete survey data for groundwater measuring points are given on Table 2.

In June 2002, an effort was made to gather data from within the conduits by making measurements inside one or both pump stations (Figure 1). A detailed summary of a field visit conducted on June 13, 2002, is presented in Appendix A of this report. Due to physical restrictions of the facilities themselves, measurement of water levels was not accomplished, although some visual observations were made.

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Other data such as geological, meteorological, topographical, etc., were also factored into the analysis.

3.1 Monitoring of Niagara River Surface Water Levels

Data on Niagara River surface water levels were collected using existing NYPA and NOAA staff gauges. Over the month of August 2002, staff gauge data were gathered hourly (Table 3). Surface water gauges were monitored at the American Falls (Gauge ID: NOAA-NFALLS3009), near the NYPA intakes (Gauge ID: GN-RIVER_INT), and about 6,000 feet upstream of the Chippawa-Grass Island Pool (Gauge ID: GN-LASALLE). One surface water gauge located in the Chippawa-Grass Island Pool (Gauge ID: GO-MATERIAL) is used to measure the official water level fluctuations to determine compliance with U.S. and Canadian agreements on the use of the Niagara River for power generation. However, for the purposes of this study, it was determined that the water levels recorded at the GN-RIVER_INT gauge were better for the evaluation of Project effects on groundwater within the investigation area. See Figure 10 for surface water gauge locations.

3.2 Monitoring of Groundwater Levels

Groundwater elevation data were collected from 30 wells distributed widely across the investigation area. Information pertaining to the construction and installation of these wells is provided on Table 2. As mentioned above, in addition to NYPA-owned wells, data were gathered from wells on lands of the Tuscarora Nation, or owned by government entities or local industry (Table 3). Locations of groundwater wells monitored during this investigation are shown in Figure 10. For meaningful analysis of results, wells were grouped not on the basis of ownership, but rather of geographic location in relation to major influences and areas of interest. Four groups were established as follows:

- Conduit Observation Wells (OW-206D, OW-400D, OW-650D and OW-157);

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- Tuscarora Nation (TN-01, TN-02 and TN-05) and Lewiston Reservoir (NW-05, NW-16, OW-212, OW-186, OW-189, OW-193 and OW-198) wells;

- Upper Niagara River (MW-15, MW-16, DEC-3R, DEC-4R and DEC-5R) and City of Niagara Falls (NFB-6 and 85-2) wells; and

- Conduit-Influence Wells (VH-147D, VH-147F, VH-148B, VH-148C, VH-148D, VH-152B/C, VH-152C/D, VH-156C and VH-156D).

3.2.1 Conduit Observation Wells

Groundwater levels in four bedrock wells along the conduits (namely, OW-157, OW-206D, OW-400D, and OW-650D) were monitored using dataloggers (Figure 10). Except for OW-206D, which lies approximately 1,500 feet from the intakes, these "conduit wells" are generally located along the route of the conduits (PASNY circa 1963). The "OW" wells along the conduits were originally installed as well pairs to monitor groundwater near the conduits. Wells (e.g., OW-650D) installed near the outer edge of the conduit right-of-way (usually within 50 feet of the conduits) were drilled through rock to a depth below the conduit invert. Wells installed between the two conduits (e.g., OW-157) were angle-drilled to intercept the continuous corner drains (see Figure 8) (PASNY circa 1963). Conduit observation wells were not constructed to monitor discrete hydrogeologic flow zones. Data from conduit groundwater monitoring wells were collected at 5-minute intervals from August 6 through 27, 2002.

3.2.2 Tuscarora Nation and Lewiston Reservoir Wells

Groundwater levels in three bedrock wells located on Tuscarora Nation lands and seven Lewiston Reservoir dike-monitoring wells located on NYPA land were monitored using dataloggers (Figure 10). The wells monitored on Tuscarora lands were identified as TN-01, TN-02, and TN-05, and the seven reservoir dike wells were those prefixed by OW or NW (Figure 10). Wells TN-01 and TN-02 are abandoned residential supply wells. TN-05, near the reservoir's southeast corner, is an active well,

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supplying limited volumes of groundwater to a small business. A subset of reservoir wells with dataloggers (NW-05, NW-16, OW-112, OW-186, OW-189, OW-193 and OW-198) was selected to represent the effects of the reservoir and to limit the volume of data presented. Datalogger data from the Tuscarora Nation wells were collected at 5-minute intervals from August 7 through August 27, 2002. Datalogger data from the reservoir wells were collected at six-hour intervals from August 1 through August 31, 2002.

Reservoir wells designated "OW" were installed between 1958 and 1960 (during reservoir construction) to provide data for the evaluation of the reservoir dike stability. The OW wells were constructed as 6-inch diameter wells set directly above or below the bedrock surface. Wells designated as "NW" were installed in 1991 as piezometers using 2-inch ID PVC casings and 20-foot-long 0.01-inch slotted screens. Wells NW-05 and NW-16 are set 54 feet and 49.7 feet into bedrock, respectively. Well construction details for the Tuscarora Nation wells are not available. The total depth measurements (below top of casing) for TN-01, TN-02 and TN-05 were 40.10 feet, 39.00 feet and 52.81 feet, respectively (approximately 39, 38, and 52 feet below ground surface, respectively).

The differences in the construction of the different types of wells (i.e., monitoring versus residential supply, and screened versus unscreened) may influence the comparisons of water levels between wells due to uncertainty in the flow zones intercepted by each well.

3.2.3 Upper Niagara River and City of Niagara Falls Wells

Groundwater levels in five bedrock monitoring wells along the upper river and two further inland (within the City of Niagara Falls) were monitored using dataloggers (Figure 10). Two wells (MW-15 and MW-16) are owned by a local industry, three (DEC-3R, DEC-4R and DEC-5R) by NYSDEC, and two (NFB-6 and 85-2) by the United States Geologic Survey (USGS). (DEC-3R and MW-16 on the one hand, and DEC-4R and MW-15 on the other, although they are separate wells, are constructed as functional duplicates.) The NYSDEC- and industry-owned wells are located along the north shore of the Chippawa-Grass Island Pool. The USGS wells are located away from the river (Figure 10). At all seven wells, water level data were collected at 5-minute intervals for up to 18 days, depending on location.

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3.2.4 Conduit-Influence Monitoring Wells

To investigate conduit influence at some distance from the conduits, groundwater levels in nine industry-owned bedrock wells east of the conduits were monitored using dataloggers. All nine wells belong to DuPont Corporation. Seven of the nine wells are located in a more or less straight line, perpendicular to the conduits, making it possible to note attenuation of effect with distance from the conduits (Figure 10). The closest well is 2,000 feet from the conduits, and the farthest, 6,400 feet. These wells were expected to provide an indication of the lateral extent of influence of the conduit external drains on local groundwater flow patterns.

4.0 RESULTS

4.1 Surface Water

4.1.1 Niagara River and Chippawa-Grass Island Pool

Water level fluctuations related to power generation were recorded by the three gauges on or near the Niagara River (GN-AM_FALLS3009, GN-RIVER_INT, and GN-LASALLE) (Figure 11B). Water level fluctuations in the Chippawa-Grass Island Pool result from natural flow and from both Ontario Power Generation (OPG) and NYPA operations. As represented by the gauge near the intakes (GN-RIVER_INT), water level elevations in the Chippawa-Grass Island Pool respond to withdrawals of water by U.S. and Canadian power plants (Figure 11C). The three gauges exhibited parallel responses of similar magnitude, with a monthly maximum fluctuation of 1.6 to 2.0 feet (Figure 11B). The most upstream location (GN-LASALLE, upstream of the intakes) exhibited the least fluctuation (between El. 564.3 and 562.7 [1.6 feet]). The intake gauge (GN-RIVER_INT) showed the greatest fluctuation (between El. 564.1 and 562.1 [2.0-feet]). The gauge at the American Falls (NFALLS3009), further downstream of the intakes, fluctuated between El. 561.0 and 559.2 (1.8 feet). A summary of minimum, maximum, and total displacements is provided on Table 4. For this same time frame (i.e., August 2002), daily water level fluctuations at the Material Dock gauge, used as the official gauge of surface water fluctuations in the Chippawa-Grass Island Pool, were less than 1.5 feet per day (URS et al. 2003)

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The time lag exhibited between Chippawa-Grass Island Pool and forebay fluctuations is typically one hour or less, as shown in Figure 11D.

4.1.2 Forebay and Lewiston Reservoir

The largest overall water level fluctuations were seen in the forebay and the Lewiston Reservoir. During August 2002, these ranged between El. 562.8 and 542.9 (19.9 feet) in the forebay and between El. 658.4 and 624.8 (33.6 feet) in the Lewiston Reservoir (Table 4 and Figure 11E).). While the fluctuation patterns of both water bodies are similar, the fluctuations in the reservoir are controlled by the operational response to peak demand for power and are independent of the water levels in the forebay. When demand is high, typically during weekday daylight hours, the reservoir is drawn down and water levels drop. When demand is low, typically at night, water is pumped into the reservoir and water levels rise.

4.1.3 Conduits

On June 13, 2002, a field visit was conducted in Pump Stations A and B (Appendix A). In Pump Station A the flow direction over the east weir (El. 560 feet), connecting the pump station to the east conduit, was observed to be from the conduit into the pump station. The weirs were designed and built with flap gates (baffles) that open to allow water to flow from the pump station (which derives water from the conduit drainage system) into the conduits and then close to inhibit flow from the conduits into the pump station (Figure 8). During the June 2002 field visit flow over the east weir was observed to be from the conduits to the pump station. The depth of water flowing over the weir was approximately one inch at the weir crest (the weir is approximately 1.5 feet wide) (Appendix A). (It is likely that depth would vary, depending on surface elevation of the Chippawa-Grass Island Pool or the forebay.) With respect to the west weir, which connects the pump station to the west conduit, since only the wet-well side of the weir could be observed (due to obstruction of the conduit-side view by baffles), flow direction could not be determined. Turbulence along the baffles was, however, visible.

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4.2 Groundwater

4.2.1 Conduit Observation Wells

Three of the four conduit observation wells monitored (OW-400D, OW-650D, and OW-157), exhibited notable changes in response to fluctuations in forebay level, which produces a similar response at the river intake (Figures 11G, H and I, respectively, and Table 4). One well, OW-206D, maintained a steady elevation, exhibiting no fluctuation except for a "slug effect" (not shown in the plot) immediately following insertion of the datalogger (Figure 11F). OW-206D is a relatively deep well (greater than 150 feet below ground surface) and is presumed (based on assumed well construction and lack of fluctuation) to be unconnected to water-bearing zones of the Lockport Group. The apparent maximum response was exhibited at OW-650D, where the total displacement was 5.3 feet (Table 4). However, the total displacement in OW-157 may in fact have been greater, due to the fact that water levels dropped below the elevation of the datalogger during periods of low groundwater elevation (as seen in Figure 11I), and consequently, the minimum elevation at OW-157 was not recorded.

Average groundwater piezometric elevations recorded from conduit observation wells for August 2002, were plotted along with contours presented in the Johnston and DuPont reports (Johnston 1964 and DuPont et al. 1992) (Figure 12).

4.2.2 Tuscarora Nation and Lewiston Reservoir Wells

The three Tuscarora Nation wells monitored exhibited a general trend of decreasing water level elevation during the August 2002 monitoring period, with an approximate (linear) rate of -0.06 feet per day. In TN-05, the recovery that followed periodic pumping from the well stabilized at a steadily lower static head (Figures 11J and K) at the same daily rate (-0.06 feet per day). The minimum and maximum elevations and overall displacement in each well are presented on Table 4. The seven reservoir-monitoring wells exhibited overall linear decrease in head that ranged from 0.027 (OW-198) to 0.053 (NW-16) feet per day (Figures 13B through H and Table 5). This observed overall decrease in

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groundwater elevations is considered typical for summer's end (seasonal effect), a normally dry time of year, and is not related to reservoir fluctuation (Johnston 1964 and Miller and Kappel 1987).

Cyclic fluctuations corresponding to fluctuations of the reservoir surface were observed in reservoir monitoring wells NW-05, NW-16, OW-189, and OW-198 (Figures 13B, C, F and H).

More muted fluctuations, which did not appear to correspond to either forebay or reservoir fluctuations, were observed in the Tuscarora Nation wells TN-01 and TN-02 (Figure 13I). These well fluctuations did, however, exhibit an inverse correlation to changes in barometric pressure, as would be expected from wells constructed in a confined or semi-confined aquifer. (Barometric data recorded at the Niagara Falls International Airport during the investigation period were downloaded from the National Oceanic and Atmospheric Administration [NOAA] website.) In order to more easily visualize the correlation of the Tuscarora well response to barometric pressure and to reduce the number of curves plotted, water level data from TN-02 was used as the representative for Tuscarora wells. Figure 13J presents the raw unedited water level data for TN-02 and barometric pressure (inverted). Corrections for the observed seasonal drop were made to TN-02 water levels by adding 0.0611 feet per day (the slope of the linear regression trend line TN-02) to each water level reading from TN-02. The initial elevation (608.32 feet at 10:30 am, August 7, 2002) was used as a benchmark elevation and the resultant elevations were plotted as "corrected" values (Figure 13K).

Average groundwater piezometric elevations recorded from NW, OW and Tuscarora Nation wells for August 2002 were plotted along with contours presented in Johnston's report (Johnston 1964) for comparison (Figure 12).

4.2.3 Upper Niagara River and City of Niagara Falls Wells

Groundwater levels were recorded from five wells along the upper Niagara River (MW-15, MW-16, DEC-3R, DEC-4R, and DEC-5R) (Figures 14B through F). MW-16 and DEC-3R (paired duplicates) are approximately 2,200 feet west of the conduit intakes, MW-15 and DEC-4R (paired duplicates), 3,000

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feet west of the conduit intakes, and DEC-5R, 4,000 feet west of the conduit intakes. All five wells are constructed to similar depths and all are approximately 300 feet from the river.

Fluctuations observed in all five wells were parallel to fluctuations recorded from staff gauges in the Niagara River (Figure 11B).

Neither 85-2 nor NFB-6, both wells located further from the river, exhibited a response to the Project, namely, to fluctuations in the surface elevations of the forebay or Chippawa-Grass Island Pool (Figure 14G and H). Well 85-2 exhibited an apparent seasonal decline (0.04 feet/day) (Figure 14I) similar to the declines observed in reservoir and Tuscarora Nation wells (Table 5). Well NFB-6 did not exhibit a seasonal decline, possibly due to its proximity to the Niagara River and increased potential for recharge from the river (relative to 85-2), but did exhibit fluctuations that were in apparent response to fluctuations in barometric pressure (Figure 14J).

Average groundwater elevations for all upper Niagara River and City of Niagara Falls wells for August 2002 are shown on Figure 12. Measured values for the upper Niagara River wells correlate with typical elevations for the river, as would be expected. However, measured values for 85-2 and NFB-6 do not correlate with river elevations (Figure 14K) or with contour elevations presented in the DuPont report (DuPont et al. 1992).

4.2.4 Conduit-Influence Monitoring Wells

Conduit-influence monitoring wells exhibited fluctuations in apparent response to both Project and non-project effects (Figure 15B through J). Three of the nine wells monitored, (VH-147D, VH-147F and VH-156D) exhibited an apparent response to fluctuations within the forebay, as indicated by the similarity in patterns with the forebay (Figure 15K). Well VH-148D exhibited responses to both the forebay and barometric pressure (Figures 16B and C). Observed responses in other wells were minimal and generally correlated only with barometric pressure (Figures 16D through H). The minimum and maximum elevations and overall displacement in each well are presented on Table 4.

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5.0 DISCUSSION

5.1 Surface Water

To properly evaluate Project effects on groundwater flow, it is necessary first to understand the relationship between the Project and surface water bodies.

Power generation effects on the upper Niagara River (which, when discussing the Niagara River, must include both Sir Adam Beck [i.e., Canadian] and Niagara Power Project operations) are understood to be only a component of the total influences affecting observed daily surface water level fluctuations. The Project contributes to the daily sinusoidal fluctuations on Niagara River levels, and is directly responsible for changes in water levels in the forebay and Lewiston Reservoir.

During the August 2002 monitoring period, surface water elevations in the upper Niagara River (both upstream and downstream of the conduit intakes) were seen to range between approximately El. 560 and 564 feet (Table 4). The sinusoidal fluctuations of surface water levels in the Chippawa-Grass Island Pool were observed to respond to the Project (specifically, the diversion of water from the upper Niagara River and release of water from the forebay and reservoir), understanding that river water is being diverted from the Chippawa-Grass Island Pool for similar operations on the Canadian side. The magnitude of the observed fluctuations in the river is relatively small when compared to the observed fluctuations in the forebay and reservoir (see Table 4 and Figures 11C and E).

It appears that a relatively small fraction (relative to the volume of surface water in the conduits) of conduit-conveyed surface water enters Pump Station A from flow through the pump-station weir (Appendix A). This flow (from the conduits to the conduit drainage system with the implication of continued flow into the aquifer) is conceptually possible on the basis of hydraulic head differences between the potentiometric surface within the bedrock and the pump station weir elevation of 560 feet (Figure 8). During the August 2002 monitoring period, the elevation of groundwater in the bedrock (in the area where the conduits pass under the FST, as represented by OW-650D) fluctuated between El. 553.65 feet and 558.97 feet. However, whether or not water is actually flowing from the conduit drainage

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system to the aquifer depends on the fluctuations of the forebay and the relative elevation between the conduit drainage system and the surrounding bedrock. It is likely that flow occurs from the conduits to Pump Station A when the water level in the forebay (conduit outlet) is high. When the water level in the forebay is low, however, the head in the conduits at Pump Station A likely falls below the elevation of the weir and flow would then cease. Estimates of flow and frequency of flow from within the conduit drainage system are not possible from current data. Additional study of the flow and frequency will be conducted in upcoming investigations.

5.2 Groundwater

Groundwater elevations in the Project vicinity appeared to fluctuate in response to both natural (barometric and seasonal hydrologic regime) and Project influences. Project influences include fluctuations in levels of the forebay and reservoir, and, to some extent, fluctuations in levels of the Chippawa-Grass Island Pool. The effect of the Project on area groundwater is demonstrated by the hydraulic response of individual wells, which was found to depend on well depth, geology, and distance from the Project (conduits, forebay, and reservoir).

In addition to short-term Project induced fluctuations in groundwater levels, a similar lowering or raising of groundwater piezometric surface was observed in specific regions of the investigation area. With the exception of wells OW-112, TN-01, TN-02, VH-147D, VH-147F, NFB-6 and 85-2, investigation groundwater elevations correlate fairly well with the contour elevations presented in Johnston 1964 and DuPont et al. 1992 (Figure 12), and confirm ongoing Project effects on area groundwater.

In general, based on observed groundwater elevations, regional groundwater flow is toward the conduits and forebay, and away from the reservoir (Figure 12). The conduits act as regional linear groundwater drains (Miller and Kappel 1987) and the reservoir acts as a regional area of groundwater recharge (Johnston 1964).

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Typical groundwater hydraulic gradients in the Project area vary with location relative to the Project conduits, forebay, and reservoir. Gradients are on the order of 0.004 feet per foot (ft/ft) (southwest portion of investigation area, west of conduits), to 0.014 ft/ft (southeast portion of investigation area, east of conduits), to 0.05 ft/ft (northwest portion of investigation area, west of conduits) (Figure 12). In general, hydraulic gradients are greatest in the north between the conduits and forebay and, between the reservoir and forebay (Figure 12).

Additional well installations and studies are planned to more accurately define the area of hydraulic influence and specifically address several uncertainties, including:

- Insufficient data to establish groundwater flow contours near Project features (as exhibited near TN-01 and TN-02);
- Effect of Project-induced water level fluctuations on the groundwater head and flow direction in multiple geologic zones (as exhibited by VH-147D and VH-147F);
- Inconsistent nomenclature of bedrock units, resulting in poor correlation of groundwater-producing bedding zones from location to location within the study area; and
- Effect of time on hydrologic relationships (e.g., seasonal effects, or changes in operational status, e.g., summer vs. winter, tourist vs. non-tourist).

5.2.1 Conduit Observation Wells

Based on August 2002 observations in OW-650D (located immediately south of the FST and Pump Station A) and similar observations by Yager and Kappel (1998) in OW-139 (located immediately north of the FST), water level fluctuations in the observation wells exhibited patterns similar to those of the forebay (Figures 11H and 16I). Also, typical hydraulic gradients between corresponding peaks in the near-river well OW-400D and OW-650D are greater than the gradients between OW-650D and OW-157

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(Figure 16I), reflecting the effect of the overlapping hydraulic influence of the river and forebay or possibly greater hydraulic connectivity between OW-650D and OW-157. The response time of the conduit observation wells to fluctuations of the forebay is nearly instantaneous, with apparent lag time progressing toward the Niagara River at less than one hour (Figure 16I).

Hydraulic gradients between conduit observation wells, the intake staff gauge and forebay vary in magnitude and direction, depending on whether the water level in the forebay is high or low. When the forebay is low, gradients are at their highest and all toward the forebay. When the forebay elevation is high, the gradients are generally reduced, with occasional gradient reversals. A representative daily cycle in the response of the conduit-influence wells is depicted in Figure 16I (August 23, 2002). During high-forebay-elevation conditions the gradient between OW-650D and OW-157 was observed to flatten and approach a no-flow condition, while the gradient between OW-157 and the forebay appeared to reverse (Table 6).

5.2.2 Tuscarora Nation and Lewiston Reservoir Wells

The reservoir, when filled, appears to exhibit an effect on local groundwater elevations (Johnston 1964). Johnston (1964) presented groundwater contours before and after reservoir flooding. These contours showed a significant rise (up to 17 feet) in groundwater elevation. It was, moreover, reported that, as a consequence of the flooding, an area of artesian flow developed on the western portion of the south dike. The artesian condition has been persistent, as observed during a field reconnaissance of reservoir wells on March 18, 2002, when groundwater was observed flowing under artesian conditions from OW-202. Johnston concluded that the reservoir acts as a source of groundwater recharge to the bedrock, despite the clay and silt covering the bedrock at the bottom of the reservoir and the grout curtain that had been placed beneath the entire length of the reservoir dike.

In general, the rise in groundwater elevations observed by Johnston was confirmed by the elevations measured for this study in all NW and OW wells (except OW-112) and TN-05. OW-112, TN-01 and TN-02 exhibited elevations lower then would be expected based on the piezometric contours

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presented by Johnston (Figure 12) but may be related to conditions mentioned in Section 4.2.2. Further study is proposed to evaluate this observation.

Over the duration of the investigation, groundwater levels in Tuscarora Nation wells exhibited a steady downward trend (considered to be seasonally related). This general lowering of the groundwater surface was also noted in other wells throughout the investigation area (Table 5). Groundwater levels in the Tuscarora wells exhibited the greatest daily drop (0.06 feet per day) of all wells showing a decline.

An analysis of the elevation trends in TN-02 was conducted to determine the source of the fluctuations observed in the well. Corrections for the apparent seasonal drop (Figure 13J) were made by adding 0.0611 feet per day), to the initial elevation (608.32 feet at 10:30 am, August 7, 2002) as a benchmark elevation (Figure 13K). With a reset scale, the graph shows a good visual correlation between the corrected elevations and barometric pressure. While minor deviations do exist between the plots, the overall similarities in the shape of the curves indicate that barometric pressure dominates the day-to-day fluctuations in TN-02 and presumably TN-01 (due to the similarities in the data between the two wells). Analysis of TN-05 was not possible due to its use as a supply well.

5.2.3 Upper Niagara River and City of Niagara Falls Wells

Project effects on groundwater, as exhibited in upper Niagara River and City of Niagara Falls monitoring wells, was limited to response to fluctuations in the Niagara River, of which the Project induces only a component of the total flux.

5.2.4 Conduit-Influence Monitoring Wells

Fluctuations in groundwater levels were observed at relatively long distances from the Project (up to 2,900 feet), and in some cases these fluctuations were as great as those observed in wells closer to the Project (Table 4 and Figures 16B and 16J).

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As indicated by the responses between some well pairs (VH-147D and F and VH-156C and D), fluctuation of the potentiometric surface in the deeper wells (namely, VH-147F and VH-156D) was generally greater than fluctuation in shallower wells (VH-147D and VH-156C) (Figures 16K and 17B). The deeper wells (VH-147F and VH-156D) exhibited absolute fluctuations of 5.87 feet and 2.93 feet, respectively, and the shallower wells (VH-147D and VH-156C) exhibited fluctuations of 3.53 feet and 0.26 feet, respectively (Table 4). The fluctuations in VH-156C were not sinusoidal and are presumed to result from barometric and the seasonal influences, as observed in other wells in the study. The "D-zone" wells exhibited very similar responses despite being separated from one another by approximately 1,500 feet (Figure 17C).

A reversal in the direction of groundwater flow (toward the conduits) appears to occur during high water levels in the forebay. This is suggested when the head in the conduit drainage system (as represented by the average of elevation measured in OW-650D and OW-157) rises above the head in the D-zone (as represented by VH-147D), but not in the F-zone (as represented by VH-147F) (Table 7 and Figure 17D).

It is likely that hydrogeologic characteristics of individual flow zones vary with geographic location. In addition, the limited response of the shallower (B and C) zone wells may be due to the fact that the water level in the shallower zones lies above the elevation of groundwater in the conduit drainage system, and would consequently be less responsive to gradient changes.

Measured fluctuations in observation wells were not instantaneous with the fluctuations in the forebay. The more highly responsive observation wells (VH-147D, VH-147F and VH-156D) exhibited a time-lag ranging from 1.5 to 4 hours (Figure 17E). Accurate determination of lag times for VH-147D and VH-156D was not possible due to their relatively flat hydrographs, but lag times are approximately 4-hours .

In general, bedrock wells that did not exhibit responses that correlated with Project-induced fluctuations, did exhibit responses that correlated with changes in atmospheric pressure. The response of water levels in artesian aquifers to changes in atmospheric pressure has been well established in the

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hydrogeologic literature (Ferris et al. 1962), and all artesian aquifers will exhibit a response (the barometric response, however, may be overwhelmed by other influences, as seen in this study). Rising atmospheric pressure causes the water level to decline, and falling pressure causes the water level to rise. Water table aquifers do not ordinarily exhibit this response since, by definition, they are in direct contact with the atmosphere and at equilibrium with atmospheric pressure. Wells VH-148B, VH-148C, VH-156C, VH-152B/C and VH-152CD responded to fluctuations in barometric pressure (Figure 16C through H). Well VH-148D exhibited a combined response to both barometric fluctuation and the forebay (Figure 16B and C). Other influences, such as industrial remediation pumping or industrial operational pumping systems, may have contributed to changes in elevation data where groundwater and barometric fluctuations diverge.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Due to the nature of subsurface hydraulics in the vicinity of the Project (i.e., the interconnected nature of surface water and groundwater), it has been necessary to investigate the effect of the Niagara Project on surface water as well as on groundwater. The Project was observed to have a direct effect on surface water elevations in the forebay and Lewiston Reservoir, and to be a contributory influence on the daily fluctuation of Niagara River levels. (Canadian operations as well as natural factors (wind, ice, etc.) also contribute to this effect).

Observed effects on groundwater were from a combination of influences resulting from the Project, and other influences (e.g., manmade tunnels, barometric pressure, seasonal [long-term] effects on recharge). Observed Project effects include:

- A static (persistent) rise in groundwater elevations in wells near the reservoir and depression of groundwater levels near the conduit drainage system,

- Flow of surface water in the conduit at Pump Station A to the conduit drainage system, at least part of the time,

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- Predominant influence of the forebay on hydrogeologic flow zones intersected by the conduits, presumably via the conduit drainage system,

- Short time-lag responses in groundwater levels to fluctuations of the forebay (typically less then one hour), which increase with distance from the conduits,

- In areas influenced by fluctuations of the forebay, hydraulic gradients are typically toward the forebay when the water elevation in the forebay is low, and sometimes reversed (away from the forebay or conduit drainage system) when the water elevation in the forebay is high,

- In conduit-intercepted flow zones the magnitude of response to forebay fluctuations is a function of both the hydrogeology of the particular flow zone and distance from the Project, and

- Monitoring wells near the reservoir respond to reservoir fluctuations, with observed artesian conditions in selected observation wells (near the southwest corner).

Other sources of influence on the regional flow of groundwater, which have been inferred but not observed in this study, may include the following:

- Industrial remediation systems (e.g. extraction wells, fractured bedrock/enhanced-flow systems and flow-reducing grout curtains);

- Industrial operation/production systems (e.g., process wells, or dewatering pumps/drains associated with mining operations);

- Groundwater flow from the conduit drains to the conduits at the pump stations, and then to the forebay;

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- The discharge into and flow of groundwater near manmade tunnels;
- The extent of the groundwater divide south of the Niagara escarpment;
- The magnitude of groundwater discharge along the Niagara escarpment; and
- The extent to which local creeks act to drain or recharge groundwater.

The primary effects of the Project on groundwater and groundwater users (namely, municipalities and industries) are the sinusoidal fluctuations in water levels and altered piezometric elevations (generally, elevated near the reservoir and depressed near the conduits). In this study, groundwater was readily observed in bedrock wells throughout the investigation area at elevations comparable to historically reported values (Johnston 1964 and DuPont et al. 1992).

While it was noted that the Project appears to affect groundwater levels and the flow path of groundwater near the Project, these effects appear to diminish with distance from the Project, as evidenced by the response of industrial-owned and Tuscarora Nation wells.

Due to the limitation in the number of available measuring points and the limited time frame for this study, further study is required to quantify the magnitude and extent of Project effects on groundwater flow within the investigation area. To accomplish this, additional field investigation and groundwater modeling efforts are planned. Their purpose will be to:

- Determine interaction between conduit-transported river water, flow at conduit weirs, flow within the conduit drainage system, infiltration of groundwater and/or surface water into the FST, and infiltration of groundwater into the forebay;
- Document existing information on groundwater hydraulic influence;

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- Determine effects of the Project on groundwater flow and water quality (chemical and biological) for the Tuscarora Nation, the Town of Lewiston, and other surrounding communities;

- Use existing information to determine the effect of river water fluctuation on groundwater flow patterns along the Niagara River;

- Assess the impact on water quality and flow of surface waters receiving groundwater due to the Project.

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TABLES

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TABLE 1

SURFACE WATER GAUGES AND WELLS MONITORED DURING INVESTIGATION

Surface Water Gauges	Gauge Owner
NFALLS3009 American Falls	NOAA
GN-RIVER_INT Intakes	NYPA
GN-LASALLE LaSalle	NYPA
GN-FOREBAY Forebay	NYPA
GN-RESERVOIR Lewiston Reservoir	NYPA
Monitoring Wells	**Monitoring Well Owner**
NW-05	NYPA
NW-16	NYPA
OW-112	NYPA
OW-157	NYPA
OW-186	NYPA
OW-189	NYPA
OW-193	NYPA
OW-198	NYPA
OW-206D	NYPA
OW-400D	NYPA
OW-650D	NYPA
DEC-3R	NYSDEC
DEC-4R	NYSDEC

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TABLE 1 (CONT.)

SURFACE WATER GAUGES AND WELLS MONITORED DURING INVESTIGATION

Monitoring Wells (cont.)	Monitoring Well Owner (cont.)
DEC-5R	NYSDEC
MW-15	NYSDEC
MW-16	NYSDEC
NFB-6	USGS
85-2	USGS
TN-01	Tuscarora Nation
TN-02	Tuscarora Nation
TN-05	Tuscarora Nation
VH-147D	DuPont
VH-147F	DuPont
VH-148B	DuPont
VH-148C	DuPont
VH-148D	DuPont
VH-152B/C	DuPont
VH-152C/D	DuPont
VH-156C	DuPont
VH-156D	DuPont

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TABLE 2

GROUNDWATER MEASURING POINT SURVEY DATA, AUGUST 2002

Well ID	Measuring Point Elevation	Northing*	Easting*	Total Depth	Open Hole/Screened Interval		Comments
					Top	Bottom	
NW-05	620.80	1148908	394950	60.03	581.27	561.27**	Reservoir bedrock monitoring well
NW-16	618.25	1143273.8780	1033253.6230	60.04	578.71	558.71**	Reservoir bedrock monitoring well
OW-112	623.80	1150266.99	384893.76	84.63	559.67	539.67**	Reservoir bedrock monitoring well
OW-157	591.73	1134338.4700	1033606.9700	36.70	575.53	555.53**	Reservoir bedrock monitoring well
OW-186	621.80	1147290.08	383159.73	61.55	580.75	560.75**	Reservoir bedrock monitoring well
OW-189	613.30	1143451.78	385627.96	10.66	607.64	602.64	Reservoir overburden monitoring well
OW-193	620.80	1147008.19	395585.09	7.39	618.41	613.41	Reservoir overburden monitoring well
OW-198	608.90	1143449	386712	24.49	594.41	584.41	Reservoir bedrock monitoring well

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TABLE 2 (CONT.)

GROUNDWATER MEASURING POINT SURVEY DATA, AUGUST 2002

Well ID	Measuring Point Elevation	Northing*	Easting*	Total Depth	Open Hole/Screened Interval		Comments
					Top	Bottom	
OW-206D	576.18	1120888.5290	1034759.3660	175.00	Unknown	401.18	Deep bedrock well within area of intake grout curtain
OW-400D	579.71	1122003.1690	1032828.7280	53.90	Unknown	525.81	Bedrock monitoring well
OW-650D	568.75	1124331.7050	1032421.3590	58.50	556.45	510.25	Bedrock monitoring well
DEC-3R	574.35	1122073.8470	1029797.7290	23.70	Unknown	550.65	Shallow bedrock well near upper Niagara River
DEC-4R	575.81	1122032.2040	1029015.2190	24.35	Unknown	551.46	Shallow bedrock well near upper Niagara River
DEC-5R	582.19	1122014.6090	1028034.8880	23.45	Unknown	558.74	Shallow bedrock well near upper Niagara River
MW-15	575.94	1122032.1350	1029022.1190	23.60	Unknown	552.34	Well paired with DEC-4R
MW-16	574.79	1122068.4940	1029798.8940	20.28	Unknown	554.51	Well paired with DEC-3R

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TABLE 2 (CONT.)

GROUNDWATER MEASURING POINT SURVEY DATA, AUGUST 2002

Well ID	Measuring Point Elevation	Northing*	Easting*	Total Depth	Open Hole/Screened Interval		Comments
					Top	Bottom	
NFB-6	575.66	1124350.0240	1024807.0780	27.21	Unknown	548.45	USGS shallow bedrock monitoring well
85-2	588.70	1137311.2260	1024295.3150	16.70	Unknown	572.00	USGS shallow bedrock monitoring well
TN-01	632.43	1154441.0960	1041325.3990	40.10	Unknown	592.33	Abandoned Tuscarora residential shallow bedrock well
TN-02	629.60	1154270.1100	1041202.7150	39.00	Unknown	590.60	Abandoned Tuscarora residential shallow bedrock well
TN-05	637.31	1145676.3160	1044904.3440	52.81	Unknown	584.50	Tuscarora shall bedrock supply well
VH-147D	581.58	1127345.3340	1035123.6950	54.93	554.15	526.65	DuPont bedrock monitoring well
VH-147F	581.67	1127341.5330	1035141.4310	82.83	528.84	498.84	DuPont bedrock monitoring well
VH-148B	576.64	1127189.7320	1035898.3980	16.62	569.95	560.05	DuPont bedrock monitoring well

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TABLE 2 (CONT.)

GROUNDWATER MEASURING POINT SURVEY DATA, AUGUST 2002

Well ID	Measuring Point Elevation	Northing*	Easting*	Total Depth	Open Hole/Screened Interval		Comments
					Top	Bottom	
VH-148C	576.80	1127188.0480	1035917.0010	25.41	563.19	551.39	DuPont bedrock monitoring well
VH-148D	576.49	1127204.2610	1035908.9270	52.46	549.03	524.03	DuPont bedrock monitoring well
VH-152B/C	577.05	1126439.1840	1039369.8990	42.94	552.11	534.11	DuPont bedrock monitoring well
VH-152C/D	576.87	1126442.4870	1039352.1450	58.76	533.11	518.11	DuPont bedrock monitoring well
VH-156-C	594.46	1128785.5250	1035374.3120	25.74	583.72	568.72	DuPont bedrock monitoring well
VH-156-D	595.03	1128800.5260	1035398.0740	57.59	556.64	537.44	DuPont bedrock monitoring well

* New York State Plane Coordinate System
**Bottom of screened interval 0.5 feet above bottom of borehole

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TABLE 3

SUMMARY OF MONITORING WELL FIELD DATA, AUGUST 2002

Well ID	Well Owner	Date Datalogger Installed	Date Datalogger Extracted	Days of Recorded Data	Datalogger Serial Number	Total Depth (feet below MP)
NW-05	NYPA	Continual Monitoring	NA	31	8839	NA
NW-16	NYPA	Continual Monitoring	NA	31	8710	NA
OW-112	NYPA	Continual Monitoring	NA	31	8733	NA
OW-157	NYPA	8/6/02	8/27/02	21	12900	36.70
OW-186	NYPA	Continual Monitoring	NA	31	8717	NA

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TABLE 3 (CONT.)

SUMMARY OF MONITORING WELL FIELD DATA, AUGUST 2002

Well ID	Well Owner	Date Datalogger Installed	Date Datalogger Extracted	Days of Recorded Data	Datalogger Serial Number	Total Depth (feet below MP)
OW-189	NYPA	Continual Monitoring	NA	31	8708	NA
OW-193	NYPA	Continual Monitoring	NA	31	8698	NA
OW-198	NYPA	Continual Monitoring	NA	31	8722	NA
OW-206D *	NYPA	8/6/02	8/22/02 & 8/27/02	21	12875	175.00
OW-400D	NYPA	8/6/02	8/27/02	21	12877	53.90
OW-650D	NYPA	8/6/02	8/27/02	21	12870	58.50

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TABLE 3 (CONT.)

SUMMARY OF MONITORING WELL FIELD DATA, AUGUST 2002

Well ID	Well Owner	Date Datalogger Installed	Date Datalogger Extracted	Days of Recorded Data	Datalogger Serial Number	Total Depth (feet below MP)
DEC-3R	NYSDEC	8/9/02	8/27/02	18	12906	23.70
DEC-4R	NYSDEC	8/9/02	8/27/02	18	12931	24.35
DEC-5R	NYSDEC	8/9/02	8/27/02	18	13311	23.45
MW-15	DuPont	8/9/02	8/27/02	18	12910	23.60
MW-16	DuPont	8/9/02	8/27/02	18	12901	20.28
NFB-6	USGS	8/21/02	8/27/02	6	13350	27.21
85-2	USGS	8/21/02	8/27/02	6	13323	16.70

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TABLE 3 (CONT.)

SUMMARY OF MONITORING WELL FIELD DATA, AUGUST 2002

Well ID	Well Owner	Date Datalogger Installed	Date Datalogger Extracted	Days of Recorded Data	Datalogger Serial Number	Total Depth (feet below MP)
TN-01	Tuscarora Nation	8/8/02	8/28/02	20	12905	40.10
TN-02	Tuscarora Nation	8/8/02	8/28/02	20	12903	39.00
TN-05	Tuscarora Nation	8/8/02	8/28/02	20	12902	52.81
VH-147D	DuPont	8/13/02	8/27/02	14	13312	54.93
VH-147F	DuPont	8/13/02	8/27/02	14	13313	82.83
VH-148B	DuPont	8/14/02	8/27/02	13	13320	16.62
VH-148C	DuPont	8/14/02	8/27/02	13	13318	25.41

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TABLE 3 (CONT.)

SUMMARY OF MONITORING WELL FIELD DATA, AUGUST 2002

Well ID	Well Owner	Date Datalogger Installed	Date Datalogger Extracted	Days of Recorded Data	Datalogger Serial Number	Total Depth (feet below MP)
VH-148D	DuPont	8/14/02	8/27/02	13	13319	52.46
VH-152B/C	DuPont	8/14/02	8/27/02	13	13315	42.94
VH-152C/D	DuPont	8/14/02	8/27/02	13	13314	58.76
VH-156C	DuPont	8/14/02	8/27/02	13	13316	25.74
VH-156D	DuPont	8/14/02	8/27/02	13	13317	57.59

* Datalogger replaced by #13322 on 8/22/02

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TABLE 4

WATER ELEVATION FLUCTUATIONS, AUGUST 2002

Location	Maximum Recorded Elevation	Minimum Recorded Elevation	Total[1] Displacement
NFALLS3009 American Falls	561.0	559.2	1.8
GN-RIVER_INT Intakes	564.1	562.1	2.0
GN-LASALLE LaSalle	564.3	562.7	1.6
GO-MATERIAL Material Dock	563.4	561.6	1.8
GN-FOREBAY Forebay	562.8	542.9	19.9
GN-RESERVOIR Lewiston Reservoir	658.4	624.8	33.6
NW-05	617.2	612.1	5.1
NW-16	606.9	597.2	9.7
OW-112	598.1	595.7	2.4
OW-157	558.84	555.26[2]	3.58
OW-186	613.5	610.5	3.0
OW-189	610.2	604.0	6.2
OW-193	616.2	612.2	4.0

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TABLE 4 (CONT.)

WATER ELEVATION FLUCTUATIONS, AUGUST 2002

Location	Maximum Recorded Elevation	Minimum Recorded Elevation	Total[1] Displacement
OW-198	602.9	600.5	2.4
OW-206D	554.83	554.83	0.00
OW-400D	560.72	556.74	3.98
OW-650D	558.97	553.65	5.32
DEC-3R	563.67	561.77	1.90
DEC-4R	563.73	561.87	1.87
DEC-5R	563.68	562.05	1.63
MW-15	563.8	562.1	1.7
MW-16	563.7	561.9	2.2
NFB-6	553.56	553.36	0.20
85-2	579.13	578.80	0.33
TN-01	608.06	606.82	1.25

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TABLE 4 (CONT.)

WATER ELEVATION FLUCTUATIONS, AUGUST 2002

Location	Maximum Recorded Elevation	Minimum Recorded Elevation	Total[1] Displacement
TN-02	608.36	607.06	1.30
TN-05	615.20	608.64	6.56
VH-147D	558.25	554.72	3.53
VH-147F	561.15	555.29	5.87
VH-148B	568.60	568.27	0.32
VH-148C	562.77	562.49	0.28
VH-148D	564.56	564.19	0.37
VH-152B/C	564.07	563.59	0.48
VH-152C/D	563.66	563.13	0.53
VH-156C	578.29	578.04	0.26
VH-156D	557.64	554.71	2.93

[1] Total displacement is the range of surface water elevations (in feet) between the maximum and minimum values recorded over the entire month

[2] Minimum elevation not established (well went dry below 555.26 feet)

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TABLE 5

RATE OF CHANGE OF GROUNDWATER ELEVATION, SELECTED WELLS

Well	Rate of Change in Groundwater Elevation (feet/day)
TN-05	-0.06
TN-02	-0.06
TN-01	-0.06
NW-16	-0.05
NW-05	-0.05
OW-112	-0.05
OW-189	-0.05
OW-186	-0.04
OW-193	-0.03
OW-198	-0.03
VH-152B/C	-0.02
VH-148B	-0.02

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TABLE 5 (CONT.)

RATE OF CHANGE OF GROUNDWATER ELEVATION, SELECTED WELLS

Well	Rate of Change in Groundwater Elevation (feet/day)
VH-148D	-0.02
VH-156C	-0.01
VH-148C	-0.01
VH-152C/D	-0.01

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TABLE 6

HYDRAULIC GRADIENTS AND FLOW DIRECTION BETWEEN SELECTED GAUGES AND WELLS, AUGUST 9, 2002

INTERVAL	FOREBAY ELEVATION[1]	GRADIENT[2]	FLOW DIRECTION
Intakes and OW-400D	High	0.0066	Toward Forebay
	Low	0.0076	Toward Forebay
OW-400D and OW-650D	High	0.0007	Toward Forebay
	Low	0.0011	Toward Forebay
OW-650D and OW-157	High	< 0.0001	No Flow
	Low	0.0001	Toward Forebay
OW-157 and Forebay	High	0.0002	Toward Intakes
	Low	0.0009	Toward Forebay

[1]Low- and high-forebay-elevation conditions are relative, due to time lags and missing water level data below El. 555.29 in OW-157.

[2]Gradients (Difference in Head/Distance) were calculated using data collected on August 9, 2002, at 1:00 pm for high-forebay-elevation conditions and on August 9, 2002, at 8:00 pm for low-forebay-elevation conditions.

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TABLE 7

HYDRAULIC GRADIENTS AND FLOW DIRECTION BETWEEN SELECTED WELLS, AUGUST 23, 2002

Interval	Forebay Elevation	Gradient[2]	Flow Direction
Conduit Drainage System[3] and VH-147D	High	0.0003	Toward Well
	Low	0.0008	Toward Conduit
Conduit Drainage System[3] and VH-147F	High	0.0012	Toward Conduit
	Low	0.0014	Toward Conduit

[1]Low and High Forebay Elevation conditions are relative, due to time lags and missing water levels below elevation 555.35 in OW-157.

[2]Gradients (Difference in Head/Distance) were calculated using data collected on August 23, 2002, at 10:00 am for high-forebay-elevation conditions and on August 23, 2002, at 8:00 pm for low-forebay elevation conditions.

[3]The elevation of the conduit drainage system is the average of the elevations of OW-650D and OW-157 at that time.

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FIGURES

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This material is contained in:
Volume 2
Section: Groundwater Flow Investigations in the Vicinity of the Niagara Power Project

FIGURE 1

MAJOR SURFACE AND SUBSURFACE FEATURES WITHIN INVESTIGATION AREA

[NIP – General Location Maps]

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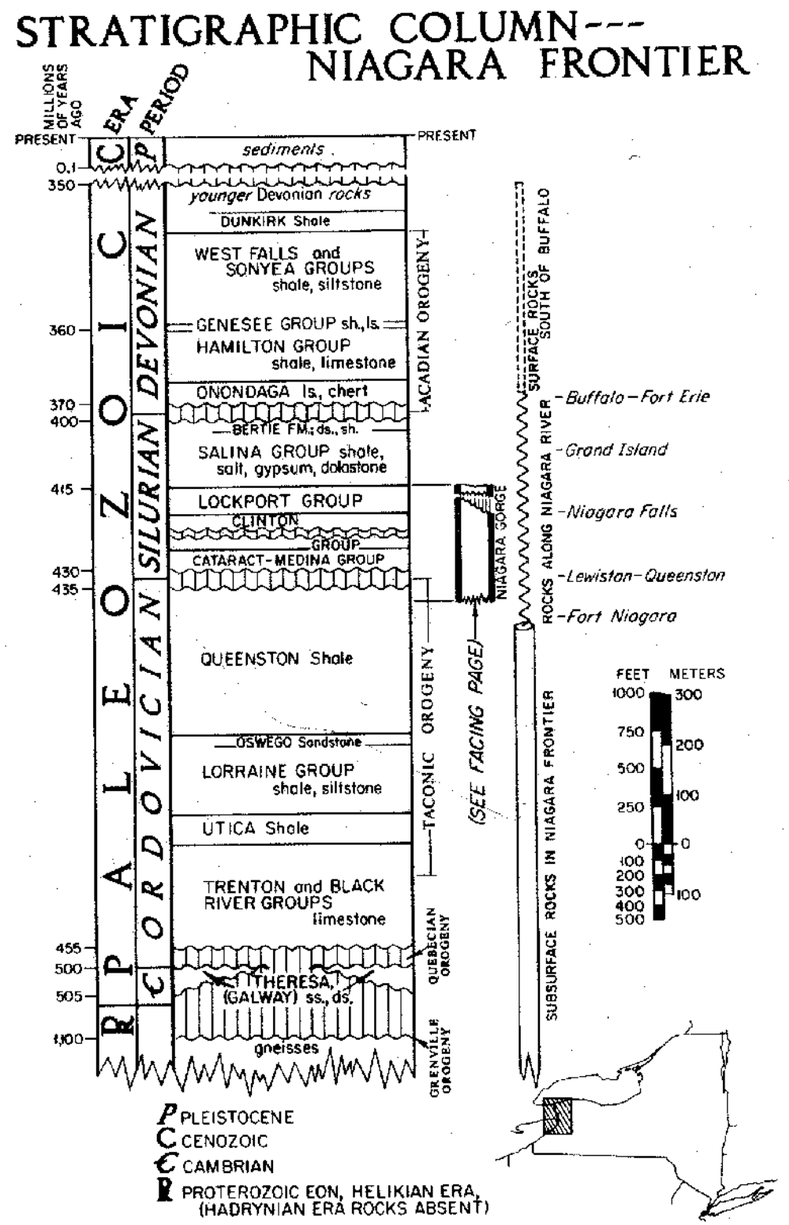

Fig. 2-6. Stratigraphic column - Niagara Frontier.

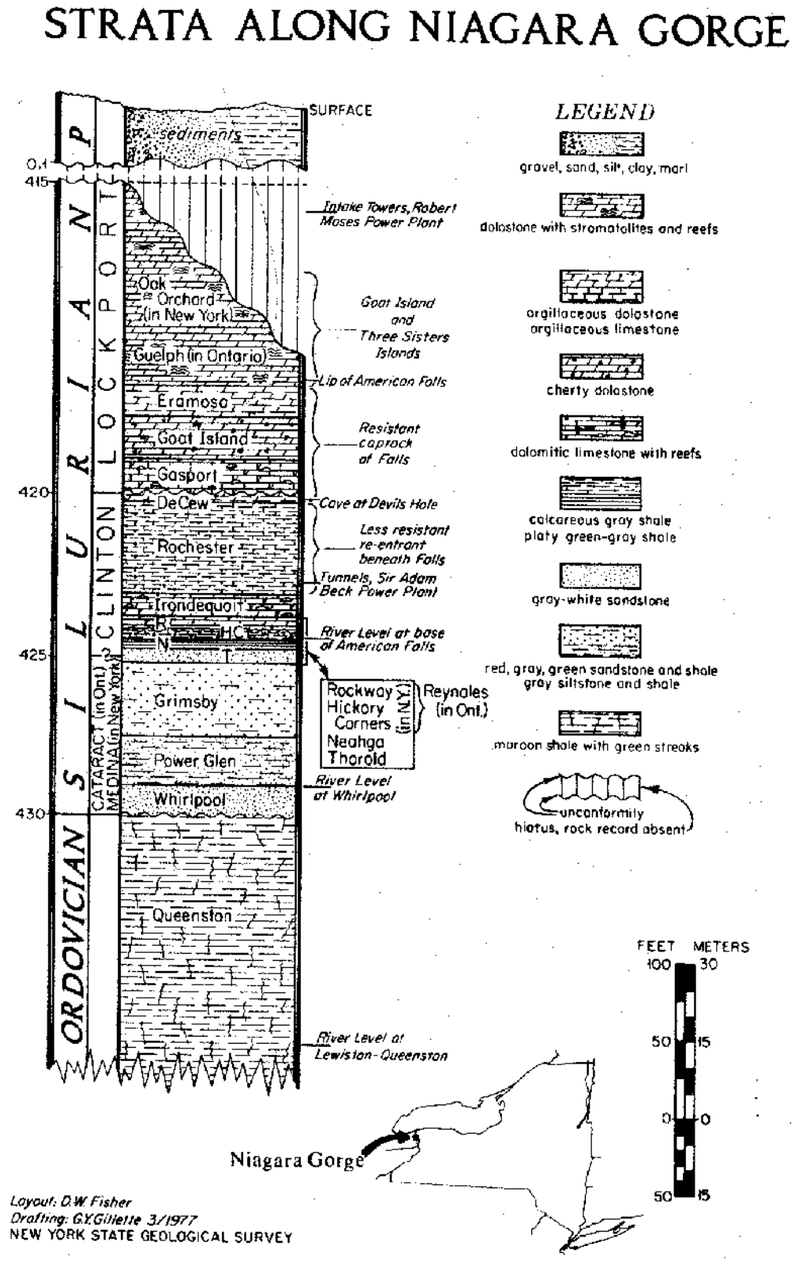

Fig. 2-7. Strata exposed along the Niagara Gorge.

NIAGARA POWER PROJECT (FERC N0. 2216)
GROUNDWATER FLOW IN THE VICINITY OF THE NIAGARA POWER PROJECT

Stratigraphic Section

DATA SOURCE:
Tesmer, Irving H. 1981. Colossal Cataract, The Geologic History of Niagara Falls. Albany, NY: State of New York University Press. p. 1-162

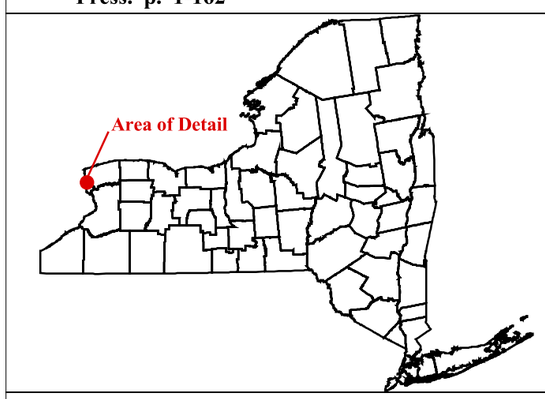

FIGURE 2

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NIAGARA POWER PROJECT

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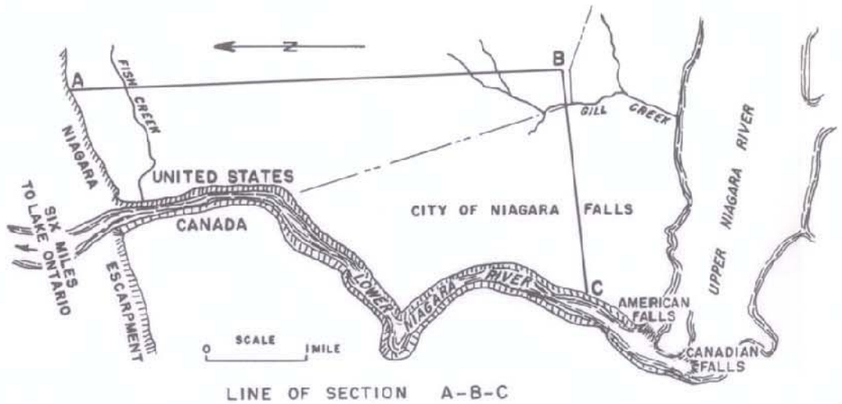
NIAGARA POWER PROJECT (FERC N0. 2216)
GROUNDWATER FLOW IN THE VICINITY OF THE NIAGARA POWER PROJECT

Generalized Stratigraphy and Groundwater Flow in the Vicinity of Niagara Falls

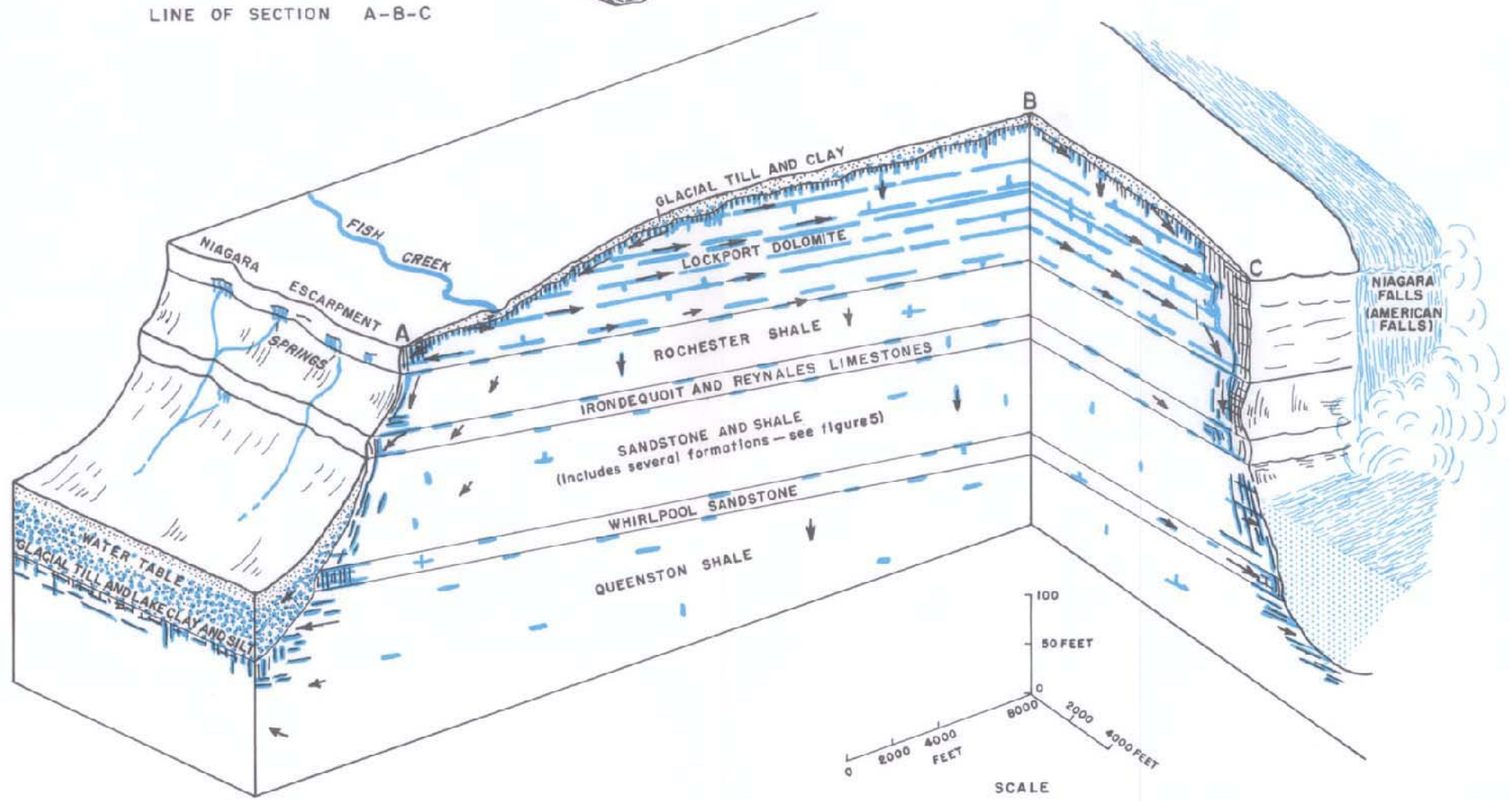


LEGEND

WATER-BEARING ZONES AND OPENINGS IN BEDROCK

ZONE OF SATURATION IN THE UNCONSOLIDATED DEPOSITS

DIRECTION OF GROUND-WATER MOVEMENT IN PLANE OF SECTION



DATA SOURCE:
Groundwater in the Niagara Falls Area, New York
by Richard H. Johnston, Geologist
U.S. Geological Survey

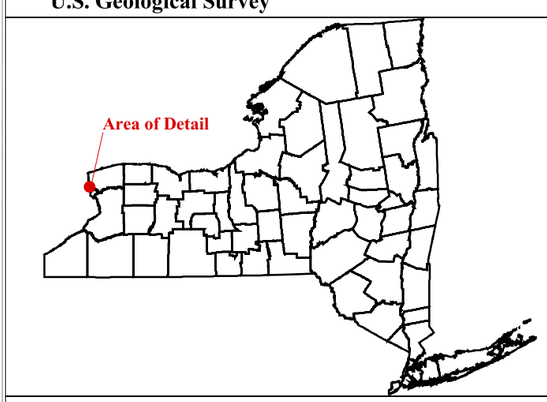


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FIGURE 3

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NIAGARA POWER PROJECT

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FIGURE 4

GENERALIZED GROUNDWATER FLOW, UPPER LOCKPORT, WITH SUBSURFACE FEATURES

[NIP – General Location Maps]

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FIGURE 5

GENERALIZED GROUNDWATER FLOW, UPPER LOCKPORT, WITH INDUSTRIAL REMEDIATION WELLS

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FIGURE 6

CONDUITS LONGITUDINAL SECTION

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FIGURE 7

CONDUIT CROSS-SECTIONS

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FIGURE 8

CONDUIT DRAINAGE SYSTEM

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FIGURE 9
FLUCTUATION IN SURFACE WATER ELEVATION - RESERVOIR AND FOREBAY
2002

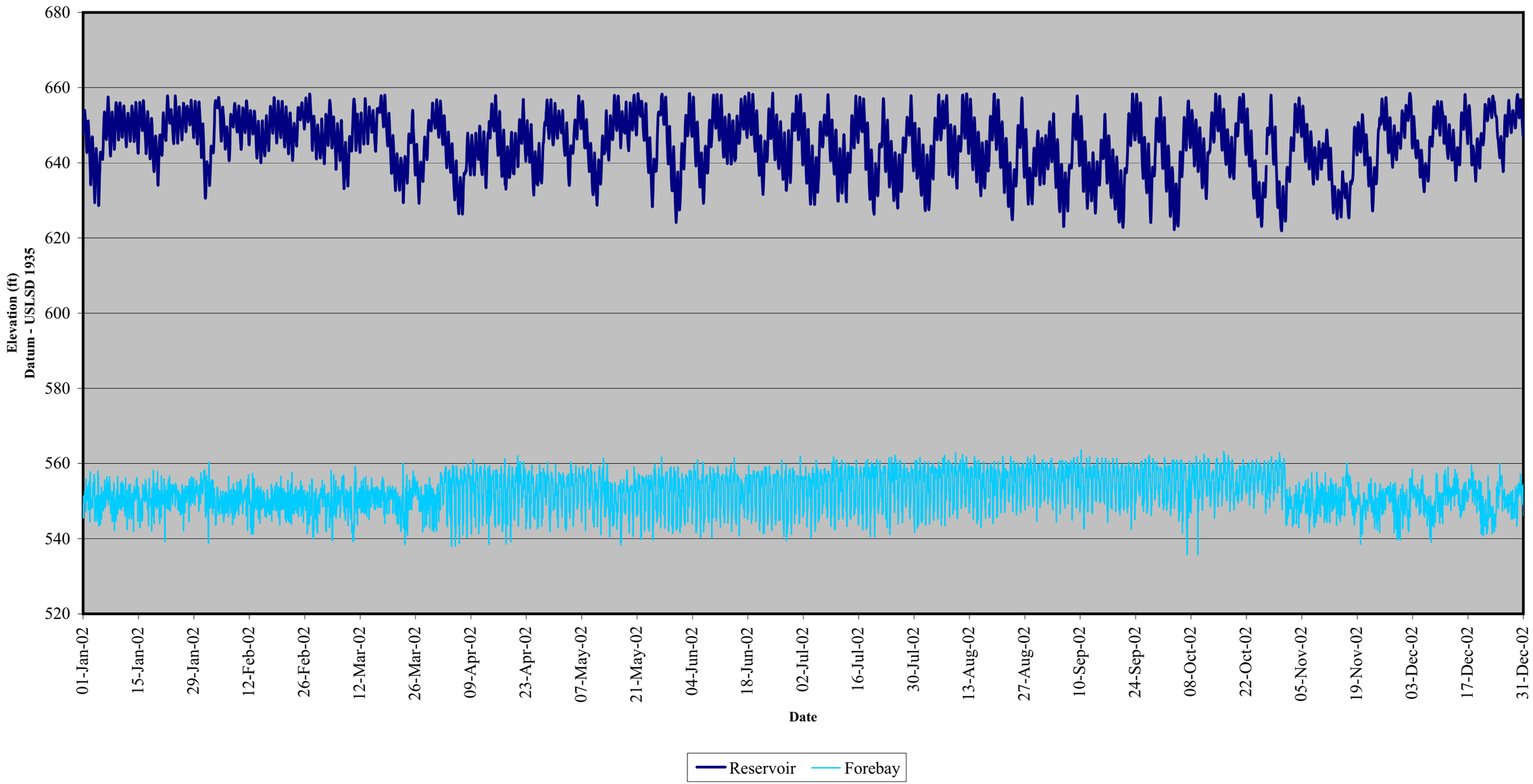

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FIGURE 10

SURFACE WATER AND GROUNDWATER MONITORING LOCATIONS

[NIP – General Location Maps]

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FIGURE 11

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

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FIGURE 12

COMPARISON OF PREVIOUS GROUNDWATER CONTOURS AND RECENT GROUNDWATER ELEVATIONS

[NIP – General Location Maps]

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FIGURE 13

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

[NIP – General Location Maps]

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FIGURE 14

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

[NIP – General Location Maps]

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FIGURE 15

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

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FIGURE 16

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

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FIGURE 17

WATER LEVEL DATA, VARIOUS MONITORING LOCATIONS

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GLOSSARY

Aquifer	Saturated rock or sediment sufficiently permeable to supply economic quantities of water to wells or springs
Aquitard	A low-permeability unit that can store groundwater, but that transmits groundwater slowly
Artesian water	Groundwater that is under pressure sufficient to raise it above the level at which it is encountered in a borehole or well
Barometric pressure	Atmospheric pressure measured by a barometer. Changes in atmospheric pressure are capable of inducing changes in water elevation
Bedding plane	In sedimentary rocks, the planes or surfaces that separate individual layers, beds, or strata that tend to split more or less horizontally or parallel to ground surface
Bedrock	Solid rock either exposed at the surface of the earth or overlain by unconsolidated material
Confining unit	A low-permeability material that lies adjacent to an aquifer and confines groundwater within the aquifer. It may lie above or below the aquifer.
Discharge	The process by which water is removed from a groundwater system along a discharge area, which may include a spring, seepage from an excavation face, or inflow to a stream
Dolomite	A limestone rock that contains magnesium carbonate, or the mineral dolomite that is not easily weathered or dissolved
Drainage system	As applied to groundwater, a mechanical system that locally increases flow and facilitates the area drainage of groundwater

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Escarpment	A steep-faced linear ridge frequently presented by the abrupt termination of sedimentary rock layers
Flow pattern	The direction of movement of groundwater both horizontally and vertically. Flow patterns may change with depth and geologic unit
Fractures	Breaks in rock occurring at a variety of possible angles due to intense folding or faulting, or in response to glacial unloading or stress release
Geologic Dip	The angle at which a stratum or bedding plane of a sedimentary rock is inclined from the horizontal
Groundwater	Underground water occupying openings, cavities, and spaces in rock and sediments
Groundwater divide	The line of separation between groundwater flow systems. It marks the high point of groundwater elevations, with lower groundwater elevations and flow moving away from this divide
Grout curtain	Grout-filled segment approximating an impermeable wall in bedrock, formed by the pressure-injection of cement grout into a linearly spaced sequence of boreholes.
Headwater	The upstream end or upper tributaries of a stream or river
Hydraulic boundary	A boundary to the flow of water, such as a groundwater divide or low-permeability rock unit
Hydraulic conductivity	Rate at which a fluid moves through a given permeable material under a hydraulic gradient (driving force) equal to 1.0 (i.e., rise equals run). Ranges of hydraulic conductivity have been determined for various geological materials
Hydraulic gradient	The slope of an underground water surface expressed as the change in total head (i.e., groundwater surface elevation) with change in distance in a given direction

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Hydraulic head	The pressure exerted by a fluid upon a unit area (surface) due to the height at which the fluid level stands above the surface. Usually expressed as pounds per square inch, sometimes as actual feet of head or fluid column
Hydrogeology	The study of geological factors relating to the occurrence and movement of underground water and its relationship to surface water and rainfall
Infiltration	The flow of water downward from the land surface into and through the underlying soil or rock
Joints	Fractures in rock that occur more or less vertical to bedding, along which no appreciable movement has occurred.
Lacustrine	Sediments deposited in a lake, consisting of layers of clay, silt, and fine sand
Limestone	A bedded, fine-textured sedimentary rock consisting chiefly of calcium carbonate.
Linear drain	A linear feature towards which groundwater converges and is discharged, as at the face of a linear excavation or escarpment face
Nonpoint source	A diffuse, undefinable area over which discharge of a fluid or other substance occurs.
Overburden	Loose, unconsolidated material (soil) that rests upon solid rock
Permeability	Capacity of a soil or rock to transmit a fluid. Depends upon the size and shape of the pores and their interconnection. It is measured by the rate of fluid movement in the porous medium.
Piezometric surface	A surface that represents the level to which water will rise in a well. The water table is a piezometric surface for an unconfined aquifer
Point drain	A point to which groundwater converges and is discharged, as to a supply well or quarry excavation

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Point source	A discrete, identifiable point or area from which a discharge of a fluid or other substance occurs, commonly into air or a water body.
Recharge	The process by which water is added to groundwater, which may include the downward infiltration of precipitation or inflow from streams or other surface water bodies
Sedimentary rock	Rock formed by the accumulation of sediments or chemical precipitates (e.g., gypsum) that forms bedding layers
Shale	A sedimentary rock made up of clay- and silt-sized particles, hardened into rock
Sinusoidal fluctuation	Changes in a characteristic (such as water level) that, when plotted, appear as a regularly undulating, smooth, up-and-down curve about a central horizontal axis (sine curve)
Stratigraphic Unit	Recognizable unit consisting of stratified, mainly sedimentary, rocks grouped for description and mapping over an area
Till	Sediments deposited by the glacial ice sheet, consisting of a mixture of clays, silt, and sand, with cobbles and boulders
Topographic boundary	A physical feature of the land surface that forms a boundary, such as a ridge or stream
Unconfined Aquifer	An aquifer not confined from above by low-permeability material, having a water table surface between unsaturated material above and saturated material below
Water table	The upper surface of the zone of groundwater saturation. Above the water table, the pores in soil or rock are unsaturated, i.e., not completely filled with water.
Weir	A device, usually a low dam, placed across a stream or flow section to control and measure flow volume

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APPENDIX A – SITE VISIT TO CONDUIT PUMP STATIONS

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SITE VISIT TO CONDUIT PUMP STATIONS

1.0 BACKGROUND

On June 13, 2002, a site visit was made to the two pump stations located along the NYPA conduits at the Niagara Power Project. The following summary provides a description of findings and a cursory review of the interaction between surface water (water within the conduits) and groundwater at the pump station locations, as observed on that date. Because access was limited at Pump Station B, the focus of this evaluation is on Pump Station A (the southernmost pump station), which is near the Falls Street Tunnel (a large-diameter rock-tunnel sewer, unlined, that receives infiltration from groundwater).

The two parallel Power Authority conduits pass beneath the Falls Street Tunnel within the City of Niagara Falls, lying at a perpendicular to the tunnel. (So that the conduits could be placed beneath the tunnel, the tunnel was bisected during conduit construction and was afterwards reconstructed with a section of large-diameter concrete pipe.) Pump Station A is situated between the two conduits, in the area where the conduits pass beneath the tunnel (Figure 1). The conduit excavations are filled with shotrock, which may be very permeable.

Along the walls and the floor of the conduits is the conduit drainage system. The conduit drainage system is connected via pipes to each pump station. The pump stations are furnished with weirs (constructed with flap gates designed to permit flow in one direction, namely, from the pump station to the conduits), forming a direct connection to both conduits (see Figure 8, main report)). The pump station is therefore in hydraulic contact with both the conduits (via weirs) and the aquifer (via the conduit drainage system).

2.0 DESCRIPTION OF FIELD ACTIVITIES

2.1 Objective

The main focus of the site visit was to inspect the pump stations and the weirs, and to identify ways of monitoring flow direction and flow rate over the weirs.

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2.3 Observations

NYPA and URS personnel entered Pump Station A. Openings in the pump station floor were identified, allowing the weirs to be seen. Both inlet and outlet to the east weir were visible, whereas only the inlet could be observed for the west weir.

The flow direction in the east weir was from the conduits into the pump station. The average flow depth was approximately 1 inch over the crest of the outlet (the outlet consisting of two rectangular openings, each approximately 1.5 feet long) (Photos 1 and 2). The water level in the central sump of the pump house was just below the weir crest. The water level on the inlet side of the weir was higher than the flap gate and observed to fluctuate slightly (approximately 3 to 6 inches).

The flow direction over the west weir could not be determined. This is because only the inlet of the weir was visible. Weir inlets are equipped with flap gates, obstructing the view. However, the flow was evidenced by the turbulence visible along the flap gate.

3.0 INTERPRETATION

3.1 Flow Regime

The flow observed over the east weir was from the conduit into the pump station. It is concluded that the water levels in the conduits are higher than local groundwater levels. Consequently, the pump station may serve to recharge the aquifer through the conduit drainage system. However, the extent of recharge would be dependent on the gradient between the conduit drainage system (which responds to water level changes in the forebay) and the potentiometric surface of groundwater along the conduits. Therefore, it is possible that a portion of the recharged water may enter the Falls Street Tunnel (unlined excavation in bedrock) directly through open fractures and joints in the bedrock.

It is likely that the same situation exists at the west weir, although the flow direction could not be directly observed there. Since the conduits are constructed in parallel and are connected to the same water bodies, it is likely that weir elevations and water levels in both conduits are the same.

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3.2 Comparison of Elevations (Literature Sources vs. Observations)

The weir elevations at Pump Station A are given in the literature as 560 feet (Figure 8, main report). The ground surface around the pump station is at an elevation of approximately 570 feet (Figure 1). By visual estimate, the weirs were in fact judged to be approximately 10 feet below ground surface, confirming the elevations cited in the literature.

Water bodies that control the flow in the conduits are the Niagara River at the intakes, and the forebay at the conduit outlet. Permanent water level gauges at both locations record water elevations every 15 minutes (Figure 11, main report). Elevations of water surface in the Niagara River at the inlet to the conduits fluctuates between approximately 561 and 565 feet (Table 1). It is likely that the water level in the conduits at the location of Pump Station A is at a similar elevation when the water level in the forebay (conduit outlet) is high (Table 2). Thus, the flow direction would potentially be from the conduits into the pump station, at least part of the time.

From the pump station the water would enter the conduit drainage system and from there potentially leak into the aquifer. This conclusion is supported by an examination of the relationship between the water levels in the pump station (approximately 560 feet) and the potentiometric surface in the aquifer (approximately 550 feet) in the area where the conduits pass beneath the tunnel. The flow of groundwater between the conduit drainage system and the aquifer, however, depends on the fluctuation of the forebay surface, which controls the relative elevation and flow of water between the conduit drainage system and the surrounding bedrock. (The Falls Street Tunnel, whose invert elevation is at approximately 540 feet, may act as a sink for a portion of the water entering the aquifer through the conduit drainage system.)

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TABLE 1

ANALYSIS OF WATER LEVEL FLUCTUATION

Gauge: GN RIVER_INT

Year	Tourist Season Water Level (USLS 1935)			Non-Tourist Season Water Level (USLS 1935)			Yearly Water Level (USLS 1935)			Tourist/Non-Tourist Comparison (Diff. in Feet)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
1991	561.83	564.66	563.02	562.08	565.11	563.2	561.83	565.11	563.09	-0.25	-0.45	-0.18
1992	561.83	564.68	563.22	561.79	565.02	563.21	561.79	565.02	563.21	0.04	-0.34	0.01
1993	561.91	564.92	563.24	562.07	564.78	563.05	561.91	564.92	563.17	-0.16	0.14	0.19
1994	561.77	564.29	563.17	561.81	564.23	562.89	561.77	564.29	563.05	-0.04	0.06	0.28
1995	561.73	564.16	563.11	561.86	564.56	562.88	561.73	564.56	563.02	-0.13	-0.4	0.23
1996	561.3	564.98	563.4	561.77	564.96	562.98	561.3	564.98	563.22	-0.47	0.02	0.42
1997	561.9	564.82	563.33	562.13	565.21	563.36	561.9	565.21	563.34	-0.23	-0.39	-0.03
1998	561.84	564.41	563.23	562.06	564.58	563.25	561.84	564.58	563.24	-0.22	-0.17	-0.02
1999	561.91	564.4	563.3	561.76	564.47	563.02	561.76	564.47	563.19	0.15	-0.07	0.28
2000	561.71	564.02	562.98	561.96	564.35	563.0	561.71	564.35	562.99	-0.25	-0.33	-0.02
2001	561.95	564.55	563.18	562.16	563.97	562.94	561.95	564.55	563.08	-0.21	0.58	0.24
2002	562.03	564.16	563.23	561.93	565.47	562.92	561.93	565.47	563.1	0.1	-1.31	0.31

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TABLE 2

ANALYSIS OF WATER LEVEL FLUCTUATION

Gauge: GN FOREBAY

Year	Tourist Season Water Level (USLS 1935)			Non-Tourist Season Water Level (USLS 1935)			Yearly Water Level (USLS 1935)			Tourist/Non-Tourist Comparison (Diff. in feet)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
1991	537.15	561.72	551.93	537.54	558.42	547.63	537.15	561.72	550.4	-0.39	3.3	4.3
1992	536.06	561.74	549.47	536.67	565.11	546.55	536.06	565.11	548.27	-0.61	-3.37	2.92
1993	536.16	561.13	547.21	536.74	555.03	542.45	536.16	561.13	545.24	-0.58	6.1	4.76
1994	536.52	561.25	548.62	536.6	559.51	545.97	536.52	561.25	547.5	-0.08	1.74	2.65
1995	536.38	564.26	550.63	535.88	556.65	545.1	535.88	564.26	548.34	0.5	7.61	5.53
1996	536.02	561.54	549.14	535.93	562.11	546.66	535.93	562.11	548.11	0.09	-0.57	2.48
1997	535.49	559.59	544.35	535	563.59	543.2	535	563.59	543.87	0.49	-4.0	1.15
1998	535.31	562	546.51	535.87	554.75	543.33	535.31	562	545.19	-0.56	7.25	3.18
1999	537.38	566.07	554.69	537.35	561.47	550.36	537.35	566.07	552.88	0.03	4.6	4.33
2000	538.61	564.16	554.72	538.08	560.98	552.39	538.08	564.16	553.75	0.53	3.18	2.33
2001	537.56	565.24	555.51	538.83	563.44	552.47	537.56	565.24	554.25	-1.27	1.8	3.04
2002	538.42	560.32	550.34	535.71	563.63	553.64	535.71	563.63	552.28	2.71	-3.31	-3.30

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FIGURE 1

AREA OF NYPA CONDUITS/FALLS STREET TUNNEL CROSSING

[NIP – General Location Maps]

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PHOTO 1

PUMP STATION A—WEIR INLET

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PHOTO 2

PUMP STATION A—FLOW OVER OUTLET OF EAST WEIR AND WATER LEVEL IN THE CENTRAL SUMP

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