NIAGARA POWER PROJECT

RELICENSING

DETERMINE TO WHAT EXTENT PROJECT OPERATIONS AFFECT THE TRANSPORT OF GROUNDWATER AND CONTAMINANTS

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Niagara Power Project
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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
BTEX	Abbreviation for benzene, toluene, ethylbenzene, and xylenes, all classified as volatile organic compounds, constituents of motor fuels, and commonly used as indicators of soil and water contamination by such fuels.
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
Bioherm	A carbonate rock formation in the form of an ancient reef or hummock, consisting of the fossilized remains of corals, algae, mollusks, and other sedentary marine life, and commonly surrounded by rock of a different lithology
Boundary Effect	The potentiometric head in the aquifer is affected by fluctuating water levels in a surface water body. This condition forms a boundary of the aquifer. Energy in the form of pressure waves is transmitted from the surface water body into the aquifer with the energy gradually diminishing with distance from the fluctuating source.

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Clast	an individual grain or constituent particle of a rock
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.
Crinoid	any of a large class (Crinoidea) of echinoderms, such as the sea lily, usually having a somewhat cup-shaped body with five or more feathery arms atop a stalk. Found from Ordovician to the present.
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
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
Forebay Efficiency	The relationship between the cyclic water level fluctuations in the forebay and corresponding groundwater fluctuations observed in each well. The efficiency of the well is a mathematical representation of the "connectedness" of a well and is calculated by dividing the net change in groundwater elevation (for half of one complete cycle) by the corresponding net change in forebay level. Efficiency values range between 0.0 and 1.0 (i.e. 0 to 100%) with 0 indicating no connection and 1.0 indicating a complete connection.

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Geologic Dip	The angle at which a stratum or bedding plane of a sedimentary rock is inclined from the horizontal
Gradient	In an aquifer, the rate of change of total head per unit of distance of flow at a given point and in a given direction (i.e., upgradient or downgradient)
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
Groundwater Modeling	A three dimensional numerical model was used to simulate groundwater conditions in an aquifer. The model utilized boundaries, multiple layers, rows and columns that formed individual cells. The modeling tool was used to estimate flow rates and flow direction within the aquifer.
Groundwater Sink	The conduit drainage system acts as a groundwater sink that is, it has a drain effect on groundwater in the vicinity of the drainage system.
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. total head or head
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
Leakance	The ability of an aquitard to transmit vertical flow between two horizontal aquifers. Leakance is defined as the ratio of its vertical hydraulic conductivity to its thickness. It is synonymous with coefficient of leakage.
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
Non point - source	A diffuse, indefinable area over which discharge of a fluid or other substance occurs.
Operational Cycle	Daily fluctuation in electrical power demands are reflected in water level changes in the Lewiston Reservoir. During low demand at night water is added to the reservoir. During high demand hours during the day water is drained from the reservoir for power generation.
Overburden	Loose, unconsolidated material (soil) that rests upon solid rock

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Packer test	A test of the transmissivity of rock in proximity to a borehole. A pair of connected, expandable/retractable rubber glands (called a packer assembly) is set within a borehole to isolate a single test interval. The inflated packer assembly prevents water from moving above or below the test interval in the borehole. Water is injected under pressure through the packer assembly and into the rock formation.
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.
Piezometer	A tube set into a borehole, through which tube the distance of the piezometric surface below ground surface may be measured.
Piezometric surface	A surface that represents the level to which water will rise in a tightly sealed piezometer or well. The water table is a piezometric surface for an unconfined aquifer. Also called a potentiometric surface
Point drain	A point to which groundwater converges and is discharged, as to a supply well or quarry excavation
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
Reservoir Efficiency	The relationship between the cyclic fluctuations in the reservoir and corresponding groundwater fluctuations observed in each well. The efficiency of the well is a mathematical representation of the "connectedness" of a well and is calculated by dividing the net change in groundwater elevation (for half of one complete cycle) by the corresponding net change in reservoir level. Efficiency values range between 0.0 and 1.0 (i.e. 0 to 100%) with 0 indicating no connection and 1.0 indicating a complete connection.
SVOCs	Abbreviation for semivolatile organic compounds. SVOCs tend to evaporate or volatilize relatively slowly at standard conditions of temperature and pressure.

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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)
Spatially and temporally	Water withdrawn from wells located some distance from each other and withdrawn at different times.
Stratigraphic Unit	Recognizable unit consisting of stratified, mainly sedimentary, rocks grouped for description and mapping over an area
Stylolite	A surface or contact, usually between two layers of carbonate rock, that is marked by an irregular, interlocking penetration, in cross-section resembling a row of interlocking columns or teeth on one side fitting into their counterparts on the other side.
Subcrop	A “subsurface outcrop” that describes the areal limits of a truncated rock unit at a buried unconformity surface.
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
Transmissivity	The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.
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

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VOCs	Abbreviation for volatile organic compounds. VOCs tend to evaporate or volatilize readily at standard conditions of temperature and pressure.
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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EXECUTIVE SUMMARY

The New York Power Authority (NYPA) is in the process of relicensing the Niagara Power Project (NPP), in Lewiston, New York. As part of the relicensing process, NYPA is developing information related to various aspects of the NPP, including assessment of the effect of Project operations on groundwater flow patterns and groundwater quality. This report describes the activities and presents the findings of the groundwater investigation conducted in the Project vicinity from spring 2003 through spring 2004.

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.

Investigation Activities

The scope of work developed to perform this evaluation included the following tasks:

1. Groundwater flow modeling – this task involved using an existing regional groundwater flow model prepared by the United States Geological Survey (USGS), and preparing a focused model of groundwater flow in the vicinity of the Lewiston Reservoir. The model was used to evaluate NPP effects on groundwater flow patterns.

2. Groundwater monitoring well installation – this task involved drilling and installing nested groundwater monitoring wells throughout the study area in order to evaluate NPP effects on groundwater levels and groundwater quality. A total of 91 nested piezometers were installed at 17 groundwater sampling locations.

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3. Groundwater level monitoring – this task involved completion of a groundwater level monitoring program to assess groundwater level fluctuations and groundwater flow in the vicinity of the conduits and reservoir. Monitoring was performed using water level probes and pressure transducers equipped with dataloggers. A detailed study of water level fluctuation effects on groundwater quality in the vicinity of the conduits was also conducted using electronic water quality probes/dataloggers.

4. Falls Street Tunnel flow monitoring – this task involved placement of flow metering equipment at three locations within the Falls Street Tunnel (FST)/South Side Interceptor (SSI) system in order to assess groundwater infiltration to the FST near the conduits as well as evaluation of factors contributing to groundwater infiltration.

5. Surface water and groundwater quality sampling program – this task involved completion of three sampling events, with each event including collection of groundwater samples from the 91 piezometers installed as part of this investigation, and collection of surface water samples from 11 locations.

6. Preparation of this report presenting the investigation activities and findings.

Groundwater Modeling

Groundwater modeling activities included: (1) conversion of the existing USGS model from MODFLOW computer code to Groundwater Modeling System (GMS) environment, (2) verification of accurate model conversion through comparison of flow budgets and predicted hydraulic heads for the two model formats, (3) preliminary modeling, and (4) focused modeling of the Lewiston Reservoir area.

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Results of the focused model of the Lewiston Reservoir area indicate that the reservoir area of influence on groundwater flow is limited north and east of the reservoir, due to the presence of groundwater flow divides in these areas. The northern groundwater flow divide (based on the results of numerical modeling) is located from 1,000 to 4,000 feet south of the Niagara escarpment, throughout the length of the escarpment, within the study area. The presence of the northern groundwater divide prevents reservoir-influenced groundwater flow from migrating to and discharging from the Niagara escarpment. A groundwater flow divide located approximately 1,500 feet east of the reservoir, determines the eastern extent of reservoir-influenced groundwater flow. Vertically, the maximum extent of reservoir-influenced groundwater flow is seen in the upper weathered bedrock water-bearing zone, and decreases for each successively deeper water-bearing zone. The two deepest identified water-bearing zones, the Gasport water-bearing zone and the Gasport/DeCew water-bearing zone, are not influenced by the reservoir, and therefore, there is no groundwater flow divide. East of the reservoir, groundwater flow for these zones is inferred to be from the northeast, toward the reservoir. East of the reservoir, the vertical extent of reservoir influenced groundwater flow extends to a depth of approximately 30 to 60 feet below ground surface.

Drilling and Well Installation

In order to evaluate Project effects on groundwater levels and groundwater quality, a total of 17 nested groundwater monitoring wells was installed in the vicinity of the NPP. Eleven nested wells (GW03-001 through GW03-011) were installed in the vicinity of the Lewiston Reservoir, and six (GW03-012 through GW03-017) along and adjacent to the NYPA conduits.

Continuous rock coring was completed at each of the 17 well locations in order to log (observe and describe) the lithology within the borehole and identify water-bearing zones to target for piezometer placement. The results of geologic descriptions are presented in geologic boring logs, and lithology was correlated between well locations as shown in geologic cross-sections presented in this report. Throughout the area, bedrock is overlain by overburden materials consisting of glacial sediments (till and lacustrine silt and clay). Thickness of overburden observed during this investigation ranged from approximately 3 feet to 40 feet. The relatively simple bedrock stratigraphy identified during the drilling program exhibited a slight southward dip of approximately 30 feet per mile, with beds subcropping

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progressively northward at the overburden/bedrock contact. At each nested well location, borings were completed through the entire thickness of the Lockport Group dolomite, which consists of the following dolomite formations (in order from oldest to youngest): Gasport, Goat Island, Eramosa, and Guelph. At all locations, the borings were terminated in either the DeCew dolomite or the Rochester shale, both of the Clinton Group, which underlies the Lockport Group.

Water-bearing zones were identified by visual observation of fracturing and/or by packer testing of selected boreholes. Discrete piezometers were placed to intercept nine targeted regional water-bearing zones, mainly associated with bedding planes at stratigraphic contacts. A total of 91 discrete piezometers were placed at 17 nested well locations installed during this investigation. The selected regional water-bearing zones were chosen to be representative of groundwater flow model layers presented in the USGS groundwater flow model. One additional water-bearing zone, the Gasport/DeCew, situated beneath the lowest modeled water-bearing zones, was also targeted. Due to the gentle southward dip of regional stratigraphy, the number of water-bearing zones decreases northward. Near the Niagara escarpment, only two water-bearing zones within the Lockport, the weathered bedrock and Gasport/DeCew water-bearing zones, were present. The uppermost water-bearing zone, (the weathered bedrock) is independent of stratigraphy and occurs throughout the investigation area.

Groundwater Level Monitoring Program

To evaluate NPP effects on area groundwater levels, a groundwater-level monitoring program was implemented. The program consisted of water level measurement using a combination of electronic pressure transducers with dataloggers, manual water level measurements, and permanent surface water level gauges. Water level data collection began in July 2003 and continued through May 2004. Locations where water levels were measured included piezometers at nested groundwater monitoring wells, existing NYPA observation wells, the two NYPA conduit pump stations, and permanent gauges at surface water bodies (Lewiston Reservoir, forebay, and upper Niagara River).

Groundwater level data collected from monitoring wells throughout the study area were analyzed and compared to water level data for surface water bodies directly influenced by Project operations (e.g.,

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forebay, reservoir, and conduits). Responses to Project-induced water level fluctuations were evaluated in terms of reservoir and forebay efficiencies, presented as a percentage of the surface water level change, with 0% being no response, and 100% representing a groundwater level change magnitude equal to the surface water level fluctuation.

Efficiencies calculated for wells located near the reservoir ranged from 0.03% to 13.42%. Generally, the wells showing the highest reservoir efficiency were NYPA observation wells located immediately adjacent to the reservoir. Groundwater level fluctuations resulting from daily reservoir fluctuations observed in these wells were on the order of 1 to 2.5 feet. Of the piezometers installed in bedrock as part of this study, the highest efficiencies were exhibited in the upper weathered bedrock zone, which has the most direct contact with reservoir water. Groundwater level fluctuations observed in these piezometers (installed at distances greater than 600 feet from the reservoir) were on the order of one foot or less. In general, fluctuations in groundwater levels around the reservoir showed limited reservoir influence relative to natural seasonal effects observed to be on the order of approximately 7 feet.

Groundwater levels north of the reservoir along a north-south line defined by wells GW03-001 to GW03-004 confirm the presence of the northern groundwater flow divide in the upper weathered bedrock water-bearing zone as well as in the underlying Gasport/DeCew water-bearing zone. Based on water level data from these wells, the groundwater divide at this location is between 1,000 feet and 3,500 feet north of the reservoir.

Forebay water level fluctuations directly impact groundwater levels along the conduits. Water levels measured in piezometers installed along the conduits were seen to fluctuate as much as approximately 7 feet due to forebay fluctuations. This effect, transmitted via the conduit drainage system (CDS), affects hydraulic gradients within the CDS as well as groundwater flow to and from the CDS. When forebay water levels are low, hydraulic gradients within the conduits are stronger from the south to the north (i.e., towards the forebay), and groundwater flow gradients from the surrounding groundwater toward the CDS are greater. Conversely, higher forebay water levels create a decreased northward hydraulic gradient, and even reverse to the south at times. Under these conditions groundwater flow gradients toward the conduits from surrounding bedrock are reduced , and even turn away from the

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conduits at times. The extent of the effect of the conduits on groundwater has been estimated by others to be approximately ½ mile on either side of the conduits.

Average forebay water levels are 5 feet lower during non-tourist season than during tourist season. As a result, CDS hydraulic heads are lower during non-tourist season, which may increase the amount of groundwater flow to the conduits.

Falls Street Tunnel

As part of the evaluation of NPP effects on groundwater infiltration into the FST, a tunnel reconnaissance was performed to assess existing tunnel conditions and evaluate possible flow measuring opportunities. During tunnel reconnaissance, more significant groundwater infiltration was observed upstream (east) of the conduit crossing than was observed in the downstream (west) portion. Based on these observations, a flow monitoring program was developed that incorporated measurement of flows at three locations within the FST/SSI system. The sum of these measurements were taken as representative of all FST groundwater infiltration at the conduit crossing.

The flow monitoring program consisted of installing and maintaining electronic flow meters at three locations: (1) a depth/velocity probe placed at the flow measuring weir at Drop Shaft 12, (2) an area/velocity probe placed in the SSI west bypass tunnel, and (3) an area/velocity probe placed in the SSI east bypass tunnel. Maintenance activities during the flow monitoring program included checking the datalogger status and downloading data for each of the three meters every three days. A rain gauge was also installed at Pump Station A in order to track precipitation events. The FST flow monitoring program was performed from October 20, 2003, through November 25, 2003. This flow monitoring period was designed to coincide with the change from tourist season to non-tourist season on November 1, 2003.

Results of flow monitoring indicated that during tourist season, total dry-weather groundwater infiltration into the FST is approximately 5,000 gallons per minute (gpm) (7.2 million gallons per day [mgd]), while during non-tourist season, total dry-weather groundwater infiltration is approximately 4,100 gpm (5.9 mgd). Groundwater infiltration east of the FST/conduit crossing is approximately twice that

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west of the crossing. Evaluation of infiltration rates and local groundwater levels indicate a direct correlation of FST infiltration with fluctuations in forebay levels.

Results of an evaluation of possible groundwater flow pathways indicate that 75 to 85% of infiltration into the FST likely comes from the external drainage system associated with the NYPA conduits (Conduit Drainage System, or CDS). Approximately 15 to 25% of the flow is estimated to originate as flow from the Niagara River through the high-transmissivity zone in the Lockport aquifer.

Surface Water and Groundwater Quality

To evaluate groundwater quality in the vicinity of the Project, a surface water and groundwater sampling program was implemented. This sampling program involved collection of groundwater samples from the 91 piezometers installed in nested groundwater monitoring wells and collection of surface water samples from 11 locations. Sampling events were conducted at approximately 3-month intervals starting in September 2003. Sampling events conducted during this study were completed in September/October 2003, November/December 2003, and February/March 2004.

Surface Water Quality

Surface water samples were collected from six river-sourced locations (i.e., from locations whose primary source is the upper Niagara River) in the vicinity of the NPP. These were: (1) the upper Niagara River itself, at the conduit intakes, (2) one each from the two conduits at the air intake vents located immediately north of Royal Avenue in the City of Niagara Falls, (3) one from the forebay at the Robert Moses Power Plant, and (4) two from the Lewiston Reservoir—one from the west side near the Lewiston Pump Generating Plant, and one from the east side at the eastern reservoir dike. Five local-sourced (i.e., area creeks and swamps/ponds near Lewiston Reservoir whose source is not the upper Niagara River) surface water samples were collected from Fish Creek (one upstream and one downstream of the reservoir), Gill Creek (one upstream and one downstream of the reservoir), and the wetland at the head of Gill Creek located on the Tuscarora Nation.

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Surface water sampling analytical results indicate that river-sourced water is generally free of significant contamination. Monomethyl mercury was detected in at least one sampling event at very low concentrations in all surface water sample locations except the forebay and the western reservoir sample location (SW03-006). Detection of monomethyl mercury at these very low concentrations in surface waters throughout the study area is likely indicative of the regional presence of inorganic mercury due to naturally occurring sources (atmospheric deposition) or exogenous sources (industrial sources). Other than monomethyl mercury, no chemical contaminants were detected in surface water samples collected from the upper Niagara River at the intakes or the forebay during any of the three sampling events. Two pesticide compounds, delta-BHC and 4,4-DDT, were detected in very low concentrations in a conduit sample (4,4-DDT), and in both reservoir sample locations (delta-BHC).

In the water samples collected from Fish and Gill Creeks, relatively low concentrations of acetone, and carbon disulfide were detected. Lead was detected in the surface water samples collected from the wetland at the head of Gill Creekduring the October and November 2003 sampling events.

Groundwater Quality

Groundwater in the study area may be conceived of as two flow systems: a freshwater system, and a (deeper) saline flow system. Generally, the groundwater in the freshwater flow system is moderately to highly mineralized, containing (1) sulfates dissolved from soluble gypsum within the dolomite, and (2) calcium and magnesium bicarbonate, also dissolved from dolomite.

Groundwater Quality in the Conduit Vicinity

Groundwater in the vicinity of the conduits is affected by contaminant plumes originating from various active and inactive hazardous waste sites in the region. The worst contamination adjacent to the conduits was identified in the once heavily industrialized southern portion of the study area near the upper Niagara River. In this area, the conduits pass beneath chemical storage and manufacturing facilities, landfills, and other sites of present or past industrial operations. The predominant compounds identified in groundwater in the vicinity of the conduits were chlorinated volatile organic compounds (VOCs) and

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non-chlorinated VOCs. Compounds detected in this area with the greatest frequency and at the highest concentrations were 1,2-dichloroethene (cis), trichloroethene (TCE), tetrachloroethene (PCE), vinyl chloride, and benzene.

The worst contamination, consisting mainly of chlorinated and non-chlorinated VOCs, was identified in the southern portion of the conduit right-of-way (well locations GW03-014 through GW03-017). Contaminants detected in this area with the greatest frequency and at the highest concentrations were detected in the Gasport/DeCew water-bearing zone. With a few exceptions, the water-bearing zones intersecting the conduits and CDS exhibited lower overall contaminant concentrations. This was possibly due to dilution of contaminated groundwater by the influence of Niagara River water within the CDS.

Contaminants detected in the northern portion of the conduit right-of-way (piezometers GW03-012 and GW03-013) were predominantly gasoline-related compounds (including benzene, toluene, ethylbenzene, and xylenes, or BTEX), all detected at relatively low concentrations. Other analytes detected included carbon disulfide, caprolactum, cadmium, lead, phthalates, phenols, MEK, PCE, and TCE. Piezometer GW03-012A-P3, screened in the Gasport/DeCew water-bearing zone in the vicinity of the forebay, exhibited the highest contaminant concentrations in the northern portion of the conduit right-of-way.

Observed variations in contaminant concentrations for some of the water-bearing zones intersecting the conduits seem to indicate an effect related to Treaty flow changes between tourist and non-tourist season. For instance, contaminant concentrations detected at piezometer GW03-015B-P5 increased from non-detect in October (tourist season) to 720 ug/L in December (non-tourist season). The cause of this change is likely to be lower hydraulic heads within the CDS (caused by lower forebay levels during non-tourist season) creating a steeper groundwater flow gradient from the surrounding bedrock toward the conduits, and thus transporting greater amounts of contaminants from surrounding plumes. . Results of a detailed study of water level fluctuation effects on groundwater quality in the vicinity of the conduits confirm that short-term forebay induced CDS water level fluctuations influence water quality immediately adjacent to the conduits. Groundwater quality was shown to fluctuate with water levels indicating a greater river water influence during high CDS water levels, and a greater groundwater influence during lower CDS water levels. During tourist season, when average forebay levels are higher,

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the gradient toward the conduits is reduced and groundwater quality is less influenced by surrounding contaminant plumes.

Groundwater Quality in the Reservoir Vicinity

The most predominant chemical contaminants detected in groundwater in the vicinity of the Lewiston Reservoir were gasoline-related VOCs, such as BTEX and methyl tert-butyl ether (MTBE). BTEX compounds and MTBE were detected in all water-bearing zones except 8A (Eramosa Unit A), with the highest concentrations east of the reservoir. As these compounds were not detected in water samples collected from the Lewiston Reservoir itself, their detection in piezometers installed near the reservoir is likely related to the presence of fuel service stations in the area, with possibly leaking underground storage tanks.

The most significant detections of gasoline related compounds were in the deeper water-bearing zones, particularly in piezometers screened in the Gasport/DeCew water-bearing zone (e.g., GW03-005A-P2, GW03-007A-P3, and GW03-009A-P3). Significant concentrations of MTBE were also identified in overlying water-bearing zones at well GW03-009, located southeast of the reservoir. The predominant contaminants detected in samples collected from the Gasport/DeCew water-bearing zone were the BTEX compounds, whereas MTBE was the predominant compound detected in the overlying water-bearing zones. Benzene concentrations detected in the Gasport/DeCew water-bearing zone ranged from 20 ug/L in piezometer GW03-007A-P3 to 280 ug/L in GW03-005A-P2. Relatively low concentrations of MTBE (less than 5 ug/L) were also detected in water-bearing zones, downgradient of GW03-009 at location GW03-010. The two deepest zones, the Gasport/DeCew water-bearing zone and the zone immediately overlying it, which exhibit the highest gasoline contaminant concentrations, are not subject to reservoir-induced groundwater flow.

Significant BTEX concentrations at reservoir area piezometers were generally detected in deeper saline water-bearing zones that exhibit high chloride levels (greater than 500 mg/L). The upper weathered bedrock water-bearing zone generally exhibited low contaminant concentrations. Gasoline related contaminants likely migrate downward through vertical fracturing to the deeper zones. Higher

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contaminant concentrations in the deeper zones may be caused by relative lack of groundwater flow in these zones, which would allow contaminants to accumulate, whereas the relatively higher groundwater flow in the upper water-bearing zones may act to dilute or disperse contaminants in these zones.

Non-gasoline-related analytes detected in samples collected from reservoir area wells (GW03-001 through GW03-011) included acetone, methyl ethyl ketone, 1,1,1-trichloroethane, chloroform, carbon disulfide, arsenic, cadmium, lead, monomethyl mercury, bis (2-ethylhexyl)phthalate, phenol, and caprolactum. The source or sources of these contaminants is unknown. With the exception of monomethyl mercury, none of these contaminants was detected in water samples collected from the Lewiston Reservoir itself.

Contaminants detected in Lewiston Reservoir sediments, with the exception of lead and arsenic, were not detected in groundwater samples collected from nearby piezometers. Lead and arsenic were detected in several reservoir area piezometers associated with different water-bearing zones within the groundwater flow influence of the Lewiston Reservoir. The presence of monomethyl mercury in several reservoir vicinity piezometers may also be indicative of the presence of elemental mercury, possibly from naturally occurring sources or from reservoir sediments, where mercuric compounds were also detected. Monomethyl mercury was detected in reservoir water samples as well. It should be noted that these three analytes (arsenic, lead, and monomethyl mercury) were also detected in piezometers that are not within the apparent direct influence of reservoir-induced groundwater flow (namely, the Gasport/DeCew water-bearing zone), a fact that suggests the possibility of another source.

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1.0 INTRODUCTION

The New York Power Authority (NYPA) is engaged in the relicensing of the Niagara Power Project in Lewiston, Niagara County, New York. The present operating license of the plant expires in August 2007. As part of its preparation for the relicensing of the Niagara Project, NYPA is developing information related to the ecological, engineering, recreational, cultural, and socioeconomic aspects of the Project. This report presents the results of detailed investigations of effects of Project operations on groundwater flow and quality in the vicinity of the Project.

1.1 Project Background

The 1,880-MW (firm capacity) Niagara Power Project (NPP) is one of the largest non-federal hydroelectric facilities in North America. The Project was licensed to the Power Authority of the State of New York (now the New York Power Authority) in 1957. Construction of the Project began in 1958 and the electricity was first produced in 1961.

The Project has several components (Figure 1.1-1). Twin intakes are located approximately 2.6 miles above Niagara Falls. Water entering these intakes is routed around the Falls via two large low-head conduits to a 1.8-billion-gallon forebay, lying on an east-west axis about 4 miles downstream of the Falls. The forebay is located on the east bank of the Niagara River. At the west end of the forebay, between the forebay itself and the river, is the Robert Moses Niagara Power Plant (RMNPP), NYPA's main generating plant at Niagara. This plant has 13 turbines that generate electricity from water stored in the forebay. Head is approximately 300 feet. At the eastern end of the forebay is the Lewiston Pump Generating Plant (LPGP). Under non-peak usage conditions (i.e., at night and on weekends), water is pumped from the forebay via the plant's 12 pumps into the 22-billion-gallon Lewiston Reservoir, which lies east of the plant. During peak usage conditions (i.e., daytime Monday through Friday), the pumps are reversed for use as generators, and water is allowed to flow back through the plant, producing electricity. The forebay, therefore, serves as headwater for the Robert Moses plant and tailwater for the LPGP. South of the forebay is a switchyard, which serves as the electrical interface between the Project and its service area.

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For purposes of generating electricity using the Niagara River, two seasons are recognized: tourist season and non-tourist season. By the provisions of the 1950 Niagara River Water Diversion Treaty, at least 100,000 cfs must be allowed to flow over Niagara Falls during daytime and evening hours in the tourist season (April 1 – October 31), and at least 50,000 cfs at all other times. Canada and the United States are entitled by international treaty to produce hydroelectric power using the remaining flows.

Water level fluctuations in the Chippawa-Grass Island Pool (in the upper Niagara River) are limited by an International Joint Commission directive to 1.5 feet per day unless conditions triggering special provisions occur. It is important to note that water level fluctuations in both the upper and lower Niagara River occur due to a number of factors other than operation of the NPP. These may include wind, natural flow and ice conditions, as well as operation of power plants on the Canadian side of the river.

Water-level fluctuations in the lower Niagara River (upstream of the RMNPP tailrace) from all causes can be as great as 12 feet per day. Most of this daily fluctuation is due to the change in the treaty-mandated control of flow over Niagara Falls. Water level fluctuations downstream of the RMNPP tailrace are much smaller. The average daily water level fluctuation 1.4 miles downstream of the RMNPP tailrace, during the 2002 tourist season, was approximately 1.5 feet.

Operation of the NPP can result in water level fluctuations in the Lewiston Reservoir of 3-18 feet per day, and as much as 38 feet per week.

1.2 Study Objectives

The objectives of this investigation were developed in consultation with the stakeholders as part of the scoping of this study. The objectives of this investigation are to:

- Document existing information on groundwater hydraulic influence;

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- Use existing information to determine the effect of river water fluctuation on groundwater flow patterns along the Niagara River;
- Determine interaction between conduit-transported river water, flow at conduit weir(s), flow within the conduit external drainage system, infiltration of groundwater and/or surface water into the Falls Street Tunnel (FST), and infiltration of groundwater into the forebay;
- Determine effects of Project features and operations on Tuscarora Nation, the Town of Lewiston and other surrounding communities groundwater flow and water quality (chemical and biological);
- Assess the impact on water quality and flow of surface waters receiving groundwater due to Project operations.

1.3 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 1.1-1).

1.4 Report Organization

This report is organized into seven sections:

1.0 Introduction
2.0 Environmental Setting
3.0 NYPA 2002 Groundwater Study
4.0 Investigation Activities
5.0 Results
6.0 Discussion
7.0 Conclusions

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Section 2.0 presents a summary of the environmental setting within which this study is being conducted. This section includes discussion of natural features such as topography, surface water, and hydrogeology. Also discussed are manmade features such as the NPP itself (conduits, forebay, and Lewiston Reservoir), other features exhibiting hydraulic influence such as sewers, tunnels, and the LaFarge Redland Quarry, and existing groundwater contaminant plumes within the study area.

Section 3.0 presents a summary of conclusions for the report, Groundwater Flow Investigations in the Vicinity of the Niagara Power Project (URS et al. 2003). This report describes the study, conducted in 2002, of NPP effects on water levels in the vicinity of the Project. It was prepared as a preliminary look at NPP effects in order to establish context for the more detailed study discussed in this report.

Section 4.0 presents the scope of work conducted for the various data collection efforts included in this overall study of NPP effects on groundwater. This section discusses investigation activities performed for (1) groundwater modeling, (2) geologic investigation and groundwater monitoring well installation, (3) a groundwater level monitoring program, (4) investigation of groundwater infiltration into the Falls Street Tunnel (FST), and (5) a water quality sampling program including collection of both surface water and groundwater samples.

Section 5.0 presents the results of the data collection efforts described immediately above. The results are presented in the same order as the tasks presented in Section 4.0.

Section 6.0 presents a detailed discussion of the results of all of the data collection efforts in the context of the relationship between the NPP and groundwater levels, groundwater flow, groundwater infiltration into the FST, and surface water and groundwater quality in the vicinity of the NPP.

Section 7.0 presents conclusions developed as a result of this detailed evaluation of the relationship between the NPP and groundwater flow and groundwater quality.

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This material is contained in:
Volume 2
Section: Determine to What Extent Project Operations Affect the Transport of Groundwater and Contaminants

FIGURE 1.1-1

INVESTIGATION AREA

[NIP – General Location Maps]

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2.0 ENVIRONMENTAL SETTING

2.1 Natural Elements

To properly assess the effects of the operation and features of the Niagara Power Project (NPP) on local groundwater flow it is necessary to have an understanding of the natural elements that affect flow, such as topography, hydrology, geology, and hydrogeology within the investigation area.

2.1.1 Topography

Except for the Niagara escarpment, the Falls, and the Niagara River gorge, the area around the Project is of relatively low relief (Figure 2.1.1-1).

2.1.1.1 Niagara Escarpment

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. South of the escarpment, surface elevations range from El. 575 feet (United States Lake Survey Datum [USLSD] 1935, the datum used for construction of the Project) along the upper Niagara River to El. 650 feet on Tuscarora Nation lands to the north (Figure 2.1.1-1). Immediately north of the escarpment, surface elevations are approximately El. 350 feet.

The carbonate bedrock units (dolomites and limestones) in the investigation area are more resistant to weathering than the shale units above and below and consequently form the most predominant part of the Niagara escarpment.

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2.1.1.2 Niagara Falls and Niagara Gorge

The Niagara gorge runs north-south, with its southern end at the Falls and its northern end at the Niagara escarpment. The depth of the gorge is approximately 250 feet below the surrounding land surface. Approximately halfway along the gorge, downstream of the Falls, is the Whirlpool, a unique structure formed following the most recent glaciation when the river intersected a pre-glacial riverbed.

2.1.2 Surface Water

All surface water bodies in the Project vicinity drain northward to Lake Ontario either directly or indirectly via the Niagara River. Streams in the investigation area drain either south or west to the Niagara River

2.1.2.1 Niagara River

For the purposes of discussion, the Niagara River may be subdivided into the upper Niagara River (i.e., the river upstream of the Falls) and the lower Niagara River (i.e., the river below the Falls) (Figure 2.1.1-1). Flow at the river's head at Buffalo, averages 212,300 cubic feet per second (cfs).

The upper Niagara River, including the Chippawa-Grass Island Pool, is located in the southern portion of the investigation area. The Chippawa-Grass Island Pool is an approximately 3-mile long reach extending from the northern tip of Grand Island to the International Niagara Control Structure (a linear array of 18 sluice gates extending about halfway across the river from the Canadian side, 4,500 feet upstream of the Falls). The International Control Structure, whose primary purpose is to regulate flow over Niagara Falls, also regulates surface elevation of the Pool. From the Chippawa-Grass Island Pool, Niagara River water enters the conduits and flows to the forebay under the force of gravity alone. By international agreement, 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 of the river, and the two Sir Adam Beck plants on the Canadian side.

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As mentioned above, flow over Niagara Falls is controlled primarily by the International Niagara Control Structure. This structure also helps regulate water surface elevation in the Chippawa-Grass Island Pool. According to international agreement, the change in surface elevation of the Chippawa-Grass Island Pool may not exceed 1.5 feet over a 24-hour period.

Below the Falls, namely in the lower Niagara River, flow continues northward through the gorge and past the escarpment, with discharge to Lake Ontario. River water diverted for power generation above the Falls by both U.S. and Canadian hydro plants is returned to the river below the Falls (near the escarpment) via plant tailraces.

2.1.2.2 Gill Creek

The approximately 7-mile long Gill Creek originates in a wetland on the Tuscarora Nation. It flows along the south dike of the Lewiston Reservoir and then south, eventually discharging to the upper Niagara River downstream of the intakes (Figure 2.1.1-1).

A small amount of Project water is discharged from the Lewiston Reservoir to Gill Creek in order to maintain a continuous flow in this small stream. This augmentation flow ranges from a high of approximately 3 cfs in the summer to a low of zero in winter and spring. NYPA provides this augmentation flow from approximately June through September as part of an agreement with the City of Niagara Falls. As noted in ENCRPB 1974, the purpose of this augmentation is to enhance the recreational use of Gill Creek as it flows through Hyde Park (in the City of Niagara Falls) by reducing stagnation and improving the appearance of the creek.

2.1.2.3 Fish Creek

Fish Creek, which is approximately 5 miles long, flows westward from headwaters in the center of the Tuscarora Nation along the east and north dikes of the Lewiston Reservoir, and eventually discharges to the lower Niagara River downstream of the NPP tailraces (Figure 2.1.1-1)

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2.1.2.4 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 (1996), 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 (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 2.1.1-1).

2.1.3 Hydrogeology

2.1.3.1 Stratigraphy

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 of the investigation area is well understood (Figure 2.1.3-1).

Overburden

Throughout the region, a relatively thin layer of unconsolidated overburden overlies generally horizontal layers of sedimentary bedrock. The overburden layer in the Project vicinity is 5 to 15 feet thick, although in some places (southeast of the Project, 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, silt and sand deposited by the glacial ice sheet. The lacustrine deposits, which typically overlie the till, were deposited as bottom sediments in 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 Project vicinity.

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Bedrock

Bedrock found within the investigation area is Silurian in age (deposited between 400 and 440 million years ago) and is classified into two groups: The Clinton Group and the Lockport Group (Brett et al. 1995) (See Table 2.1.3-1 and Figures 2.1.3-2). The predominant group in the investigation area is the Lockport Group, which consists of nearly horizontal massive- to medium-bedded, argillaceous (i.e., containing significant amounts of clay) dolomite (Figure 2.1.3-2). The four formations compromising the Lockport Group are from bottom to top (i.e., from oldest to youngest): Gasport Formation (dolomite), Goat Island Formation (dolomite), Eramosa Formation (dolomite), and Guelph Formation (dolomite). Within the investigation area the thickness of the Lockport Group is approximately 150 feet. The upper layers decrease in thickness and pinch out in the northern half of the investigation area. Along the Niagara escarpment the thickness of the Lockport Group decreases to about 20 feet, and only the Goat Island and Gasport formations are observed. Below the Lockport Group lie the DeCew dolomite and Rochester shale, the upper two of the five formations of the Clinton Group. The DeCew Formation is typically 10-feet thick within the investigation area; the thickness of the Rochester Formation was not determined during this investigation but is reported to be 62-feet (Brett et al. 1995).

2.1.3.2 Groundwater

General

The presence of significant volumes of clay and silt in overburden soils in the Project vicinity, 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 that can occur into 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

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snowmelt by the force of gravity. Preferential localized recharge of the bedrock aquifer occurs where natural soils have been disturbed, as by land filling 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.

The nature of water-bearing openings occurring in the Lockport Group results in the following bulk hydrogeologic character: (1) a permeable zone in the top 15 feet, consisting of gypsum cavities and both vertical and horizontal bedding joints that have been widened by solution processes, and (2) several deeper, essentially horizontal, permeable zones characterized by bedding joints and surrounded by very low-permeability rock. The bedding planes are approximately parallel to ground surface, with a slope or geologic "dip" to the south of about 30 feet per mile.

In the upper, more highly fractured zone, groundwater occurs under artesian, semiartesian, or unconfined conditions (artesian conditions predominating). In the lower water-bearing zones, conditions are exclusively artesian. The lower horizontal zones generally act as separate artesian aquifers (Johnston 1964) (Figure 2.1.3-4).

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 FST crosses over the twin conduits lies within this more highly fractured zone (Figure 2.1.3-5).

Bedrock Stratigraphy, Water-Bearing Zones, and Groundwater Model Layers

Bedrock of the Lockport Group comprises the only regionally extensive aquifer system in the Niagara Falls area. The water-bearing zones of this aquifer consist of vertical and horizontal fractures and joints, dissolution zones along bedding planes, and small cavities from which gypsum has been dissolved. Nine regionally extensive horizontal water-bearing zones have been defined within the Lockport Group; they are represented by model layers in a three-dimensional groundwater flow model

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presented in USGS Water-Supply Paper 2487 (Yager 1996) (Figure 2.1.3-6). The model defines 10 layers with unique characteristics: the top most layer, Layer 1, represents unconsolidated glacial sediments and Layer 2 represents a stratigraphically independent layer of weathered bedrock. Layers 3, 4 and 5 are bedrock formations that are not present within the investigation area. Layers 6, 7, 8, 9, and 10 represent bedrock formations of the Lockport Group and in some cases are further subdivided into Regional Water-Bearing Zones (RWBZs [8A, 8B, 9A and 9B]). The underlying Clinton Group, which has sufficiently low permeability to act as an aquitard, is not included or defined in the model.

2.2 Human Elements

2.2.1 Niagara Power Project

2.2.1.1 Conduits

NYPA's two parallel low-head conduits, which carry water below ground for approximately four miles from the upper river to the forebay (Section 2.2.1.2), convey an average of 70,000 cfs . The conduit intakes are located on the river approximately 2,000 feet upstream of the mouth of Gill Creek (Figure 1.1-1). 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 in the center (Figures 2.2.1-1 and 2.2.1-2).

Conduit inspections were performed in 1989 and 1994 using a manned submersible vehicle. Inspections were performed while the conduit intake gates were closed. Because of equipment limitations, only approximately 34% of the conduits were inspected in 1989. For the 1994 inspection, a custom umbilical cable was manufactured to allow inspection of the full length of both conduits. Conduit 2, the western conduit, was inspected on September 17 and 18, 1994, and Conduit 1 was inspected on October 15 and 16, 1994 (BMD-Candive, 1994). During the inspections, three areas of water inflow were observed at cracks in the conduit floor slabs of Conduit 1. The approximate locations of these areas

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where groundwater inflow was observed within Conduit 1 are shown on Figure 2.2.1-3. During inspections of Conduit 2, no areas of groundwater inflow were observed.

2.2.1.1.1 Conduit Drainage System

A network of gravity drains outside the walls and beneath the floor of the conduits serves to relieve hydrostatic pressure from groundwater (Figure 2.2.1-4). The conduit drainage system (CDS) consists of four pipes paralleling the conduits; two 1- by 2-feet rectangular corner drains and two 24-inch half-round pipes beneath the floors. The system also contains lateral pipes connecting all four horizontal drains at 40-foot intervals. Vertical drains located every 10 feet along the conduit walls connect the corner drains to the conduit backfill. The CDS is hydraulically connected to two pump stations (Section 2.2.1.1.2), one near each end of the conduit system.

2.2.1.1.2 Pump Stations

Pump stations lie at two locations along the conduits. The pump stations are designed to relieve excess hydrostatic pressure from around the conduits. Under typical operating conditions, a system of weirs in each pump station acts to passively relieve excess hydrostatic pressure by allowing groundwater from the CDS to flow into the conduits when the CDS water level exceeds the weir elevation. In the event the conduits ever needed to be dewatered, the pump stations also accommodate pumping equipment to actively pump water from the CDS and relieve excess hydrostatic pressure from around the conduit walls. Pump Station A is located north of the conduit intakes, and Pump Station B is located just upstream of the forebay. The pump stations consist of a system of concrete sumps extending to just below the full depth of the conduits (Figure 2.2.1-3). The main sump, measuring approximately 26- by 40 feet, is connected to the CDS via a pair of 24-inch concrete pipes. The two outer sumps, each measuring 4.5 by 8.33 feet, are connected to their corresponding east and west conduits via a pair of 5- by 7-foot connecting pipes. The main and outer sumps are connected to each other via weirs equipped with flap gates. The weir elevations for Pump Stations A and B are at El. 560.00 and 550.00 feet, respectively. The main sump formerly housed the pumping equipment used for dewatering. In 1974, however, to protect pumps and electrical equipment from corrosion damage, all such items were removed from both stations. The

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gravity drainage system remains hydraulically connected to both conduits (via pump station sumps and weirs) and to the surrounding bedrock (Figure 2.2.1-3), which has been shown to be hydraulically connected to both the Niagara River and the forebay (Miller and Kappel 1987; and Yager and Kappel 1998).

2.2.1.2 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 1.1-1). 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 consist of bedrock primarily of the Lockport Group, although a portion of its base, near the conduit outlet, is in the Rochester Formation (Figure 2.2.1-2). Daily water level fluctuations in the forebay are dependent on the seasonal diversion schedule, the demand for power generation, and the flow of the Niagara River. During 2003, water levels in the forebay ranged from elevations of approximately El. 537 feet to 564 feet for non-tourist season, and from approximately El. 540 feet to 568 feet for tourist season. (Figure 2.2.1-5).

To reduce permeability of fractured rock in the vicinity of the RMNPP, a grout curtain was installed along the walls of the lower Niagara River gorge and the forebay (Figure 1.1-1). The gorge grout curtain extends across the Robert Moses Power Plant intake structure and extends approximately 2,000 feet on the north and south sides of the Forebay. The forebay grout curtain extends for approximately 1,500 feet eastward from the gorge along the north wall of the forebay. The gorge grout curtain extends approximately 275 feet into the Queenston Formation while the forebay grout curtain extends approximately 100 feet into the Rochester Formation.

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2.2.1.3 Lewiston Reservoir

The Lewiston Reservoir occupies approximately 3 square miles of land east of the forebay and the Lewiston Pump Generating Plant (Figure 1.1-1). The reservoir, constructed entirely above the ground surface, 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), with 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 weekly drawdown of approximately 36 feet in 2002 (URS et al. 2005). 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 (URS et al. 2005) (Figure 2.2.1-5). The average reservoir water level for 2003 was El. 649 feet for non-tourist season and approximately El. 643 feet for tourist season.

To reduce permeability of fractured rock beneath Lewiston Reservoir, a grout curtain was installed beneath the reservoir dike core (Figure 1.1-1). The grout curtain was installed by injecting grout under pressure into boreholes drilled into bedrock spaced every 15 feet around the perimeter of the reservoir. The typical drill pattern consisted of grout injection boreholes drilled to depths of between 25 feet to 50 feet below the top of rock approximately every 15 feet, and boreholes drilled into the Rochester Shale approximately every 120 feet.

2.2.2 Falls Street Tunnel

The east-west trending FST, an approximately 3.2 mile-long unlined rock tunnel, was hand-excavated through the Lockport Dolomite in the early 1900s (Figure 1.1-1). 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 in the City of Niagara Falls was the transport of wastewater

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discharging from combined sewers. In wet weather, the excess FST flow 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 1.1-1). 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 1.1-1). 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 1.1-1). 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 1.1-1).

The NYPA conduits pass beneath the FST at Royal Avenue (Figures 1.1-1 and 2.2.1-2). Since the conduits pass below the FST, the FST had to be cut through at that point to construct the conduits. The 300-foot section of tunnel opened for 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

Groundwater infiltration into the FST has historically been a problem for the City of Niagara Falls. As described below in Section 4.4, the greatest volume of groundwater inflow has historically 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:

- 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,

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- 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 (Roll and Lannon, 2001) 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, while less than half that amount (approximately 3.5 mgd) was entering the upstream section. In 2000, a grouting project was completed along the downstream (west) section of tunnel, reportedly reducing the inflow in that stretch to about 1.6 mgd (about 5 percent of average treatment plant flow). Therefore, not accounting for possible increased infiltration in the eastern stretch due to shifting from the grouted western section, the total infiltration near the conduits after the 2000 grouting effort would have been approximately 5 mgd.

2.2.3 LaFarge Redland Quarry

The LaFarge 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 1.1-1). 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.

2.2.4 Chemical Contamination

Toxic chemicals from various industrial processes in the Niagara Falls area have contaminated the soil and underlying groundwater as a result of either leaks and spills from plant operations, or from the disposal of waste products in lagoons, dump sites, and landfills. In the area of the Niagara Power Project, 41 sites have been investigated for the presence of hazardous waste (DuPont et al. 1992). See

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Table 2.2.4-1, which lists contaminants by group in both soil/waste and groundwater. In addition to hazardous waste sites, another potential significant source of groundwater contamination is the numerous fuel service stations that are located throughout the study area.

2.2.4.1 Hazardous Waste Sites

Historically, the most significant hazardous waste sites in terms of their potential to affect groundwater and subsequently the Niagara River include: the Buffalo Avenue Plant (Occidental Chemical), the Necco Park and BFI/CECOS landfills (DuPont Chemical), and the Hyde Park landfill (Occidental Chemical) (USEPA and NYSDEC 2000). Of these sites, only the Hyde Park landfill is located outside the zone of influence of the underground conduit system as defined by the groundwater flow divide located west of the conduits (see Study Area description in DuPont et al. 1992). Farther north on the northern side of the forebay, remediation efforts for soil and groundwater contamination continue at the former Stauffer Chemical Plant site. Figure 2.2.4-1 shows the locations of these hazardous waste sites within the investigation area. It should be mentioned that, since the 1980s, significant reductions in area wide contamination have been achieved through the implementation of groundwater remediation programs at area hazardous waste sites.

2.2.4.1.1 Groundwater Contamination and Migration

Local groundwater studies have shown that, where contaminant migration has occurred, the direction of transport is generally consistent with the known pattern of groundwater flow (Figure 2.2.4-2). Yager (1996) analyzed the movement of groundwater near hazardous waste sites in the Niagara Falls area as part of a comprehensive groundwater model developed for the Lockport bedrock. The direction of horizontal flow in the upper bedrock zone at these sites was found to be mainly toward the FST and NYPA conduits, or the Niagara River (Figure 2.2.4-2). Vertical flow was also found to occur from the upper Lockport to the underlying fracture zones through vertical fractures.

Flow in the underlying fracture zones is generally parallel to the direction of flow in the upper zone, except near the southern end of the underground conduits. Flow near the southern end of the

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conduits is captured by production wells at the Olin Plant site. Toward the north, at the former Stauffer Chemical site, flow is directed toward the forebay canal. Investigations in the area of the Necco Park and BFI/CECOS landfills have further determined that groundwater in the upper Lockport tends to flow southward toward the FST, whereas groundwater in the underlying fracture zones is directed westward (and possibly northward) toward the conduit drains. Groundwater that collects in the conduit drain system discharges either toward the FST or to the forebay.

Groundwater contaminant plumes in the area of the Niagara Power Project are most apparent where several sources of contamination exist close to one another. These include industrialized areas along the river and plumes associated with the Necco Park and BFI/CECOS landfills (Figure 2.2.4-2). Plumes of many contaminants (chlorinated and non-chlorinated volatiles and semivolatiles, PCBs, pesticides, and metals) were identified in the upper Lockport along the river section west of the underground conduits, as well as in the vicinity of the Necco Park Landfill (DuPont et al. 1992). The contaminant plumes west of the conduits, in the vicinity of the DuPont and Olin Buffalo Avenue Plant sites, are centered on Gill Creek south of Buffalo Avenue in the vicinity of probable source areas. Lower concentration trends suggest contaminant migration toward the FST to the north, the conduits to the east, and the Niagara River to the south. Contaminant plumes centered upon the Necco Park Landfill also suggest contaminant migration toward the John Avenue and Falls Street Tunnels to the south, and to the conduits to the southwest.

East of the conduits, three sites are associated with contaminant plumes (DuPont et al. 1992). Plumes of volatile organics, including chlorinated solvents, fuel-related benzene, toluene, ethylbenzene, xylene (BTEX) compounds, and chlorinated benzenes and toluenes, were observed to originate at the Buffalo Avenue (Occidental Chemical) and Royal Avenue (Frontier Chemical) sites (Figure 2.2.4-2). It was observed that the highest levels of these contaminants were confined primarily to the immediate vicinity of these plant sites, with lower levels detected in the vicinity of the FST and the conduits. Contaminant plumes containing chlorinated semivolatile compounds (e.g., hexachloroethane, hexachlorobutadiene, hexachlorocyclopentadiene, and octachlorocyclopentene) and pesticides/PCBs were also identified in the area of Occidental Chemical's S-Area landfill (Buffalo Avenue site), with lower concentration trends directed toward the Niagara River and main plant site (Figure 2.2.4-2). Localized concentrations of BTEX, chlorinated benzene and toluene, and phenols/methylphenols, were also

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identified in the upper Lockport at Occidental Chemical's Durez plant, located west of the BFI/CECOS landfill. As with the other sites described above, the Durez site is located within the dewatering influence of the conduit drains. It has been determined that groundwater flow at the Durez plant is to the southwest.

Of the approximately 12 Niagara Falls-area sites with elevated levels of contaminants in the bedrock aquifer, two sites, namely, the Hyde Park landfill and the Stauffer Chemical site, are located beyond the influence of the underground conduit drain system (see Study Area description in DuPont et al. 1992). Migration of contaminants at these sites is primarily toward the Niagara gorge, with some probable migration in the lower Lockport toward the forebay, particularly from the Stauffer Chemical site. Contaminant plumes at the Hyde Park landfill (i.e., phenols and methylphenols, chlorophenols, chlorinated benzene and toluene, chlorinated semivolatiles, and pesticides/PCBs), and the Stauffer Chemical site (i.e., chlorinated volatiles, chlorobenzene, and BTEX compounds) are shown in Figure 2.2.4-2. As with the other sites discussed, higher concentrations of chemicals were reported on site near probable source areas, with levels decreasing with distance from the site. It was found that groundwater contamination at the Stauffer site was confined to the western portion of the former plant site and adjacent Power Authority property, with vertical migration of volatile organics observed farther west, nearer to the Niagara gorge (CRA 1991).

Downward migration of contaminants in groundwater below the Lockport is restricted by the relatively impermeable Rochester Formation. Contaminants detected in the existing NYPA conduit observation wells (installed at the time of NPP construction), which monitor the entire Lockport Group, have included chlorinated volatile and semivolatile compounds, with maximum concentrations of less than 1.1 mg/L (Dupont et al. 1992).

2.2.4.1.2 Remediation Systems and Flow Barriers

Groundwater remediation programs have been initiated within the Lockport Group at all industrial sites where elevated levels of chemicals have been detected. The locations of area recovery wells for contaminant plume control and remediation are shown in Figure 2.2.4-3.

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Most chemicals identified within groundwater plumes mentioned in Section 2.2.4.1.1 are now largely controlled by the respective ongoing site remediation programs. These programs will, in effect, control future chemical migration into and through the Lockport Group. The remaining comparatively small mass of chemicals present in the bedrock aquifer beyond the influence of these remediation systems is expected to become attenuated, or potentially to reach the Niagara River. The primary migration pathway to the Niagara River is through the underground conduit drains and the FST, which, apart from the river itself, are the main collectors of Lockport groundwater. All dry-weather flow in the FST is now treated at the Niagara Falls Wastewater Treatment Plant (WWTP) prior to being discharged to the river below the Falls. As a result of these combined remedial measures, USEPA estimates that discharge of potentially toxic chemicals to the Niagara River has been reduced by about 80%. The actual reduction is likely greater since this estimate was based on remedial actions occurring only at the priority waste sites and does not take into account the recent completion of remedial systems. While the FST is operating as an effective collector of upper Lockport groundwater, an unknown amount of flow and associated chemicals is transmitted downward into the Lockport Group (through bedrock fractures) or is discharged to the conduit drainage system and forebay.

2.2.4.1.3 Sites of Interest

Stauffer Chemical Plant

The former Stauffer Chemical Company plant is located immediately north of the Robert Moses Power Plant Forebay (Figure 2.2.4-1). Between 1900 and 1930, portions of the site were owned by the Titanium Alloy Manufacturing Company, the American Magnesium Corporation and Niagara Smelting Company. From 1930-1980, the site was owned and operated by Stauffer Chemical Company. Between 1930 and 1976, the plant produced carbon tetrachloride and various metal chlorides. The primary chemical feedstock was carbon disulfide, which reacted with chlorine to produce carbon tetrachloride and sulfur chlorides. Parachlorothiophenol was produced from chlorobenzene and sulfur chlorides. Bulk methylene chloride and tetrachloroethylene were also brought to the plant and repackaged. In addition, two areas east of the plant were used as landfills for the disposal of "inert materials". The plant ceased operation in 1976 and building structures were demolished in 1980.

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Several investigations to determine whether previous site operations have impacted soil and groundwater have been conducted. Results of these investigations determined that several VOCs had impacted soil and were migrating to the groundwater table. A Site Specific Parameter List (SSPL) was developed and includes:

- Carbon Disulfide
- Carbon Tetrachloride
- Chloroform
- Methylene Chloride
- Tetrachloroethylene
- Trichloroethylene
- Benzene
- Toluene

According to a Final Site Investigation Report, prepared by Contestoga-Rovers and Associates (CRA) (April 1991), several hydrogeologic units were identified at the site. Overburden units were divided into fill deposits and glacial/lacustrine clays. Three bedrock water-bearing units were identified within the Lockport Group. The Upper Lockport Water-bearing Zone (UWBZ) consists of the overburden and top 25 feet of the Lockport Formation. The Upper Aquitard separates the UWBZ and lower water-bearing zone (LWBZ). The Lower Lockport WBZ, which ranges from 50-75 feet below the top of rock. Beneath the LWBZ and above the Rochester Formation are undifferentiated water-bearing zones and aquitards in the Lockport Formation. The Lockport/Rochester WBZ located at the base of the Lockport at or near the Rochester Shale contact.

In 1995, based on the results of site investigations, three soil vapor extraction (SVE) systems were constructed to address soil contamination. The major "areas" of contamination where identified as Area A (located in the central portion of the site); Area C (the former landfill area), and Area T-4 (located southwest of Area A).

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Area A is the largest, and contains 32 SVE wells, and three dual-phase groundwater/SVE wells. The area is also covered with a PVC geomembrane liner cover and geotextile cushion. Significant groundwater present in the Area A SVE system (suspected to be originating from preferential pathways created by underground utilities and structural bedding materials) led to the installation of a clay barrier trench. The trench (installed in August/September 2000) was excavated to one foot into native soil and ranged in depths from 3.5 – 7.5 feet below grade. A drainage pipe was installed around the edge of the liner. No information was noted in reports, as to where this drainage pipe discharges. A 2000 Annual Operations and Maintenance Report (CRA, 2000) notes that water levels measured on October 24, 2000, indicated 21 out of the 32 SVE wells were dry. This was the highest number ever observed to date.

Area C is located in the former landfill area that lies within NYPA property immediately east of the Stauffer Plant property. The original SVE system consisted of three SVE wells, a cover comprised of a PVC geomembrane liner, and geotextile cushion. In November 2000, confirmatory soil samples were collected from the area. Analytical results indicated while the majority of the area met soil cleanup objectives of less than 10 ppm total VOCs, an isolated pocket existed within the central portion of the area. Based upon these results, two additional SVE wells were installed. According to the 2002 Annual Operations and Maintenance Report (CRA 2003) it appears that only the two newly installed SVE wells now comprise the SVE system. No additional information is available as to the nature of the old SVE wells. Additionally, the 2000, 2002, and 2003 Annual Operations and Maintenance Reports indicate an Area B (a second former Stauffer landfill area also located on NYPA property immediately east of the former Stauffer Plant). However, after review of available materials, no information regarding this area was available.

The T-4 Area is located southwest of Area A. The remediation system consists of three SVE wells and one dual-phase groundwater/SVE well. Following confirmatory soil sampling in November 2000, which indicated soil sample results below the cleanup criteria of 10 ppm, the SVE system was decommissioned in September 2001. A shallow groundwater extraction well was shut down in mid-2002.

A DNAPL Recovery System consisting of a wooden equipment shed and a concrete secondary containment pad are around well OW-03. Prior to the end of 2001, this well was manually pumped and inspected for the presence of product. At the end of 2001 the well was converted to a permanent

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extraction well. No information was available as to the methodology/reasoning for the DNAPL recovery system at this location (i.e., when free-phase product was discovered in this well, how much was recovered).

In order to address identified groundwater contamination, a groundwater extraction well network was implemented. As of the 2003 Annual Operations and Maintenance Report, there were four deep bedrock groundwater wells, three shallow bedrock extraction wells, plus the shallow well in T-4 area and the three dual-phase wells in Area A. Groundwater from each well is pumped to an on-site treatment system. Treated water is discharged through an outfall to NYPA Forebay.

The 2000 and 2003 Annual Operations and Maintenance Reports (CRA) concentrate on four of the sites WBZs (Upper Lockport WBZ, Lower Lockport WBZ, Lockport/Rochester WBZ and the Rochester WBZ). For purposes of this investigation, only the first three will be discussed. Groundwater level potentiometric contours are presented in both reports. The 2000 report also presents pre-pumping and pumping groundwater contours. In addition, chemical isocontours were completed for carbon disulfide and carbon tetrachloride and chloroform combined. Review of the data indicates:

- Upper Lockport WBZ exhibits little to some local response to pumping. Pre-pumping conditions indicate groundwater flow from east to west toward the gorge. Elevated concentrations of all three compounds (carbon disulfide, carbon tetrachloride, and chloroform) within the dual SVE/Extraction wells located within Area A. Chemical isocontours presented in the 2003 Operations and Maintenance Report indicate effective containment of carbon disulfide, and partial containment of chloroform and carbon tetrachloride.
- Lower Lockport WBZ exhibits high response to pumping. Pre-pumping groundwater flow is from north to south toward the Forebay. During pumping, flow is toward the interior of the site. Elevated levels of carbon disulfide where detected in two wells either within or near the capture zone in Area A. The 2003 Operations and Maintenance Report indicates that contaminants of the Lower Lockport WBZ are being contained, captured on site, and recovered by the groundwater extraction system.

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- Lockport/Rochester WBZ also exhibits a high response to pumping. Pre-pumping conditions indicate flow from north to south/southwest toward the Forebay. Pumping conditions exhibit an inward flow toward extraction wells. The 2003 Operations and Maintenance Report indicates that contaminants of the Lockport/Rochester WBZ are being contained, captured on site, and recovered by the groundwater extraction system.

Hyde Park Landfill Site

Hyde Park landfill is a 15-acre National Priority List Category 1 site. Approximately 80, 000 tons of waste were disposed there from 1953 until 1975. The types of waste disposed of at the landfill and chemicals found in the sites soil and groundwater during previous investigations are summarized in Table 2.2.4.1 (Hooker-Hyde Park Landfill). The clean-up remedies at the site include:

- A source control extraction system of wells to remove non-aqueous phase liquids (NAPL) from the overburden in the landfill.
- An overburden drain system surrounding the landfill. It consists of an overburden collection trench that extends around the north, west, and south sides of the Site, and is located within the limits of the overburden aqueous phase liquid (APL) plume.
- A bedrock remedial system consisting of 17 recovery wells to control a NAPL plume and a 2 well APL recovery well system. This system has been operational since 1994. New recovery wells were added since 1994 to gain complete control of the plume. This is an on-going effort.
- A landfill cap was installed in 1978 to prevent infiltration. The cap was modernized with a composite clay and plastic liner and an overlying geocomposite drainage layer in 1994.
- APL (chlorinated acids, hexachloropentadiene, chlorinated toluenes, benzenes, phenolics, and total organic halides) extracted via groundwater

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extraction pumps and is carbon-treated onsite. About 4,000,000-7,000,000 gallons of groundwater per quarter are treated.

- Approximately 325,00 gallons of NAPL have been incinerated as of April 2002. NAPL was incinerated at the Occidental Buffalo Avenue plant but is now shipped to Texas for incineration.
- A network of approximately 170 groundwater monitoring wells is located on and around the site.
- Restricted access to seeps along the Niagara River gorge face; diversion of seep water and removal of contaminated sediments from the seep face to prevent human exposure.
- Excavation and removal of 29,200 cubic yards of leachate contaminated sediments from Bloody Run and the collection of leachate at the landfill.

Groundwater recovery wells placed between the landfill and the Niagara River currently prevent groundwater contamination from reaching the Niagara River. Samples taken from gorge face seeps by the potential responsible party (PRP) have indicated that the seep water currently requires no additional control or remediation, and is similar in composition to groundwater, which is recharged near the gorge.

Groundwater flow modeling (S.S. Papadopulos, 2001) defined 3 bedrock water-bearing zones within the Lockport Group dolomite: upper (Guelph and Eramosa Units A-F, middle (Goat Island), and lower (Gasport and DeCew). Modeling results indicate that Groundwater flows radially outward from the site:

- west toward the Niagara Gorge where it discharges in seeps,
- east toward the NYPA conduits (about 1 mile east)
- north toward the forebay (about 1 mile north)
- and toward the south

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Modeling results also indicate there is significant downward flow from the upper water-bearing zone to middle and lower water-bearing zones.

Groundwater modeling was used to evaluate the performance of the remedial pumping system for the period between March 1999 and March 2000. Results of this analysis indicated:

- in the Upper bedrock zone, only the southern portion of groundwater within the NAPL plume boundary is captured
- in the Middle bedrock zone, the major portion of groundwater within the NAPL plume boundary is captured
- in the Lower bedrock zone, the groundwater within the NAPL plume boundary is completely captured

Stauffer Chemical Whittaker Subdivision Site

The Stauffer Chemical Whittaker Subdivision Site was used for disposal of approximately 50,000 to 75,000 cubic yards of waste associated with chemical and industrial plant operations. Disposal activities occurred from approximately 1930 to 1952. The site consisted of an excavated canal, measuring approximately 100 feet wide by 2,000 feet long, located in the Town of Lewiston immediately west of the Tuscarora Nation boundary in the vicinity of Upper Mountain Rd (Figure 2.2.4-1).

According to NYSDEC records, wastes disposed of in the canal included asbestos, concrete cell parts, reactor linings, scrap sulfur, graphite, scrap metal, silicon, zirconium and titanium oxides, flux, cinders, and phenol. Site investigation activities occurred from approximately 1979 to 1993. Contaminants identified in soil and groundwater included PCBs, numerous SVOCs, phenol, sulfur, fluorides, chlorides, mercury, arsenic, trichloroethylene, antimony, chromium, and lead. One area near Upper Mountain Road included elevated levels of PCBs (26 ppm) and mercury (132 ppm) in soil. Groundwater samples in this area contained detectable concentrations of TCE, antimony, chromium, and lead.

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The site was delisted from the NYSDEC Inactive Hazardous Waste Sites Registry in 1995.

2.2.4.2 Fuel Service Stations/Petroleum USTs

Another significant source of groundwater contamination is leaking fuel underground storage tanks (USTs). Underground releases of gasoline or diesel from leaking fuel USTs can create plumes of non-aqueous phase liquids (namely, gasoline or diesel product accumulation in the subsurface) or plumes of constituent chemical contaminants dissolved in and migrating with groundwater. Constituent chemicals of gasoline are typically much more soluble and volatile that those found in diesel fuel, and therefore more likely to dissolve into groundwater. Gasoline-related contaminants typically identified in groundwater include benzene, toluene, ethylbenzene, xylenes, MTBE, cyclohexanes, and numerous other common components. Fuel service stations are ubiquitous throughout the study area in both the urban and industrialized areas such as City of Niagara Falls, and the more rural areas such as the Tuscarora Nation.

2.2.4.3 Lewiston Reservoir Sediment Quality

A study was conducted in 2002 to determine the quality of sediment in the Lewiston Reservoir. The findings were presented in a report entitled *Extent of Sedimentation and Quality of Sediment in the Lewiston Reservoir and Forebay* (ESI 2005). Five reservoir sediment samples were collected and analyzed for 18 priority toxic pollutants identified in the Niagara River Toxics Management Plan (NRTMP) and five additional parameters identified by NYSDEC.

A summary of analytes detected in sediment samples is presented in Table 2.2.4-2. Results indicated several PAHs and PCBs detected in reservoir sediments. Total PAH concentrations ranged from 5,500 micrograms per kilogram (ug/kg) to 9,500 ug/kg and total PCB concentrations ranged from 44 ug/kg to 190 ug/kg. Several metals (arsenic, lead and mercury) were detected in all five samples. One pesticide compound (mirex) was detected in one sample at a concentration of 53 ug/kg.

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The report concluded based on pH and sediment organic carbon levels that lead and mercury would not be expected to partition into the overlying water column. Due to the presence of clays in the benthic substrate, arsenic would be unlikely to leach into surface or groundwater. PAHs and PCBs are expected to remain in sediments due to their low solubility and affinity to sorb to organic carbon in sediments. Similarly, mirex adsorbs to sediment particles and has a very low solubility (ESI 2005).

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TABLE 2.1.3-1

BEDROCK STRATIGRAPHY OF THE NIAGARA FALLS AREA

System	Series	Group	Formation	Average Thickness (feet)	Description
Silurian	Cayuga	Salina	Vernon Shale	57 (in study area)	Green and red shale
	Niagaran	Lockport	Guelph Dolomite	33	Brownish-gray to dark gray, fine to medium, thick-bedded dolomite, with some argillaceous dolomicrite, particularly near contact with the Vernon Shale
			Eramosa Dolomite	52	Brownish-gray, biostromal, bituminous, medium- to massive-bedded dolomite, with some argillaceous dolomicrite
			Goat Island Dolomite	41	Light olive-gray to brownish gray, fine to medium crystalline, thick- to massive-bedded saccharoidal, cherty dolomite, with argillaceous dolomicrite near top of formation
			Gasport Limestone	33	Basal unit is dolomitic, crinoidal grainstone, overlain by argillaceous limestone
		Clinton	DeCew Dolomite	10	Very fine crystalline dolomite, medium to dark gray, thin to medium bedded
			Rochester Shale	60	Dark-gray calcareous shale weathering to light gray to olive
			Irondequoit Limestone	12	Light-gray to pinkish-white coarse-grained limestone
			Reynales Limestone	10	White to yellowish-gray shaly limestone and dolomite
			Neahga Shale	5	Greenish-gray soft fissile shale
		Medina[1]	Thorold Sandstone	8	Greenish-gray shaly sandstone
			Grimsby Sandstone	45	Reddish-brown to greenish-gray cross-bedded sandstone interbedded with red to greenish-gray shale
			Power Glen Shale	40	Gray to greenish-gray shale interbedded with light gray sandstone
			Whirlpool Sandstone	20	White, quartzitic sandstone
Ordovician	Upper	Richmond	Queenston Shale	1,200	Brick-red sandy to argillaceous shale

[1]Designated Albion Group by the U.S. Geological Survey

Source: Yager 1996.

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TABLE 2.2.4-1

HAZARDOUS WASTE SITES IN THE INVESTIGATION AREA

SITE NAME	NYSDEC ID#	Classification	Waste Description	Contaminants Identified in Soil/Waste [1]	Contaminants Identified in Groundwater [1]
Basic Carbon	932004	Former disposal or fill area/ Manufacture of carbon product	Coal tar pitch, carbon, graphite	7, 10	
Niagara Recycling (BFI/CECOS)	932042	Landfill	Municipal and industrial waste, chlorinated hydrocarbons	1,10,11	1,2,3,4,6
Airco Speer Carbon-Graphite	932002	Landfill/ Operating industrial facility/Manufacture of furnace electrodes	Carbonaceous furnace insulation, asbestos, spent refractory materials	7,10,11	
Carborundum Company-Globar	932036	Incineration/ Operating industrial facility/Manufacture of heating elements and electronic components from silicon carbide	Spent halogenated and non-halogenated solvents	1,2	1,11
City of NF, Buffalo Avenue	932080A	Former disposal or filled area/Filled wetland	Incinerator ash, characteristic lead waste	1,11	6,10, 11

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TABLE 2.2.4-1 (CONT.)

HAZARDOUS WASTE SITES IN THE INVESTIGATION AREA

SITE NAME	NYSDEC ID#	Classification	Waste Description	Contaminants Identified in Soil/Waste [1]	Contaminants Identified in Groundwater [1]
Necco Park	932047	Closed Landfill/process waste from Dupont Niagara plant	Brine sludges, barium salts, chlorinated compounds, toluene, methanol and acetone	DNAPL, 1,2,8	NAPL,1,2,3,4,5, 8,10,11
DuPont Plant Site	932013	Dump/ Operating industrial facility/Organic chemical manufacturer	Metal cyanide sludges, chlorinated volatiles and semivolatile compounds, pesticides	1,2,10,11	1,2,10,11
Forest Glenn Subdivision	932097	Former disposal or filled area/Filled marsh	Phenol, formaldehyde, PVC resins, graphite, carbon	4,7,11	
Frontier Chemical- Royal Avenue	932110	Closed Lagoons/ Operating industrial facility/Manufacture of caustic chlorine for mercury cell	Caustic sludges, solvent chemicals (chlorobenzenes, PCE, TCE, benzoyl chloride)	1	1,2, DNAPL
Hooker Main Plant	932019	Operating industrial facility/Landfill / organic chem. Manufacture	Inorganic and organic sludges (brine, sulfate, phosphate, oxalic acid)	2,6,10,11	NAPL 1,2,6,8,10

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TABLE 2.2.4-1 (CONT.)

HAZARDOUS WASTE SITES IN THE INVESTIGATION AREA

SITE NAME	NYSDEC ID#	Classification	Waste Description	Contaminants Identified in Soil/Waste [1]	Contaminants Identified in Groundwater [1]
Occidental- Durez Engineered Materials	932040	Operating industrial facility/Manufacture of phenol formaldehyde resins	Phenolic waste	4	2,4,6
Hooker - Hyde Park Landfill	932021	Closed Landfill	Brine sludges, organic phosphate, metallic and acid chlorides, phenolic tars, chlorination products	1,4,8,10	NAPL, 4,5,6,8,10
Hooker - S Area	932019A	Landfill	Organic phosphates, acid chlorides, phenol tars, benzoyl chloride, metal chlorides, chlorinated organics	1,4,6,10	1,6,8
Olin Corporation- Parking Lot/Plant Site	932051A/B	Operating industrial facility/Dump/Pond	Mercury cell brine sludge, organics (TCP,BHC)	10,11	1,2,7,8
Olin Corporation-Disposal Well	932037	Abandoned water supply well	End liquor (60-65% water, 30% sulfuric acid, 5-10% sodium chlorite)		

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TABLE 2.2.4-1 (CONT.)

HAZARDOUS WASTE SITES IN THE INVESTIGATION AREA

SITE NAME	NYSDEC ID#	Classification	Waste Description	Contaminants Identified in Soil/Waste [1]	Contaminants Identified in Groundwater [1]
Olin Corporation -Industrial Welding Site	932050	Former disposal or fill area/ Former pilot research lab and process plant	Brine sludge (w/mercury), waste transformer oil, industrial scrap and fly ash, demolition rubble	7,8,10,11	6,7,8,10,11
Vanadium Corporation of America	932001	Closed Landfill	Ferro chromium alloy dust (K090, D002) and slag, calcium hydroxide, ferro manganese slag	11	1,4,11
Solvent Chemical Plant	932096	Former industrial facility/Dump/ Manufacture of dichloro, trichlor and tetrachlorobenzene	Lead, zinc, benzene and chlorinated benzenes	2,6,11	1,6,11
Stauffer Chemical	932053	Former disposal or fill area/ Production of CCl4, metal chloride and parachlorothiophenol	Asbestos, scrap metals, sulfur, coke, zirconium and titanium oxides, misc organics (PCE, methylene chloride)	1,11	1,2,6
Stauffer Chemical Whittaker Subdivision	Delisted, 1995	Former disposal or fill area	Asbestos, scrap metals, sulfur, coke, zirconium and titanium oxides, phenols	4,11	1,11

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TABLE 2.2.4-1 (CONT.)

HAZARDOUS WASTE SITES IN THE INVESTIGATION AREA

SITE NAME	NYSDEC ID#	Classification	Waste Description	Contaminants Identified in Soil/Waste [1]	Contaminants Identified in Groundwater [1]
TAM Ceramics, Inc.	932028	Operating industrial facility/Dump /Manufacture of refractory products	Metallic ore residues, barium	11	*
Union Carbide Corp. – Carbon Products Division	932035	Operating industrial facility/Dump /Carbon products	General rubble, TCE degreasing sludges, Halowax (D003), chlorinated benzenes	1,6	1,4
Witmer Road Site	932027	Former disposal or fill area/ open burning by City of NF	Corrosive waste, air pollution control waste	7,10,11	1,11

Notes:
+ - Only iron, magnesium, manganese and sodium exceeded NYSDEC Class GA WQS.
* - Groundwater contaminants associated with adjacent Hyde Park Landfill
** - Groundwater contaminants associated with upgradient DuPont and Occidental Chemical Plant Site
NA - Site information is not available.
[1]- Chemical designation for contaminants identified

Group 1 - Chlorinated Volatiles
Group 2- BTEX
Group 3 - Nonchlorinated Volatiles
Group 4 - Phenol and Methylphenols
Group 5 - Chlorophenols
Group 6 - Chlorobenzenes and Chlorotoluenes
Group 7 -PAHs
Group 8 - Chlorinated Semivolatiles
Group 9 - Phthalates
Group 10 - Pesticides/PCBs/Dioxins
Group 11 - Heavy Metals

Source:
DuPont, 1992 and NYSDEC, 2003

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TABLE 2.2.4-2

ANALYTES DETECTED IN LEWISTON RESERVOIR SEDIMENT

	Analytes	Units	RES-SED05 Reservoir	RES-SED06 Reservoir	RES-SED07 Reservoir	RES-SED08 Reservoir	RES-SED09 Reservoir	RES-SED12 (DUP OF SED-08) Reservoir
Date Sampled			10/2/02	10/2/02	10/2/02	10/2/02	10/2/02	10/2/02
VOCs	Tetrachloroethylene	µg/kg						
PAHs	Benzo(a)anthracene	µg/kg	480	360 J	280 J	450 J	260 J	340 J
	Benzo(a)pyrene	µg/kg	710	570 J	490 J	840 J	560 J	640 J
	Benzo(b)fluoranthene	µg/kg	860	670 J	670 J	1100 J	750 J	840 J
	Benzo(k)fluoranthene	µg/kg	630	540 J	380 J	690 J	480 J	520 J
	Chrysene	µg/kg	800	640 J	620 J	1100 J	640 J	810 J
	Total PAHs	µg/kg	7400 J	6100 J	5500 J	9500 J	6000 J	7200 J
Pesticides	Hexachlorobenzene	µg/kg						
	Mirex	µg/kg	53 J					
PCBs	Aroclor 1242	µg/kg	150	130 J	79 J		57 J	99 J
	Aroclor 1248	µg/kg				44 J		
	Aroclor 1260	µg/kg	43 J	37 J	28 J			
	Total PCBs	µg/kg	190 J	170 J	110 J	44 J	57 J	99 J
Metals	Arsenic	mg/kg	5.0 J	5.4 J	5.9 J	14.5 J	8.7 J	9.1 J
	Cadmium	mg/kg						
	Lead	mg/kg	36.8 J	32.6 J	31.6 J	72.4 J	46.6 J	45.6 J
	Mercury	mg/kg	0.206	0.169 J	0.171 J	0.175 J	0.173 J	0.163 J
Miscellaneous	2,3,7,8-TCDD	pg/g						
	Total Organic Carbon	mg/kg	15100 J	13400 J	16800 J	15300 J	16600 J	16200 J
	Total Volatile Solids	%W/W	2.67	2.67	2.32	2.21	2.46	2.25

Source: ESI 2005

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VOC – Volatile Organic Compound
PAHs – Polynuclear Aromatic Hydrocarbons
PCBs – Polychlorinated Biphenyls
µg/kg – micrograms per kilogram
µg/l – micrograms per liter
mg/kg – milligrams per kilogram
mg/l – milligrams per liter
ng/l – nanograms per liter
pg/g – picograms per gram
%W/W – Percent Weight by Weight
J – Estimated Value

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FIGURE 2.1.1-1

NATURAL ELEMENTS WITHIN PROJECT AREA

[NIP – General Location Maps]

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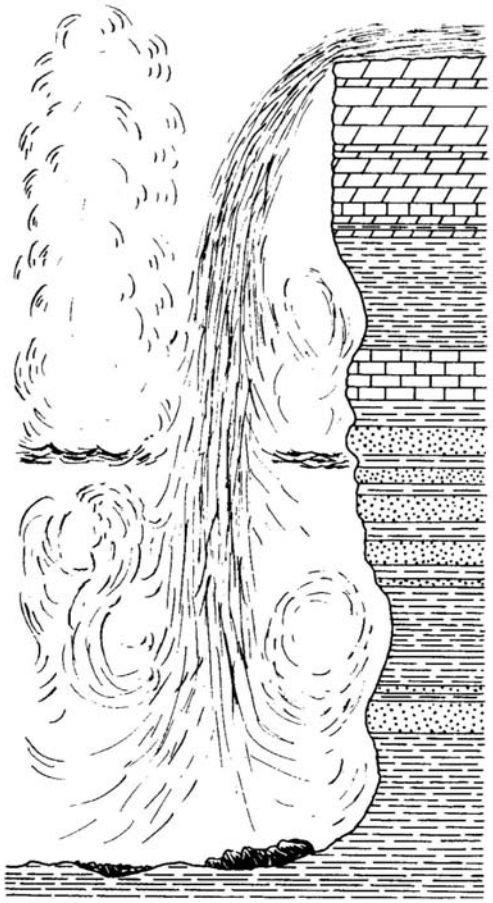
FIGURE 2.1.3-1

BEDROCK FORMATIONS IN THE NIAGARA FALLS AREA AS EXPOSED AT THE HORSESHOE FALLS



System		Group	Formation	Thickness 1/ (feet)	Description
Silurian	Middle		Lockport Dolomite	150	Dark-gray to brown, massive to thin-bedded dolomite, locally containing algal reefs and small, irregularly shaped masses of gypsum. At the base are light-gray, coarse-grained limestone (Gasport Limestone Member) and gray shaly dolomite (DeCew Limestone Member of Williams, 1919).
		Clinton	Rochester Shale	60	Dark-gray calcareous shale weathering light-gray to olive.
			Irondequoit Limestone	12	Light-gray to pinkish-white coarse-grained limestone.
			Reynales Limestone	10	White to yellowish-gray shaly limestone and dolomite.
			Neahga Shale of Sanford (1933)	5	Greenish-gray soft fissile shale.
	Lower	Albion	Thorold Sandstone	8	Greenish-gray shaly sandstone.
			Grimsby Sandstone of Williams (1914)	45	Reddish-brown to greenish-gray cross-bedded sandstone interbedded with red to greenish-gray shale.
			Unnamed unit	40	Gray to greenish-gray shale interbedded with light-gray sandstone.
			Whirlpool Sandstone	20	White, quartzitic sandstone.
Ordovician	Upper		Queenston Shale	1,200	Brick-red sandy to argillaceous shale.

1/ Average figure for area. Thickness at falls is not necessarily the same.

Drawing modified after Gilbert, 1895 (Figure 5 in Johnston 1964)

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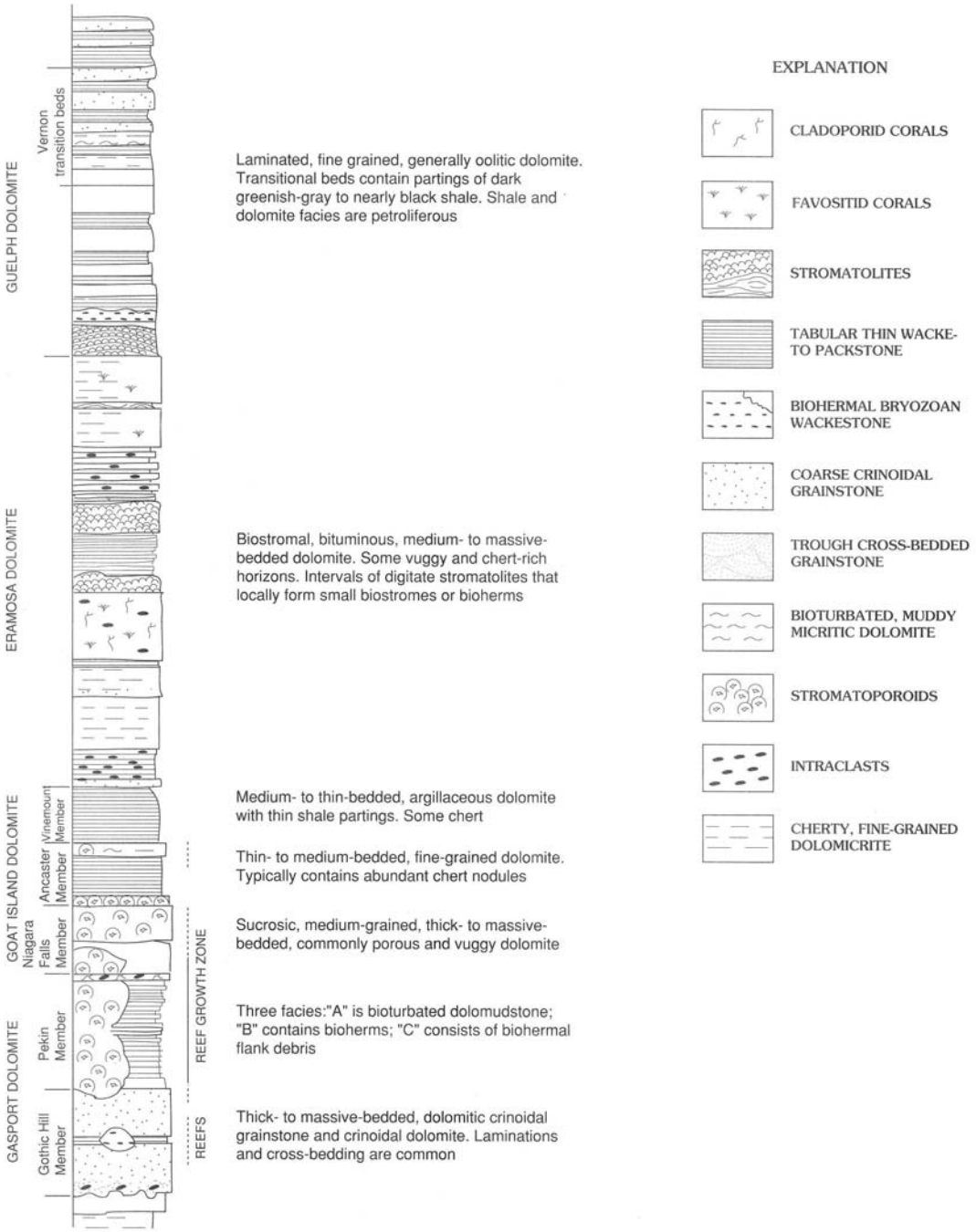
FIGURE 2.1.3-2

DESCRIPTIVE STRATIGRAPHIC COLUMN FOR THE LOCKPORT GROUP



Source: Brett et al. 1995. Composite section for Niagara County is shown.

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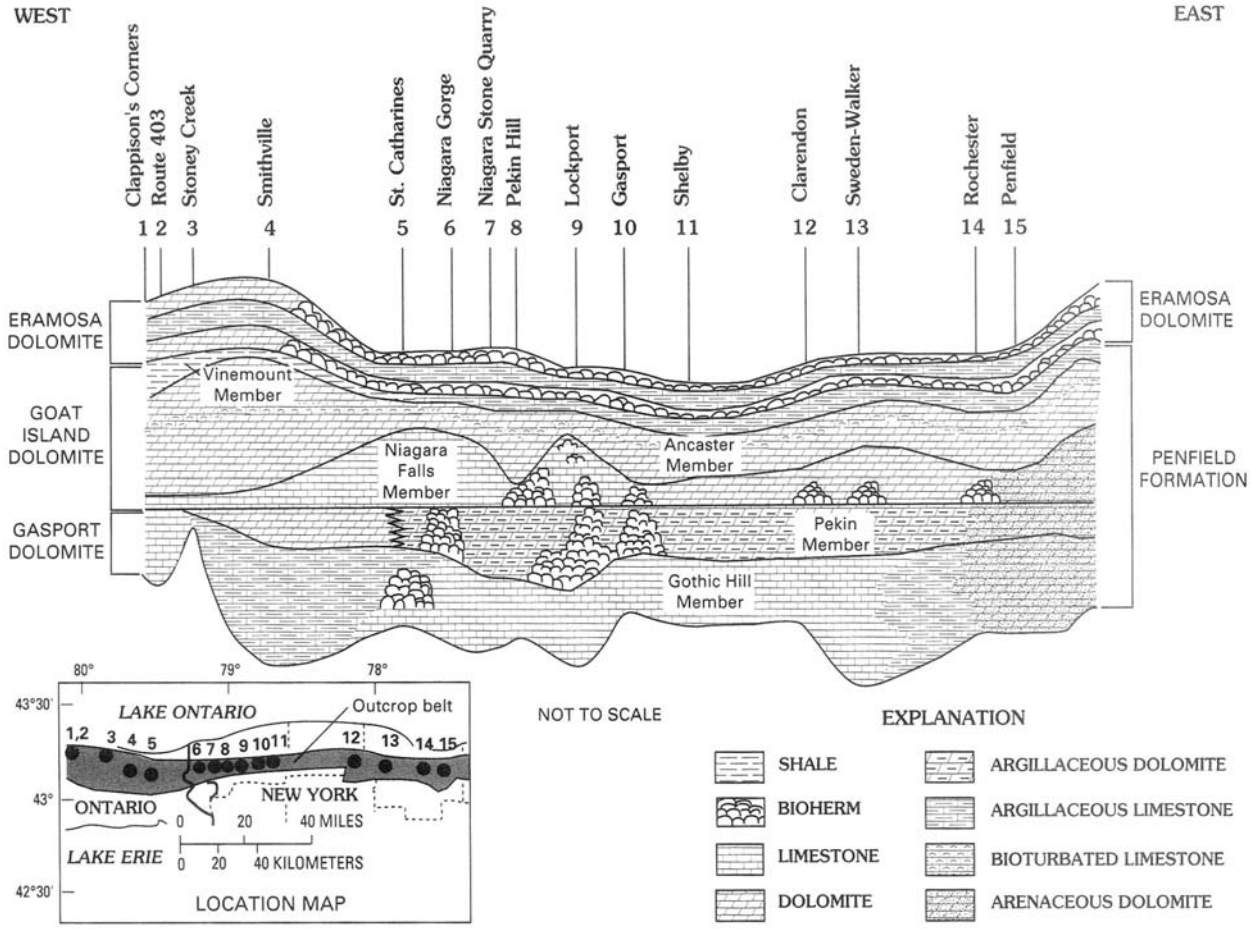
FIGURE 2.1.3-3

DIAGRAMMATIC STRATIGRAPHIC RELATIONS IN THE LOCKPORT GROUP, WITH REGIONAL CORRELATIONS BETWEEN CLAPPISON'S CORNERS, ONTARIO, AND PENFIELD, NEW YORK



Reference Datum is the contact between the Gasport dolomite and the Goat Island dolomite (Brett 1995)

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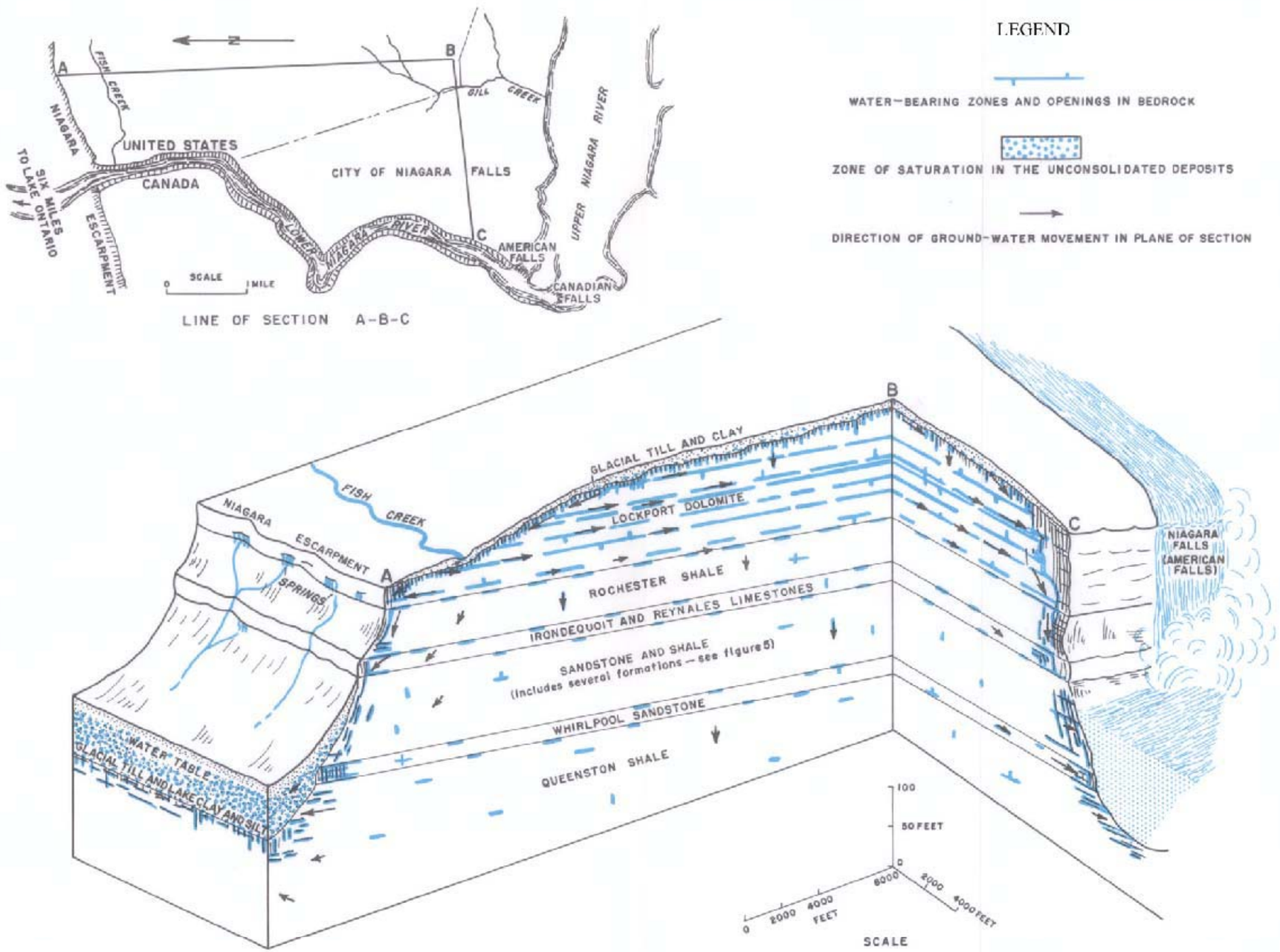
NIAGARA POWER PROJECT (FERC NO. 2216)
DETERMINE TO WHAT EXTENT PROJECT OPERATIONS AFFECT THE TRANSPORT OF GROUNDWATER AND CONTAMINANTS

Generalized Stratigraphy and Groundwater Flow in the Vicinity of Niagara Falls



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

FIGURE 2.1.3-4

New York Power Authority

NIAGARA POWER PROJECT

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FIGURE 2.1.3-5

HIGH-TRANSMISSIVITY ZONE AND FST/CONDUIT CROSSING

[NIP – General Location Maps]

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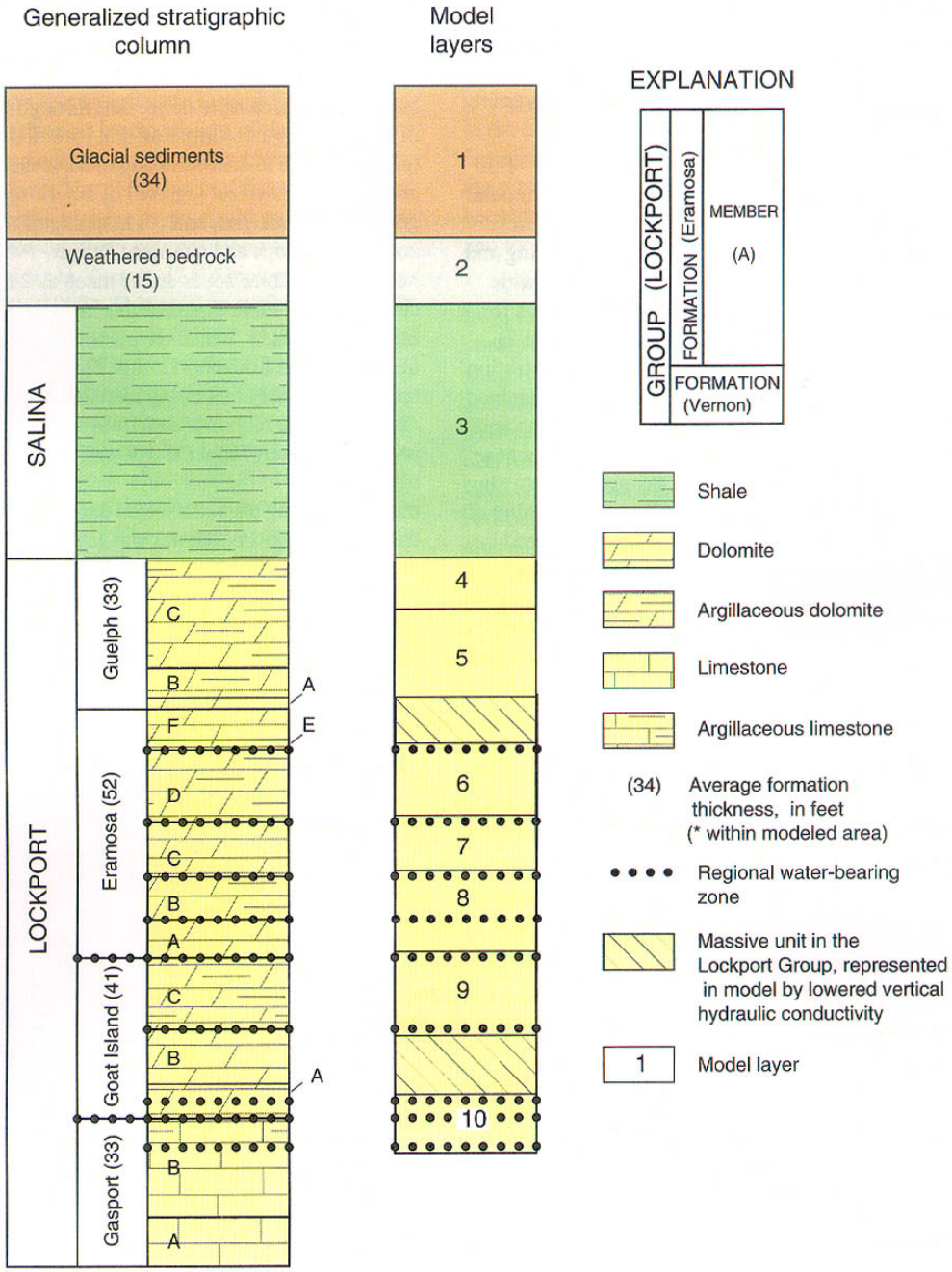
FIGURE 2.1.3-6

RELATIONS AMONG STRATIGRAPHY, REGIONAL WATER-BEARING ZONES, AND MODEL LAYERS



Source: Brett et al. 1995, Tepper et al. 1991, Yager 1996. Use of proposed nomenclature for the Lockport Group does not constitute formal acceptance by the U.S. Geological Survey.

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FIGURE 2.2.1-1

CONDUIT CROSS-SECTION

[NIP – General Location Maps]

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FIGURE 2.2.1-2

CONDUIT LONGITUDINAL SECTION

[NIP – General Location Maps]

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FIGURE 2.2.1-3

APPROXIMATE LOCATIONS OF OBSERVED GROUNDWATER INFLOW

[NIP – General Location Maps]

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FIGURE 2.2.1-4

CONDUIT DRAINAGE SYSTEM

[NIP – General Location Maps]

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FIGURE 2.2.1-5

FLUCTUATION IN SURFACE WATER ELEVATION, LEWISTON RESERVOIR AND FOREBAY, DATALOGGER DATA, JANUARY - DECEMBER 2003

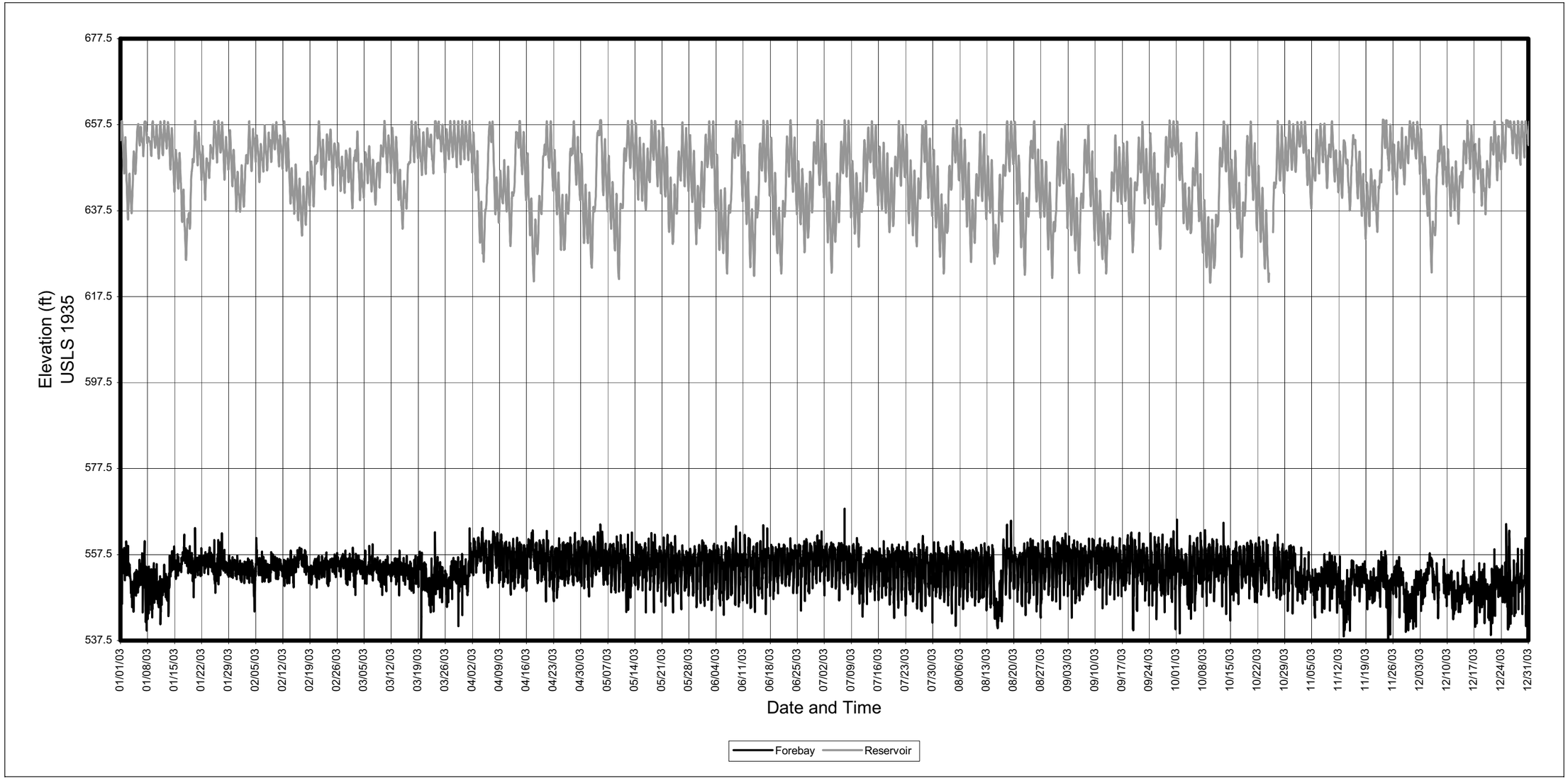

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FIGURE 2.2.4-1

NYSDEC-LISTED HAZARDOUS WASTE SITES

[NIP – General Location Maps]

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FIGURE 2.2.4-2

GROUNDWATER CONTAMINANT PLUMES

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

FIGURE 2.2.4-3

RECOVERY WELLS

[NIP – General Location Maps]

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3.0 NYPA 2002 GROUNDWATER REPORT

A preliminary groundwater study was completed in 2002 as part of the FERC relicensing of the Niagara Power Project (URS et al. 2003). The study included environmental and engineering investigations to identify the potential effect of Project operations and features on groundwater flow in the Project vicinity.

The 2002 investigation relied on existing wells and gauges for the collection of groundwater level data. No new wells or piezometers were installed as part of the 2002 investigation. Data were collected from a variety of sources that included: permanent staff gauges in the Niagara River, abandoned residential wells within Tuscarora Nation Lands, NYPA and government agency owned monitoring wells, and privately owned industrial wells. An attempt was made to correlate changes in surface water levels attributable to Project operations with changes in groundwater elevation. An attempt was also made to determine the effect of Project structures such as the forebay, Lewiston Reservoir, and the conduits on the groundwater regime. As part of this overall effort, observations were made within conduit Pump Station A.

The 2002 investigation concluded that the NPP affects groundwater flow and water levels in the vicinity of the Project. The primary effects identified as part of that study are:

- Sinusoidal fluctuations in water levels in direct response to forebay and reservoir water level fluctuations. The observed fluctuations were most pronounced and direct within the CDS and less pronounced in wells in the vicinity of the reservoir.
- Overall altered potentiometric elevations as a result of project features. Elevated groundwater levels observed near the reservoir likely resulted from increased recharge to the groundwater system from the Lewiston Reservoir. Observed levels indicate depressed water levels in the vicinity of the conduits likely as a result of the CDS acting as a regional groundwater flow sink.

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Observations made in the 2002 study were compared with observations made in previous studies and were found to be generally consistent with the observations of Johnston 1964, Miller and Kappel 1987, Dupont et al. 1992 and Yager 1996. One observation made during the 2002 investigation is that Niagara River water appears (at least sometimes) to be exiting the conduits through the CDS in a reverse pattern from system design.

Some other important observations resulting from the 2002 study were:

- Forebay water level fluctuations have a direct impact on groundwater levels in the vicinity of the conduits for much of the entire length of conduits. The response time for groundwater level fluctuations in these wells was found to be almost instantaneous with forebay level fluctuations. One result of this effect on groundwater levels along the conduit is fluctuating hydraulic gradients along the conduit. When forebay water levels are low, the gradient is typically northward toward the forebay, and when forebay levels are high, the gradient is typically flatter with occasional flow reversals toward the river.
- Forebay water level fluctuations also directly influence hydraulic heads in water-bearing zones that intersect the CDS. Forebay-level-induced fluctuations in groundwater levels were observed up to approximately 3,000 feet from the conduits.
- Groundwater levels along the upper Niagara River exhibit water level fluctuations in response to river water level fluctuations. For wells located adjacent to the upper Niagara River, but outside of the direct influence of the CDS, groundwater level fluctuations of up to approximately 1.2 feet were observed to correspond with river level fluctuations of approximately 1.5 feet. Wells located further north (approximately 2,400 feet from the upper Niagara River) show no effect of changes in river water levels.

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While it was noted that Project operations do appear to induce sinusoidal fluctuations in groundwater levels, and that Project features do appear to alter the flow path of groundwater near Project features, 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 the 2002 study, further study was recommended to quantify the magnitude and extent of Project operational and feature effects on groundwater flow within the Project area. The results of the 2002 study helped to form the basis of the current study.

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4.0 INVESTIGATION ACTIVITIES

The scope of work developed for this investigation included several tasks designed to evaluate Project effects. Tasks completed included: (1) conducting groundwater flow modeling to evaluate NPP effects on groundwater flow, (2) installation of nested groundwater monitoring wells, (3) implementation of a groundwater level monitoring program, (4) investigation of groundwater infiltration into the FST at the point where it crosses over the NYPA conduits, and (5) a water quality sampling program, including collection of surface water and groundwater samples. Each of these tasks is described in detail in the following subsections.

4.1 Groundwater Flow Model

To investigate issues related to the groundwater flow regime in the area of the NPP, numerical modeling of groundwater flow was performed. URS acquired an existing regional groundwater flow model developed by the United States Geologic Survey (USGS) and encompassing the Niagara Power Project, the City of Niagara Falls, and the surrounding area. URS converted this model to a Groundwater Modeling System (GMS) graphical pre- and post-processing environment. The model was then used to evaluate overall groundwater flow patterns in the vicinity of the NPP and to create a focused model of the area surrounding theLewiston Reservoir.

4.1.1 Development and Modification of the USGS Regional Model

In 1996 USGS developed a three-dimensional flow model to estimate rates and directions of the groundwater flow in the Lockport Group, the fractured bedrock aquifer underlying the study area (Yager 1996). The USGS MODFLOW code was utilized. The 1996 model has been modified and recalibrated over the years, with the latest changes having been incorporated in 2003 (MODFLOW 2000 version). The 10-layer model (Figure 2.1.3-6) represents an area of 110 square miles. The model grid contains 71 rows and 69 columns, with a uniform cell size of 1,000 by 1,000 feet.

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Water within the Lockport Group flows through the weathered bedrock surface and several underlying horizontal fracture zones at or near stratigraphic contacts. The fracture zones are connected by high-angle fractures and by subcrop areas where they intersect the bedrock surface. At the scale of the model, the fractured bedrock was assumed to act as a porous medium. The fracture zones were represented by the model layers, and connections between the zones were represented by vertical leakage between the layers.

The Niagara escarpment and the Niagara River gorge form the natural hydrologic boundaries on the northern and western sides of the modeled area, respectively. No-flow, defined flow, or constant-head boundaries for the southern and eastern sides were selected on the basis of potentiometric surface features indicated on maps of each layer. The upper boundary was specified as constant-head in areas underlying the Niagara River and its tributaries, and as constant-flow representing the recharge to the weathered bedrock elsewhere. The bottom boundary was specified as no-flow because an over pressured gas reservoir underlies the Lockport Group and prevents vertical flow from the modeled area. Several manmade hydraulic structures, including the Lewiston Reservoir, tunnels excavated in bedrock, and an extensive drainage system surrounding the hydropower conduits, were also represented as boundaries. A grout curtain installed around the Lewiston Reservoir was modeled as a zone of low transmissivity. The model domain and boundary conditions are shown in Figure 4.1.1-1. Figure 4.1.1-2 shows a generalized cross-section of the model layers and boundary conditions.

Yager (1996) compared results of the steady-state simulations with (1) the measured potentiometric surface of the weathered bedrock zone, (2) average heads measured by piezometers in fracture zones, (3) low-flow measurements of springs and streams, and (4) measurements of discharge from tunnels and excavations. Yager used trial-and-error and nonlinear regression to estimate recharge, transmissivity of the weathered bedrock and fracture zones, and vertical hydraulic conductivity of the bedrock. Nonlinear regression made possible the identification and estimation of values for model parameters to which the measured heads and flows were sensitive. The model developed as a result of this process is referred to as the "calibrated model" in this report.

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Parameters estimated during the calibration process are presented on Table 4.1.1-1. Modeled distribution of hydraulic heads, as well as the comparison between heads observed in monitoring wells and computed by the calibrated model, are shown in Figures 4.1.1-3 and 4.1.1-4, for the weathered bedrock and Gasport dolomite, respectively. Table 4.1.1-2 shows the comparison between the modeled and measured flow rates. Yager states that differences between observed and modeled values are likely due to local variations in transmissivity in bedrock that are not represented by the model.

Results of the USGS model indicated that (1) measured flow into the FST exceeds the amount that can be sustained by the aquifer; and that therefore a connection between the tunnel and the Niagara River may be assumed; (2) recharge within the urban parts of the modeled area is greater than in the rural parts, possibly because of losses from the municipal water supply or infiltration from unlined storm sewers that intersect the bedrock; and (3) within the lowlands near the Niagara River, widespread areas may exist in which groundwater flows upward and is discharged through evapotranspiration and surface drainage. Conclusion (1) is particularly important in the context of this groundwater report. The inability of the model to account for the large percentage of the flow measured in the Falls Street Tunnel implies that a connection exists between the Niagara River and the Tunnel, and that this connection may not be formed as an effect of the natural hydraulics of the aquifer. The possible nature of the connection is discussed in Section 6.2.

Another meaningful finding of the model is the distribution of the areas contributing to particular discharge points (Figures 4.1.1-5 and 4.1.1-6). Table 4.1.1-3 presents the water budget. Major sources of inflow are recharge, as well as leakage from the Niagara River and the Lewiston Reservoir. The main sinks are the Niagara River gorge, tributary creeks, and the FST where the two NYPA water conduits pass beneath the FST.

Alternative concepts of the aquifer system that closely reproduced the measured heads and flows used for calibration were identified through nonlinear regression. The first included additional zones of recharge; the second included different model boundary conditions; and the third included horizontal anisotropy within model layers. The calibrated model and the two best alternative models were used to estimate groundwater flow rates at 21 waste disposal sites.

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URS obtained the latest 2003 model through personal communication with Richard Yager, the model's author. The main difference between the 1996 and 2003 models is the increase, by Yager, in the estimated recharge in the rural areas of the model domain of approximately 50%. This created an increase in the total amount of water entering the system of approximately 6%. Small changes were also made to some values of transmissivity and vertical leakance. The resulting values of hydraulic heads are slightly different than those of the original 1996 model, although the flow patterns are preserved.

4.1.2 Conversion of the USGS Model to the GMS Environment

To make the model useful for the present project, it was decided to convert the USGS model to a Groundwater Modeling System (GMS) environment.

GMS (version 4.0) is a modeling environment developed by the Environmental Modeling Research Laboratory of Brigham Young University, Utah. GMS provides user interfaces to several groundwater flow and transport models, including MODFLOW. It facilitates model development and the post-processing of model results. It has extensive graphics capabilities, as well as interfacing easily with the software packages commonly used to process and present information, such as Geographic Information System (GIS) or ArcInfo.

Conversion of the MODFLOW 2000 model to the GMS modeling environment involved: (1) direct importation of non-calibrated model elements, (2) extraction of calibrated parameter array elements and importation into GMS, and (3) conversion verification by comparing flow budgets and hydraulic heads of observation wells. Detailed discussion of conversion methods is presented below and in Appendix A.

The converted model served as the basis of the focused model that was later applied to perform a more detailed assessment of groundwater levels and flow near the Lewiston Reservoir.

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4.1.2.1 Conversion Method

URS used GMS, version 4.0, as the platform for the modeling effort. The file format of the calibrated USGS model, used to create the GMS version, is that of MODFLOW 2000. Files containing information about model elements that were not the object of calibration are essentially the same as the corresponding files in the GMS format, and can be converted by the straightforward importation through a screen editor. Files containing results of calibration were converted using the method described in detail in Appendix A. This section presents a summary of the process.

Model elements subjected to calibration, namely, horizontal hydraulic conductivity (or transmissivity), vertical hydraulic conductivity (or vertical leakance) and recharge, take the form of arrays. This is the result of the division of the modeled area into a finite number of cells. For each model cell within a given layer, a single value of each parameter is required by the model, thus creating an array. The MODFLOW 2000 calibration process creates the required parameter arrays by combining four objects: a group of parameter values, an array of multiplication factors, an array of zone indicators, and a uniform multiplication factor. The four elements were extracted from the MODFLOW 2000 files and recombined to create arrays of calibrated parameters. The arrays were then imported into GMS.

The 1996 model was prepared using a MODFLOW option of defining model conductances called "Block Centered Flow" package. The 2003 model was prepared in terms of another option, namely, the "Layer Flow Package". During the conversion process, it was found that the GMS did not support certain elements of the Layer Flow Package. The conversion was therefore accomplished by using the Block Centered Flow package (the same approach as was utilized in the original 1996 USGS model).

Several methods of solving finite-difference equations are at the basis of the model. Both the USGS model and the converted GMS model use the method of a "Pre-Conditioned Conjugate Gradient Solver". During the simulation using the converted model, it was found that the model conversion could be improved by changing some of the parameters of the solver from the original values used in the USGS model. The slight change in convergence behavior of the system likely resulted from the use of different flow packages (Layer Flow Package vs. Block Center Flow Package).

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4.1.2.2 Verification of Conversion

To verify that the converted model (GMS model) was equivalent to the 2003 USGS model (MODFLOW 2000 model), both flow budgets and hydraulic heads at locations of observation wells were compared.

4.1.2.3 Flow Budget

Table 4.1.2-1 shows a comparison of flow budgets between the two models. The discrepancies in elements of the flow budget are negligible, ranging between zero and 0.06%. Most likely, they result from the GMS model using slightly different parameters of the Pre-Conditioned Conjugate Gradient Solver package.

4.1.2.4 Hydraulic Heads

The 2003 USGS model output contains the model-calculated hydraulic heads at 208 monitoring locations. These can be compared to the heads at the same locations, as calculated by the GMS model.

The comparison is shown on Table 4.1.2-2. The discrepancies range from zero to 0.7 feet, with most being on the order of 0.01 to 0.1 foot. The reasons for the discrepancy may be related to the use of slightly different parameters of the solver package. Moreover, locations of monitoring points were converted from the coordinate system used by the USGS model to the coordinate system used by URS for the NYPA project. Some degree of error can be expected from the conversion process, resulting in a corresponding error in the hydraulic heads.

Hydraulic heads in the weathered bedrock and Gasport dolomite computed with the converted model are shown on Figures 4.1.2-1 and 4.1.2-2. These may be compared with the hydraulic heads of the USGS model on Figures 4.1.1-3 and 4.1.1-4.

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In addition to weathered bedrock and the Gasport dolomite, two other model layers occur in the area of the Lewiston Reservoir. They are the Eramosa dolomite and the Goat Island dolomite. Hydraulic heads in these layers are shown in Figures 4.1.2-3 and 4.1.2-4, respectively.

4.1.3 Focused Modeling

4.1.3.1 Development of the Focused Model

A numerical groundwater flow model relies on the division of the model domain into a finite number of cells. The size of the model is defined by the total number of model cells, not by the area included in the domain. To keep the model both manageable and useful, a balance must be achieved between the accuracy (improved by decreasing the cell dimensions) and the model size (decreased by using large cell dimensions).

The regional model encompasses a large area and; therefore, it must rely on a relatively coarse discretization. This discretization is not sufficient to investigate issues related to the flow patterns in areas whose size is similar to the model cell dimension. For example, the distance between the groundwater divide that exists in the upper fractured bedrock east of the Lewiston Reservoir and the edge of the reservoir is approximately 1,500 feet. The model cell dimension is 1,000 feet on a side, meaning that the entire area of the divide is contained within just a few model cells.

The focused model is effectively a “cut-out” from the regional model. Its domain is smaller than that of the regional model, allowing for use of a smaller cell dimension without increasing the model size. The boundaries of the focused model are defined by the regional model. The advantage of the focused model is that it can “zoom in” on a particular area, allowing for a more detailed analysis of local issues.

URS used this approach to create a local model of the reservoir vicinity, based on boundaries obtained from the regional model.

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4.1.3.1.1 Model Domain and Grid

The focused model is intended as a tool for analyzing the groundwater flow regime in the vicinity of the reservoir. The limits of the domain were chosen to coincide either with natural hydrogeologic features or with arbitrary lines where the hydraulic heads and groundwater flow rates were established previously within the framework of the regional model.

The domain of the focused model has been selected based on these criteria. It is shown in Figure 4.1.3-1. To the north, the domain is bounded by the Niagara escarpment. The northwest limit is defined by the Niagara gorge. To the east, the domain extends to a regional groundwater divide. The escarpment, the gorge, and the divide are all natural features, also utilized as boundaries of the regional model. Therefore, the northward, eastward and northwestern extent of the focused model is the same as that of the regional model.

To the south and southwest, the extent of the focused model domain was chosen to include natural features that may potentially affect flow patterns in the study area. The southernmost such feature is the quarry. A line immediately south of the quarry defines the southern extent of the focused model. The location of this line was fine-tuned based on the definition of model layers established within the regional model. Several of the regional model layers are found only in the southern part. These layers were eliminated from the focused model by selecting the southern limit of the focused model domain to be north of the area where the layers "pinch out". The overall size of the focused model (i.e., the total number of cells) was therefore decreased. To the southwest, the model extent is terminated immediately east of the NYPA conduits. The conduits are a major sink in the region, creating an effective hydraulic separation of the Lockport aquifer into the east and west areas. The domain of the focused model was divided into uniform cells with the dimensions of 250 by 250 feet, arranged into 125 rows and 250 columns. Vertically, the domain was divided into seven layers, corresponding to Layers 1, 2, 6, 7, 8, 9 and 10 of the regional model [(Layers 3, 4 and 5 of the regional model do not exist within the domain of the focused model) (Figure 4.1.3-2)]. The total number of focused model cells was 218,750.

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4.1.3.1.2 Boundary Conditions

The northern, northwestern, and eastern boundaries of the focused model domain reflect existing hydrogeologic features. They are identical with the boundaries of the regional model. The boundary conditions are therefore also the same (see Figure 4.1.1-1). The southwestern and southern boundaries were chosen to include specific natural features that may affect flow patterns in the study area. These boundaries were treated as specified head boundaries, with the values of hydraulic head equal to those determined by the regional model.

4.1.3.1.3 Layers

Layer 1 of the regional model represents the sinks and sources located within the overburden. Flow in the overburden itself is not simulated. Layer 2 corresponds to the layer of fractured bedrock, extending over the entire model domain. Subsequent layers 3 through 10 simulate various fractured zones located horizontally within the relatively unfractured rock matrix of the underlying geologic units (Figure 2.1.3-6 and 4.1.3-2). These geologic units dip to the south at a rate of approximately 30 feet per mile. As a result, the geologic units, and associated fracture zones subcrop throughout the model domain, with deeper units surfacing progressively to the north. To account for this, each model layer is terminated north of the outcrop area of the fracture zone simulated by this layer. Only Layer 2, representing the fractured bedrock, is continuous throughout the model domain.

The focused model retains the same layering system. Layers 3, 4 and 5 of the regional model, however, subcrop south of the southern boundary of the focused model. As a result, they do not exist in the area contained within the domain of the focused model. Therefore, the focused model is constructed of 7 layers. The correspondence between the layers of the regional and focused models is as follows:

Geologic Formation	Regional Model	Focused Model
Overburden	Layer 1	Layer 1
Weathered Bedrock	Layer 2	Layer 2
Salina Shale	Layer 3	Not represented

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Guelph Dolomite	Layer 4	Not represented
Guelph Dolomite	Layer 5	Not represented
Eramosa Dolomite Unit D	Layer 6	Layer 3
Eramosa Dolomite Unit C	Layer 7	Layer 4
Eramosa Dolomite Units B and A	Layer 8	Layer 5
Goat Island Dolomite	Layer 9	Layer 6
Gasport Dolomite	Layer 10	Layer 7

The horizontal extent of model Layers 2 through 5 of the focused model is the same as the extent of the corresponding layers of the regional model. The horizontal extent of Layers 9 and 10 was adjusted based on site-specific data obtained from the 2003 investigation. The regional model relied on the extrapolation of relatively sparse data to define the extent of these layers. It was found that the actual outcrops of Layers 6 and 7 at the northwestern corner of the model domain (in the vicinity of the Lewiston Reservoir) are approximately 4,000 feet south of the locations used in the regional model. Subsequent simulations of the focused model indicated that the adjustment had a negligible effect on hydraulic heads produced by the model (on the order of 0.1 to 1.0 feet in the immediate vicinity of the affected region, essentially zero elsewhere in the domain).

4.1.3.1.4 Hydrogeologic Parameters

Each model layer is defined by two parameters: transmissivity and vertical leakance. Transmissivity governs the horizontal flow of groundwater within the layer. The vertical exchange of water between adjacent layers is determined by the vertical leakance. Values of these parameters were determined during the calibration of the regional model. Note that parameter values are not necessarily the same throughout a layer. In several cases, different model cells within the same layer are assigned different values of transmissivity and leakance. Values of transmissivity and leakance for each layer are stored as arrays, with each model cell assigned its own value of the given parameter.

For each layer, transmissivities and vertical leakances of the focused model were assigned by transferring values from the regional model to the focused model. Because of the different cell sizes of

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two grids (1,000 by 1,000 feet for regional model, 250 by 250 feet for the focused model) the transfer could not be accomplished directly. Instead, it was performed by interpolating from the regional model arrays to the focused model arrays.

Another hydrogeologic parameter used in the model is recharge. Similarly to the transmissivity and vertical leakance, recharge in the regional model was also obtained during the process of calibration. Recharge values vary between model cells, and are stored as an array with one value corresponding to each model cell. The same procedure of interpolation used with transmissivity and leakance was followed in transferring recharge from the regional model to the focused model.

The interpolation of parameter values from the regional model grid to the focused model grid creates a certain "mathematical" effect, which affects the solution of the focused model. In areas where the regional model parameters vary from cell to cell, the interpolation into a different (in this case finer) grid of the focused model cannot capture the variation exactly. Instead, the interpolation produces focused model arrays with the variation somewhat "smoothed" as compared to the regional model. This effect is typically very minor and does not affect the overall flow pattern.

4.1.3.1.5 Initial Hydraulic Heads

In order to initiate the solution, the model requires that a set of initial hydraulic heads be entered. Inside the model domain, initial heads are adjusted during the simulation until the satisfactory solution is achieved. The actual values of initial heads inside the model domain are therefore not relevant to the solution. However, at the specified head boundaries, the initial heads are kept constant, and define the solution. As a result, hydraulic heads at the specified head boundaries must be known in advance.

The focused model contains specified head boundaries in each of the model layers at the southern and southwestern limits of the model domain. The hydraulic heads assigned to these boundaries were taken from the regional model. The hydraulic heads were transferred from the solution of the regional

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model for each model layer to the corresponding layers of the focused model using the process of interpolation.

4.1.3.1.6 Sources/Sinks

The regional model contains numerous sources and sinks, representing both natural and anthropogenic features encountered in the model domain. Such features include outcrops of water-bearing zones along the Niagara escarpment and Niagara gorge, creeks and swamps, the Lewiston Reservoir, groundwater extraction wells, and the LaFarge Redland Quarry. These features are shown on Figure 4.1.1-1.

All sinks/sources represented in the regional model are reproduced in the focused model, if they are located within the focused model domain.

Sources/sinks may be represented in either of two ways. One is to fix the flow of water going into, or out of, a given model cell. In the regional model, groundwater extraction wells are simulated using this method. The same method is used and the same flow is assigned to the extraction wells in the focused model. The second method, used to simulate all other sinks and sources in the regional model, is to specify the flow as proportional to the difference between some given hydraulic head and the hydraulic head within the cell. This fixes the magnitude of the sink/source as a linear function of the hydraulic head in the model cell containing the feature.

The conversion of the sinks/sources of the second kind from the regional to the local model is not straightforward. This is because the proportionality constant determining the flow is a function of the number of cells used to represent the feature and/or the cell sizes. The regional and focused models are based on different cell sizes. This implies that assigning the same values of the constant of proportionality to represent the same features will not reproduce the effects of the regional model features in the focused model.

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Consider a section of a discharging stream modeled as a constant head cell in Layer 1. The amount of flow that this source cell conveys to Layer 2 is equal to the head differential between two layers multiplied by the proportionality constant (here, vertical leakance) and by the horizontal cell area. In the regional model, the cells are 1,000 by 1,000 feet. This is the minimum size of a feature that can be represented. If the stream section is 100 feet wide and 1,000 feet long (area of 100,000 square feet), it still has to be modeled as a 1,000,000 square foot cell.

In the focused model; however, the cell size is 250 by 250 feet (62,500 square feet). A 100- by 1,000-foot section of the stream is therefore modeled as 4 cells, total area of 250,000 square feet. In order to create the same flow as the original 1,000,000 square foot cell of the regional model, with the same head differential between the Layer 1 and Layer 2 cells, the vertical conductance in the focused model must be four times lower than in the regional model.

As a result of this phenomenon, proportionality constants in the focused model had to be adjusted during the construction of the regional model. This was accomplished by running the model repeatedly and varying the constants until the flow budget of a given sink/source feature in the focused model was within approximately 10% of the flow budget of that feature in the regional model.

Another implication of the difference in cell sizes between the models is the location of each sink/source feature. The 1,000-foot cell size in the regional model means that features can be located with the accuracy of approximately 1,000 feet of their actual location on the map. In the focused model, the same features can be located with the accuracy of approximately 250 feet. Therefore, locations of streams, wetlands, layer outcrops, etc., are slightly different between the two models.

4.1.3.2 Solution of the Focused Model

The solution of the focused model in the form of hydraulic heads in Layer 2 (fractured bedrock), Layer 5 (Eramosa Dolomite), Layer 6 (Goat Island Dolomite), and Layer 7 (Gasport Dolomite) is shown in Figures 4.1.4-1, 4.1.4-2, 4.1.4-3, and 4.1.4-4, respectively. Note that these four layers are found within

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the study area, that is, beneath and immediately east of the Lewiston Reservoir. The focused model essentially reproduces the solution of the regional model. See, for example, the hydraulic heads in the fractured bedrock and Gasport dolomite (Figures 4.1.2-1 and 4.1.2-2 of the regional model and Figures 4.1.4-1 and 4.1.4-4 of the focused model). Small differences exist between the two solutions, although all major features are preserved. The differences originate from the mathematical artifacts of the conversion between the two grids, as described in the previous sections (smoothing out of parameter variation during interpolation, and adjustments to the location and proportionality constants of sinks/sources).

4.2 Installation of Nested Groundwater Monitoring Wells

The groundwater investigation drilling program featured the installation of up to three piezometers within single boreholes. This arrangement is referred to as a nested well. The purpose of installing nested wells was to monitor multiple water-bearing fracture zones at a single location while reducing the number of boreholes that were drilled. A total of 91 nested bedrock piezometers were installed in 37 boreholes at 17 locations (GW03-001 to GW03-017) across the study area during June through August 2003. The piezometers were designed to target individual water-bearing horizontal fracture zones identified in the Lockport Group dolomite bedrock aquifer during core analysis or during packer testing of selected boreholes. At locations where more than three fracture zones were identified, a second or third borehole was drilled. At locations with multiple boreholes, well Ids were appended with A, B, or C as necessary to distinguish the borehole locations (e.g., GW03-015B). Additional boreholes were installed as necessary (depending on the number of water-bearing zones to be targeted) at the same general locations within approximately 10 to 20 feet of the first borehole location. A cluster of nine piezometers in three nested boreholes was installed at one particular location (GW03-017).

In addition to the 17 nested bedrock groundwater monitoring well locations, two one-inch piezometers were also installed in shallow overburden soils at location GW03-018 located in a wetland at the head of Gill Creek on Tuscarora lands.

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4.2.1 Selection of Nested Well Locations

Nested well locations were selected based on the likelihood of groundwater data from these locations contributing to an evaluation of the effect of the Niagara Power Project operations on the transport of groundwater and contaminants in the investigation area (Figure 1.1-1).

Eleven nested monitoring wells (GW03-001 through GW03-011) were installed around the Lewiston Reservoir as shown in Figure 4.2.1-1. These well locations were chosen to evaluate the effect of Lewiston Reservoir operations on groundwater quality and to further evaluate groundwater flow patterns. Four nested wells (GW03-001 through GW03-004) were installed in a straight line north of the reservoir, with the northernmost nested well located about 600 feet south of the Niagara escarpment. These wells were situated to more accurately determine the location of a groundwater divide. This divide marks the location where groundwater moves to the north toward the escarpment or south toward the Lewiston Reservoir. Five well locations, GW03-005 through GW03-009, were situated east of Lewiston Reservoir to more accurately determine the location of a groundwater flow divide projected to lie in that area. Five nested wells (GW03-005 through -009) were installed approximately 500 to 2,500 feet east of the reservoir. These nested wells were situated to examine the extent of influence on groundwater from the operation of the Lewiston Reservoir. Two nested wells (GW03-010 and -011) were installed approximately 2,000 to 3,000 feet south of the reservoir. These nested wells were also sited to examine the extent of influence on groundwater from the operation of the Lewiston Reservoir.

Six nested wells (GW03-0012 through -017) were installed along the conduits. These wells were installed to assess the effect of NPP operations on groundwater levels and flow along the conduits, and to evaluate groundwater quality in this area.

The two nested piezometers set in the wetland at the head of Gill Creek were installed to assess possible Project and seasonal effects on water levels within the wetland.

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4.2.2 Drilling Program

Drilling operations commenced on June 2, 2003. The drilling rigs consisted of two Versa Drill 2000 Advantage rigs, a Foremost CT 250, and an all-terrain Mobile B-61. Support trucks carried water tanks used during coring operations. A pressurized steam cleaner was used to clean and decontaminate the drilling rigs and all equipment used in intrusive activities before drilling commenced and between boreholes. Decontamination activities were conducted using a temporary decontamination station set up at the NYPA storage area.

4.2.2.1 Surface Casing Installation

Before drilling began, a utilities clearance was performed for each drilling location through the Underground Facilities Protective Organization (UFPO). In addition, a hand auger was used to excavate a five-foot deep hole at each drilling locations to make certain that no underground utilities were present. A backhoe was also used at one location instead of a drilling rig to avoid drilling through a water main located near GW03-017.

At the first location, a roller bit was used to drill through overburden glacial deposits to the top of bedrock. The drillers switched to a 10-inch air hammer on most subsequent holes. This proved to be a much faster method of drilling through the overburden. In three boreholes at GW03-015 and one borehole at GW03-017 a 12¼-inch roller bit was used with a soy-based mud additive (Revert) to drill through porous rocky fill. This drilling method was used to prevent hole collapse and maintain circulation of drilling fluid while drilling through the fill material.

A temporary 10-inch outside diameter (OD) steel casing was then installed through the overburden borehole to the top of rock. Soil that accumulated inside the casing was flushed out before coring began. An HQ-size (3.0-inch inside diameter [ID]) core barrel was used to core five feet into rock. After the core was retrieved, a 10-inch OD air hammer was used to ream the core hole. A batch of cement-bentonite grout was pumped through a threaded plastic pipe that extended to the bottom of the

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hole to fill a portion of the borehole. Following this, an 8-inch OD permanent steel surface casing sealed with a PVC end cap was placed into the 10-inch temporary casing and downward through the grout. The permanent casing was seated into the bottom of the rock socket. The grout in the borehole was displaced upward into the annular space between the temporary and permanent casing. The temporary casing was then withdrawn from the borehole, the level of grout in the borehole dropping as the casing was removed. Additional grout was added to bring the grout level to the ground surface. The grout was allowed to cure for a minimum of 48 hours before rock coring commenced.

4.2.2.2 Rock Coring

A single borehole was cored at each of the 17 locations across the study area. Cores were taken from the Lockport bedrock surface to a depth of five or more feet into the underlying Rochester shale. At locations where nested wells were installed, no cores were taken from subsequent boreholes that were drilled at the same location. Instead, these borings were air-hammered from the ground surface to completion depth.

An NQ-size (2.0-inch ID) wireline, eight-foot long, double-tube core barrel assembly was used for coring the bedrock. The resulting corehole measured approximately 3-inches in diameter. A wireline core assembly was used for the drilling program because it can be retrieved faster than a conventional core barrel that requires disconnecting sections of drill rods as the core barrel assembly is removed from the hole. Potable water from a Town of Lewiston hydrant was used as a drilling fluid, or "drill water" (to cool the diamond-impregnated core bit) during the coring operation. The water also removes finely ground rock particles called rock cuttings or drill cuttings. The drill water was circulated to the surface where rock cuttings settled into a tub.

A typical individual core section (termed a run) was five-feet long. (Occasionally, the core barrel would "jam" before completion of the run.) The driller would remove the core barrel from the hole, carefully remove the core from the inner barrel, and place it in the correct orientation in a wooden core box. The core was scanned with a photoionizing device to detect volatile organic compounds that may have been trapped in pore spaces and fractures in the rock. The core box was labeled and photographed.

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A URS well site geologist examined the cores and described the rock characteristics and fracturing. The core boxes were collected at the well site and moved for temporary storage to the above-mentioned NYPA storage yard.

The total length of rock section cored at individual locations increased to the south across the study area. The thickening section of rock away from the Niagara escarpment is caused by the dipping of bedrock to the south, and glacial erosion that has leveled the rock surface. At the northernmost nested well, GW03-004, near the Niagara escarpment, 32 feet of rock was cored. At the southernmost nested well, GW03-017, near the Niagara River, approximately 148 feet of rock was cored. Boring logs created from the rock core descriptions are included in Appendix B.

4.2.2.3 Reaming

The corehole was enlarged (reamed) from a 3-inch diameter opening to an 8-inch diameter opening using an air hammer drilling assembly. Before reaming, a temporary drilling water containment tub was constructed around the wellhead. The tub was constructed with a PVC pipe framework and a plastic tarp attached in a watertight arrangement. The tarp was taped to the wellhead and secured with elastic cords to the plastic frame. The containment tub, which measured approximately 12 feet long by 8 feet wide and 1.5 feet deep, held 800-1,000 gallons of water and drill cuttings.

The driller used a blast of compressed air to periodically clear cuttings and water from the borehole as the air hammer advanced. The cuttings and water were captured at the surface and directed into the tub by a rubber and metal shroud that surrounded the wellhead. The cuttings typically ranged up to ½-inch across. In fractured zones, chunks of rock as large as 4 inches across were brought to the surface.

Large volumes of water were brought to the surface, particularly at wells installed near the conduits. Vacuum trucks were used to remove water held in the containment tub while reaming to the well completion depth. Generally, two 2,000-gallon capacity vacuum trucks were used during borehole

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reaming. One truck suctioned water while the second stood by. The second truck would start working as the first brought its load of water to the six 20,000 gallon tanks stored on Royal Avenue or an additional five tanks stored at the NYPA yard. At nested well location GW03-016, four vacuum trucks were required to remove water.

The use of an air hammer to ream the boreholes reduces the hydrostatic pressure (pressure exerted by a column of water) on gases like methane and hydrogen sulfide found in some fractures. In some cases during the drilling program, the pressure reduction allowed these gases to vent to the surface. While reaming at 80 feet bgs in GW03-011, hydrogen sulfide gas (H_2S) was detected. Rotary drilling with a soy-based additive and water mixture called drilling 'mud' was used to ream the hole to its completion depth. The weight of the drilling mud fluid kept the H_2S gas from entering the borehole. Formation gases encountered during the drilling program are discussed further in Section 5.2.6.

4.2.3 Packer Water Injection Testing

Coreholes at ten nested well locations (GW03-001, -003, -005, -007, -010, -011, -013, -015, -016, -017) were tested by injecting water under pressure to sections of the corehole sealed between packers (also referred to as a packer test). Only the initial corehole was tested at these locations. Subsequent boreholes that were drilled at these locations were not packer-tested.

4.2.3.1 Purpose

The objective of the packer testing was to aid the identification of transmissive water-bearing fracture zones in the borehole sections. When the rock is relatively unfractured, as was the case at GW03-003 close to the Niagara escarpment, little water can be forced under pressure into the formation. When the rock is highly fractured, as at GW03-016, large volumes of water were injected into the formation.

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The packer test results, along with information from rock core analysis, were used to correlate identified regional fracture zones with the permeable fracture zones identified in the boreholes.

Packer test results are discussed further in Section 5.2.3.

4.2.3.2 Methods and Equipment

The coreholes were flushed with water prior to packer-testing to clear cuttings from fractures, but development was not attempted until the hole was reamed to an 8-inch diameter. The packer-testing was conducted in general accordance with the U.S Bureau of Reclamation procedure USBR 7310-89 (USBR, 1989). Packer testing was accomplished by lowering a dual packer assembly (called a straddle packer) to the bottom of the corehole at each selected location (see Figure 4.2.3-1). The straddle packer assembly used was approximately 11.4 feet in length. It consisted of two inflatable 2-foot long, metal-reinforced, rubber glands (called packers), attached on opposite ends of a 4.4-foot long perforated steel pipe. Hollow ½-inch ID steel rods were threaded together and connected to the packer assembly as it was lowered into the borehole.

The packers were inflated through plastic tubing connected to a pressurized nitrogen bottle at the wellhead or to an air compressor on the rig. When the packers were inflated and compressed against the borehole wall, a 5.6-foot test interval was isolated from the rest of the borehole. Clean potable water was pumped from a holding tank on the rig, pressurized through an FMC beam pump, and injected through the perforated pipe in the packer assembly into the rock formation. Flow was controlled through a valve on a header assembly at the wellhead. A pressure gauge located near the control valve was used to monitor water pressure. The driller used the control valve to regulate the flow of water entering the test zone. The amount of water injected into the formation was measured using an in-line water meter.

Pressure calculations were made before testing began. The objective was to determine the initial water pressure exerted on the zone being tested and the gauge pressure required at the surface. Care was taken not to use high pressures that could potentially fracture the test interval and cause erroneous

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readings. Tests were initially run using three increasing steps of pressure, and pressures were reduced in the same manner. This method of testing shows whether flow rates are similar at the same pressures on the increasing or decreasing phase of the test. Localized fractures extending relatively short distances showed a decreasing flow rate over the length of the test. After a few days of testing, packer test intervals were shortened by using a single pumping pressure (the initially calculated pressure). Multiple pressure steps were found to yield little useful information beyond that produced during a one-step packer test.

Testing began at the bottom of each borehole. After the initial test was completed, the packers were deflated and pulled up approximately five feet to test the next zone. Testing was concluded when the uppermost packer was close to the bottom of the steel casing. The time taken to test each interval ranged from one minute in zones where no water was injected to sixteen minutes in permeable zones. Flow rate into the test interval was determined by recording the number of gallons injected on a minute-by-minute basis. Gauge pressure readings were also recorded.

The packer assembly and rods were decontaminated prior to packer testing using a steam cleaner. They were steam-cleaned again before testing equipment was moved to the next borehole.

4.2.4 Piezometer Installation

After the core holes were reamed to completion depth, the air hammer was used to remove some of the fine material that had accumulated in fractures in the well bore. This procedure, called well development, is discussed further in Section 4.2.4.3.

The nested wells were constructed in a nested arrangement with up to three piezometers in a single borehole (see Figure 4.2.4-1). A total of 91 piezometers were installed during the drilling program. Five boreholes had a single piezometer, 10 boreholes had two piezometers, and 22 had three piezometers.

The two piezometers installed in shallow overburden soil in the wetland at the head of Gill Creek (GW03-018-P1 and GW03-018-P2) were constructed of 1-inch schedule 40 PVC. Each piezometer

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consisted of a 1-foot schedule 40 PVC screened interval (0.010-inch slot size) and blank PVC riser. Temporary 1.5-inch steel casing was driven into the soil using a manual slide hammer. The piezometers were then placed within the temporary casing and the casing was withdrawn allowing the soils to collapse around the piezometer screens and riser. Piezometers GW03-018-P1 and GW03-018-P2 were installed to depths of 2.14 feet and 4.23 feet, respectively.

4.2.4.1 Identifying Water-Bearing Zones

Johnston (1964) measured Lockport Group fracture elevations and their lateral extent during the construction of the conduit. His observations of fracture characteristics and location of seepage points provided a basis for understanding groundwater flow in the Niagara Region that was used by later workers (e.g., Tepper et al. 1990, and Yager 1996). Other bedrock exposures and corehole information also contributed to understanding groundwater flow in the area. Widespread horizontal bedding plane fractures in the Lockport Group were also observed in outcrops in the Niagara gorge and at the LaFarge Redland dolomite quarry. Horizontal fractures were identified in numerous rock core samples taken from hazardous waste sites such as DuPont's Necco Park landfill, located in the southern portion of the study area. Detailed analysis by geologists of rock cores taken from over 100 wells at the 24-acre Necco Park site showed that some fracture horizons are discontinuous across the site (WCC 1989). In addition, pumping tests from wells at Necco and surrounding properties show considerable variability in permeability and well yield (DuPont et al. 2002).

This study utilized previously published work, past experience in the area, and recent information gathered from rock core examination, wellhead observations, and packer testing to identify water-bearing fracture zones at the 17 locations in the study area.

Continuous rock core sampling in the Lockport Group was used to correlate lithology and fracture zones across the study area. Fractures were also noted during air-hammer drilling. In some instances, drill rods were observed to drop slightly as the air hammer encountered a fracture. Drilling water circulation loss and increased drilling rates were often noted when the core barrel encountered a

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significant fracture zone. Packer testing results were also used to determine fracture zones for piezometer screen placement.

Fracture zones identified in this study were correlated to regional fracture zones identified by Johnston (1964) and Yager (1996). The screened fracture zones identified in the study appear to be significant and regional in their extent. Fracture characteristics are discussed in Section 5.2.2.1.

4.2.4.2 Nested Well Construction

The groundwater monitoring wells were often constructed in a "nested" arrangement of two or three piezometers installed in the same borehole. A second or third piezometer screen and riser was added if the borehole intersected multiple water-bearing fracture zones.

A typical nested well construction diagram is shown for illustration purposes in Figure 4.2.4-1. Individual nested well construction diagrams are included in Appendix C.

The piezometers were constructed of 2-inch diameter Schedule 40 PVC continuously wound 0.030-inch slotted screen attached to Schedule 40 solid PVC riser pipe. The screen sections ranged from 3 to 10-feet depending on the thickness of the fracture zone. Sand was added to the borehole as filter material around the piezometer screens. Layers of impervious hydrated bentonite clay separated the filter sand from successively higher piezometers if they were installed in the same borehole.

A final layer of bentonite was added to the piezometer above the top piezometer's filter sand. After the bentonite hydrated, the remainder of the open borehole annular space was completed with cement/bentonite grout to the surface.

Nested wells located in traffic areas were finished with a cylindrical, 12-inch diameter flush-mounted wellhead with a lid secured by bolts. This type of wellhead is often called a road box. The road box was placed around the surface casing and surrounded by concrete. Riser pipes inside the road boxes

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were fitted with expandable plastic plugs. The expandable plug provides an airtight seal at the top of the riser pipe.

Nested wells located away from traffic areas were completed with the surface casing extending about 2-feet above the ground. A wellhead cap was attached to the top of the casing by hex bolts. The wellhead was secured with a padlock. Riser pipes inside the steel casing were fitted with expandable plastic plugs.

4.2.4.3 Nested Well Development

A considerable amount of water and drill cuttings were lifted to the surface during the air-hammer reaming of the core holes. After the holes were reamed to their completion depths, the air hammer assembly was raised and lowered rapidly in approximately 20-foot long strokes for a few minutes. This swabbing action agitated water contained in the boring and pulled drill cuttings lodged in borehole fractures into the well water. The water was then flushed from the borehole with a blast of compressed air through the air hammer. This jetting was done for five to ten minutes, usually until the containment tub filled with water. In relatively low-yield boreholes, a second round of flushing was carried out. Water coming from the wellhead was often observed to become less turbid toward the end of flushing.

After the nested piezometers were installed, a second phase of piezometer development was performed. Submersible pumps were lowered to a few feet from the bottom in the individual piezometers and the groundwater was pumped to the surface, where it was collected in plastic tanks. The water purged from the borehole and piezometers was later transferred to a larger tank.

Water quality parameters were measured at regular intervals during development of the piezometers. These parameters included pH, specific conductivity, temperature, turbidity, and oxygen reduction potential. When the water quality parameters were determined to be stable, piezometer development was completed. In general, more than three times the amount of water contained within the

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riser and screen was removed from the piezometers. In low-yield piezometers, water quality parameters were recorded as the piezometer was pumped to dryness. Piezometer development logs are included in Appendix D.

4.2.4.4 Management of Investigation-Derived Waste

Investigation-derived waste (IDW) from the drilling program consisted of trash, drill cuttings, used drilling mud, and water recovered from drilling and well development.

4.2.4.4.1 IDW Trash

IDW trash consisted of items such as empty sand and bentonite bags, used plastic tubing, containment tub plastic liners and miscellaneous cardboard and plastic sheeting. These materials were transported daily to a roll-off staged at the NYPA storage yard. The trash was disposed of at Modern Landfill in Lewiston, New York.

4.2.4.4.2 IDW Drill Cuttings and Drilling Mud

Used drilling mud was stored in 55-gallon drums. The drums were sealed, labeled, and stored near the wells. Drill cuttings were temporarily staged on the plastic containment tub liners at individual wellheads, covered to protect them from the weather. Composite samples of drill cuttings from wells drilled at each of the 17 locations were collected in July and August 2003 and submitted to Mitkem Corporation of Warwick, Rhode Island. The analytical work was in turn subcontracted to Severn Trent Laboratories of Shelton, New York. The samples underwent a Toxicity Characteristic Leaching Procedure (TCLP) extraction. The TCLP extract was analyzed for volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method 8260B; TCLP semivolatile organic compounds (SVOCs) by USEPA Method 8270C; TCLP pesticides by USEPA Method 8081A; TCLP herbicides by USEPA Method 8151; and TCLP metals by USEPA Methods 60110B/7470A. The drill cuttings were also analyzed for polychlorinated biphenyls (PCBs) by USEPA Method 8082, and Resource

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Conservation Recovery Act (RCRA) characteristics including corrosivity by USEPA Method 9045C, reactive cyanide by USEPA Method 9014, reactive sulfide by USEPA Method 9034M, and ignitability by USEPA Method 1030.

A summary table of the analytical results for the drill cuttings is provided in Appendix E. Complete drill cuttings analytical data tables with validation qualifiers are also provided in Appendix E.

Most of the drill cuttings were removed and transported to Modern Landfill in Lewiston, New York for disposal. Drill cuttings at remote locations GW03-001 through -008 -and -013 were left at the drill sites. Plans have been made to remove these cuttings in 2004. Scale tickets received when the trucks transporting the drill cuttings entered Modern's facility are included in Appendix F.

4.2.4.4.3 IDW Water

As discussed previously, water (a mixture of Town of Lewiston hydrant water and groundwater, with some suspended clay and silt-size rock particles) was removed as it was generated during drilling and well development. A total of approximately 225,000 gallons of water was recovered.

Six samples of water and one field duplicate were collected between July 22 and August 8, 2003, and submitted to Ecology and Environment, Inc., of Lancaster, New York. In order to evaluate the suitability of the water stored for disposal into the city's sanitary sewer system, the samples were analyzed for an array of parameters requested by the City of Niagara Falls, New York, Department of Waste Water Facilities. The parameters are: VOCs by USEPA Method 8260B; SVOCs by USEPA Method 8270C; pesticides by USEPA Method 8081A; herbicides by USEPA Method 8151; PCBs by USEPA Method 8082; metals by USEPA Methods60110B/7470A; total phosphorus by USEPA Method 365.2; total cyanide by USEPA Method 335.3; total organic carbon by USEPA Method 9060; total recoverable phenolics by USEPA Method 420.2; and total suspended solids (TSS) by USEPA Method 160.2. The TSS analysis was subcontracted to Waste Stream Technology, Inc., of Buffalo, New York.

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A summary table of the detected analytical results for the water samples is provided in Appendix E. Complete drilling water analytical data tables with validation qualifiers are also provided in Appendix E.

The analytical data were sent to Niagara Falls Wastewater Facility and the Town of Lewiston Water Pollution Control Center for review. Permits were issued by the City of Niagara Falls and the Town of Lewiston for disposal of the water. The water disposal permits issued are included in Appendix G. The approximately 125,000 gallons of water contained in six tanks located on Royal Avenue was pumped into a nearby sanitary sewer manhole (South Side Interceptor) in August 2003. During the same month, the approximately 100,000 gallons of water stored in five tanks in the NYPA storage yard was transferred by truck to the Town of Lewiston Water Pollution Control Center for treatment and disposal.

4.2.5 Well Location Survey

New York State licensed surveyors from URS used differential level surveying and Global Positioning System (GPS) receivers to survey the locations and elevations of the nested wells. Surveying fieldwork took place in September and October 2003. The survey data were checked for accuracy and tabulated on October 2, 2003. Survey data are provided on Table 4.2.5-1.

The surveyors used a Topcon automatic level instrument to survey ground surface elevations at each nested well location and the elevation of the top of riser pipes at each piezometer installed during the drilling program. The surveyors started from a record benchmark and referred to a second benchmark. Differences in elevations were balanced (i.e., error-adjusted). The elevations were referenced to the U.S. Lake Survey (USLSD) 1935 datum. Elevations are accurate to 0.05’ +/- based upon federally established record area benchmarks.

Horizontal control was established using Trimble 4400 GPS receivers. The measurements were referenced to North America Datum (NAD) 1927, used when the Project was built. The measurements

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were also referenced to NAD 1983, which is currently used. The GPS receivers use real-time kinematic positioning that is accurate to +/- 1-foot.

4.3 Groundwater Level Monitoring Program

Groundwater elevations were measured in order to evaluate groundwater flow patterns and to assist in the development of a groundwater model for the purpose of further refining the Project area of influence. A groundwater-level monitoring program was implemented beginning at the end of July 2003 and lasting through May 2004.

Groundwater and surface water elevation data were collected from various locations distributed widely across the investigation area (see Figures 4.3-1 and 4.3-2). These included a combination of wells and piezometers, either newly installed as part of the Phase I investigation (as discussed in Section 4.2) or existing conduit and reservoir monitoring wells. Groundwater elevation data were collected using a combination of manual level measurements and electronic data level measurements. Both methods are discussed in greater detail below.

4.3.1 Groundwater Level Monitoring Locations

The locations of the newly installed nested wells (GW03-001 through GW03-017) were as follows: locations GW03-001 through GW03-004 were installed at roughly 2,000-foot intervals along a north-south line on the western border of the Tuscarora Nation north of the Lewiston Reservoir; GW03-003 through GW03-008 were installed north and east of the Lewiston Reservoir at approximately 2,000-foot intervals along a north-south trending line within the Tuscarora Nation; GW03-009 through GW03-012 were installed roughly 2,000 feet from the east, west, and south walls of the reservoir; and GW03-012 through GW03-017 were installed from north to south, respectively, at 2,000-foot intervals approximately 50-feet from the east wall of the east conduit (Conduit 1). Two one-inch piezometers were also installed in shallow overburden soils at location GW03-018 located in the wetland at the head of Gill Creek within the Tuscarora Nation. Locations are shown in Figure 4.3-1.

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Other locations monitored include Pump Stations A and B (including independent monitoring of both the CDS and the conduits); one existing NYPA conduit monitoring well (OW-139); one private well installed on NYPA property (OW-650D), previously monitored in 2002; and permanent surface water level gauges GN_Intakes, GN_Forebay and GN_Reservoir (Figure 4.3-1). Reservoir dike monitoring wells are shown in Figure 4.3-2. These locations are discussed in greater detail below.

4.3.1.1 Nested Groundwater Monitoring Wells

As described in Section 4.2, a total of 17 monitoring locations (GW03-001 through GW03-017) were installed through overburden materials into bedrock (see Figure 4.2.1-1). Each monitoring location has up to three nests of between 1 and 3 piezometers each, with a maximum of nine piezometers at one location. As discussed in Section 4.2.4.1, each piezometer was designed to intersect a specific groundwater model layer as defined by Yager (1996). A complete discussion of groundwater flow model layers is presented in Section 4.1.

In order to determine groundwater elevations within a wetland located at the head of Gill Creek, two piezometers (GW03-018A-P1 and P2) were installed into the overburden materials within the wetland. These piezometers were installed by hand (via slide hammer) below ground surface within a mostly filled (via natural processes) former drainage swale located in the western half of the wetland. Piezometer P1 was advanced to 2.14 feet below the surface and P2 was advanced to 4.23 feet below the surface. Due to their shallow installation, these piezometers were not used to collect water samples for chemical characterization. Well construction details are provided in Appendix C.

4.3.1.2 Conduit Observation Wells and Lewiston Reservoir Wells

Groundwater levels in two previously installed bedrock wells along the conduits (OW-139 [NYPA well], and OW-650D [private well]) were monitored using electronic dataloggers and manual level measurements (Figure 4.3-1). The NYPA "OW" wells along the conduits were originally installed as well pairs to monitor groundwater near the conduits. Wells installed near the outer edge of the conduit

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right-of-way (usually within 50 feet of the conduits) were drilled through rock to a depth below the conduit invert (PASNY circa 1963). Conduit observation wells were not constructed to monitor discrete hydrogeologic flow zones.

Electronic data from conduit wells OW-139 and OW-650D were collected continuously at 15-minute intervals. Electronic data were collected from September 3 through December 8, 2003, at OW-139 and from August 21 through December 8, 2003, for OW-650D. In addition, dataloggers were calibrated each week with manual level measurements. After December 8, 2003, the dataloggers were pulled from both locations. Additionally, no manual measurements were recorded after December 8th.

A subset of Lewiston Reservoir wells with electronic dataloggers was selected to represent the groundwater levels near the reservoir (see Figure 4.3-2). Datalogger data from the reservoir wells were collected at six-hour intervals. Reservoir locations were not calibrated or monitored with manual level data. These are permanent gauges monitored directly by NYPA. Electronic data for these locations are collected on a continuous basis, although only data from July 2003 through May 2004 were used for this investigation to correspond with the data collection period of this investigation.

Lewiston Reservoir wells designated "OW" were installed between 1958 and 1960 (during reservoir construction) to provide data for the evaluation of reservoir dike stability. The OW wells were constructed as 6-inch diameter open hole wells set below the bedrock surface. Bedrock 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. Differences in well construction may influence comparisons of water levels between wells due to uncertainty in the flow zones intercepted by each well. Survey data for reservoir and conduit wells is presented on Table 4.3.1-1.

4.3.1.3 Pump Stations

Water level data were collected from inside both Pump Stations A and B (Figure 4.3-1). The pump houses were constructed to allow for the release of excess groundwater head in the CDS via a

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central sump (which is directly connected to the CDS of both conduits) and weirs (Figure 2.2.1-3). The sumps and weirs permit the flow of groundwater from the CDS into the conduits. Water level data were collected from both the central sump (GW03-PSA-D and GW03-PSB-D) and the receiving side of Conduit 1 (east conduit) (GW03-PSA-C and GW03-PSB-C) within each pump station.

4.3.1.4 NYPA Permanent Surface Water Gauges

In order to further understand the interaction between surface water and groundwater, data on surface water levels were collected from existing staff gauges (1) near the NYPA intakes (Gauge ID: GN-RIVER_INT), (2) at the forebay (Gauge ID: GN-FOREBAY), and (3) at the Lewiston Reservoir (Gauge ID: GN-RESERVOIR) (Figure 4.3-1). During the investigation period (July 2003 through May 2004), gauge data were gathered hourly. Data from a fourth gauge were not included in the study. This is the surface water gauge located in the Chippawa-Grass Island Pool (Gauge ID: GN-MATERIAL), which provides the official measurement of water level fluctuations to determine compliance with U.S. and Canadian agreements on the use of the Niagara River for power generation. It was determined that water levels recorded at the Intakes, Forebay and Reservoir gauges would supply more usable data for the evaluation of Project effects on groundwater within the investigation area.

Data from the three gauges used for the study were not calibrated with manual measurements.

4.3.2 Manual Water Level Measurements

Manual water level depths were measured from a fixed marked elevation point (from survey data) on each piezometer and/or well. Depth-to-water measurements were then converted from a fixed measuring point elevation to groundwater elevation data. Manual water levels were primarily used to maintain the calibration of the vertical location (i.e., elevation) of electronic dataloggers (See Section 4.3.3) used throughout the study and to monitor long-term trends in groundwater elevation within each piezometer.

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Initial water level data for Phase I investigation locations (GW03-001 through GW03-017) were collected prior to piezometer development. Following development, manual water level data were collected with a water level indicator instrument in each piezometer at each location. Manual levels were also collected from GW03-018A-P1 and P2, OW-139, and OW-650D. At the pump stations, manual water levels were recorded for the calibration of each of the four dataloggers (GW03-PSA-C and D and GW03-PSB-C and D) only twice, during initial installation of the dataloggers and following replacement of batteries in March 2004 (as discussed below in Section 4.3.3). As noted earlier, no manual level data were collected from the reservoir wells or permanent surface water level gauges.

Initially, to maintain calibration of datalogger position, manual water level data were collected twice a week through the beginning of November 2003. Due to the stability exhibited by the datalogger mounts, the schedule was scaled back to once weekly for the remainder of November. With the exception of GW03-016 and GW03-017 locations, manual water level data collection was completed on November 25, 2003. Due to datalogger rotation schedule requirements, GW03-016 and GW03-017, OW-139 and OW-650D, were monitored till December 8, 2003. No manual measurements were collected between December 2003 and March 2004. With the exception of one round of measurements taken on February 23, 2004 as a precursor to the third groundwater sampling event (see Section 4.5). Between March and May 2004, manual water levels were collected once a month.

Ideally, between July and December 2003, data on manual levels were to be collected from GW03-001 through GW03-018, OW-139, and OW-650D during each collection round. Due to logistical difficulties, however, (namely, access to locations, weather, etc) only partial rounds of data were collected during certain weeks. Tables 4.3.2-1 and 4.3.2-2 show manual groundwater elevation data for each location.

4.3.3 Electronic Water Level Measurements

Continuous groundwater level monitoring was accomplished by means of electronic dataloggers (MiniTroll Pro®, by In-Situ, Inc.®) set to record water pressure and temperature for the purpose of observing both short-term and long-term trends in the fluctuation of water level elevations. Datalogger

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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 procedures outlined in Section 4.3.4.

Each datalogger (for locations GW03-001 through GW03-018, OW-139, OW-650D and Pump Stations A and B) was programmed to record feet of water at 15-minute intervals. Initially, in order to determine that each datalogger was recording correctly and that it remained stationary inside the piezometer or well (i.e., remained calibrated), data were downloaded on a weekly basis. Downloading was accomplished by means of a pocket iPAQ™ computer, using software and hardware specifically designed to communicate with the dataloggers. No downloads were attempted between December 2003 and March 2004. Between March and May 2004, downloads were completed on a monthly basis.

Calibration was accomplished during each download by recording simultaneous manual and datalogger water level measurements. A schematic of a typical datalogger setup is presented in Figure 4.3.3-1. Due to access restrictions, dataloggers within Pump Stations A (GW03-PSA-C and D) and B GW03-PSB-C and D) were calibrated only upon installation and during battery replacement. The reservoir dike monitoring wells were not calibrated during the monitoring period.

In the beginning of the monitoring period, dataloggers collected data in a specific piezometer for two weeks. Following the collection of initial data for each piezometer, and based on the 1996 USGS model (Yager 1996) and corresponding screen intervals, the dataloggers were re-deployed. Table 4.3.3-1 shows the schedule and rotation of each piezometer and well.

After a final calibration was performed in 2003, several dataloggers were removed. However, a total of 18 dataloggers remained in place and continued to record data between December and March 2004. During this period, no calibrations were conducted. Electronic data from these locations were downloaded, removed, batteries changed, re-installed, and re-calibrated in March 04. Table 4.3.3-1 presents which locations remained, in addition to which locations were redeployed between March and May 2004.

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Since the surface water and Lewiston Reservoir monitoring well dataloggers are permanent, they were not rotated as part of this monitoring program.

Between July and December, a few piezometer dataloggers were not deployed. In some cases (GW03-006A-P3, GW03-014A-P2, GW03-015A-P3 and GW03-017A-P3), this was because the depth to water exceeded the longest available cable length. In other cases (GW03-012A-P1, GW03-012-P4, GW03-012-P5, and GW03-012-P7), it was because little to no water was observed in the piezometer (i.e., the well was dry). Due to a scheduling error, no datalogger was deployed in piezometer GW03-007-P3. Dataloggers were not re-deployed in GW03-018-P1 and P2, OW-139, and OW-650D during March through May 2004.

4.3.4 Data Management

Following each download of electronic data or manual water level collection, all data points were either converted or entered into an Excel spreadsheet. Manual water levels were entered into a spreadsheet for each piezometer and well. The measured levels were then subtracted from the fixed measuring point elevation (obtained from survey data) to obtain a value for groundwater elevations. These data were then transferred into a database and graphed. The data were cross-checked against the original field notes as a quality assurance measure.

Quality assurance measures for electronic data were more complex. Electronic data from the dataloggers were converted from a proprietary format to Excel. These data had, however, been recorded as height of the water column without an elevation reference. To convert from height of water column (HoWC), to depth to water (DTW), therefore, the depth of the datalogger within each piezometer or well had to be calculated using the simultaneous manual water level DTW and electronic water level measurement of HoWC (Figure 4.3.3-1). As noted earlier, each time data were extracted from the datalogger, in order to maintain an accurate calibration, these two measurements were made. The average of the datalogger depth calibration values was then used to determine the depth to water from the top of the piezometer or well by subtracting the HoWC (raw data) from the datalogger's average depth calibration (sum of simultaneous HoWC and DTW measurements). This calculation converted data into a

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depth to water measurement from the top of piezometer or well. Finally, in order to determine groundwater elevation, the depth to water value was then subtracted from the surveyed measuring point elevation.

After these calculations were completed, the data was imported into a database. Further quality assurance was completed by graphing each piezometer and well location and comparing to the original spreadsheet and field notes to determine whether reference elevations and depth to water calculations were correct.

Data from the permanent surface water and reservoir monitoring well locations were provided by the Niagara River Control Center and NYPA, respectively, and were imported into the database with no quality assurance checks.

4.3.5 Field Reconnaissance

Field reconnaissance was performed on Fish and Gill Creek and the LaFarge Redland quarry in order to determine the effects of groundwater flow in these areas. In addition, a limited seep reconnaissance of the escarpment (limited because of accessibility and safety issues) was also performed. These are discussed in detail below.

4.3.5.1 Escarpment Seep Reconnaissance

On June 16, 2003, in an attempt to identify and estimate the frequency and volume of seeps along the escarpment, a limited seep reconnaissance was conducted along the escarpment's northwest section. After an initial drive-by reconnaissance proved to be ineffective due to vegetative cover, a walking reconnaissance was conducted. Two sections were walked: one short section south of Route 104 (underneath the north-south power line near the western border of the Tuscarora Nation), and one long section along the former Hojack Railroad right-of-way (Figure 4.3.5-1).

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The short section was walked east to west for 300 to 500 feet approximately 3/4 of the distance up from the bottom of the escarpment (at the interface between the Lockport and Clinton Groups [i.e. the bottom of the Gasport dolomite and top of the DeCew dolomite]). The long section was walked west to east starting at Route 104 (immediately north of the Niagara Falls Country Club and Mountain View Drive) to the east for approximately 0.75 miles.

4.3.5.2 Fish and Gill Creek Reconnaissance

The reconnaissance conducted of Fish and Gill Creeks (Figures 4.3.5-2 and 4.3.5-3, respectively) included the completion of a flow profile and volume flow rate calculation for each creek.

The headwaters for both Fish and Gill Creeks are located within Tuscarora Nation Lands east of the Lewiston Reservoir.

On October 15, 2003, at each creek, a flow profile area was measured along a transect perpendicular to the direction of water flow (Figures 4.3.5-2 and 4.3.5-3). Along each transect, depth of water measurements (from water surface to creek bed) were made for each horizontal 0.5-foot increment. Current velocity rate measurements for each 0.5-foot interval were made using a Marsh McBirney Flowmate Model 2000 velocity meter. Two transects were attempted along each creek but current velocities along the A-A' transect for Fish Creek were too low for the flow meter to measure and thus measurements at that transect were discontinued.

4.4 Falls Street Tunnel Investigation

A flow study was developed to evaluate the relationship between the NYPA conduits and groundwater infiltration into the FST. The study involved conducting a tunnel reconnaissance to determine areas of groundwater infiltration, measuring and recording groundwater infiltration flow rates, and evaluating effects of NPP operations on infiltration rates.

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4.4.1 FST-Conduit Crossing

Placement of the NYPA conduits beneath the FST necessitated demolition and removal of a section of the FST (Figure 4.4.1-1). Following placement of the conduits, a section of 84-inch diameter concrete pipe, long enough to span the conduit excavation, was installed where the removed rock section had been. To carry FST flow during construction, a parallel bypass section was also constructed, also of 84-inch diameter pipe. In the 1970s, the SSI was constructed by tapping into this bypass and building out both upstream and downstream of it (Figure 4.4.1-1). The SSI was designed to carry dry-weather combined sanitary/stormwater flows to the wastewater treatment plant. Except for the bypass section, which also consists of 84-inch diameter concrete pipe, the SSI is a rock tunnel lined with 6-foot diameter concrete pipe. At the crossover, it runs parallel to the FST, approximately 150 feet south of it. Like the FST, it slopes to the west (i.e., towards the City of Niagara Falls Wastewater Treatment Plant). It passes over the conduit right-of-way just south of conduit Pump Station A.

In the vicinity of the FST-conduit crossover, both the conduits and the FST are located below the groundwater table. Even though this makes infiltration likely along the entire length of the FST, the section of the FST in the vicinity of the crossover has historically experienced higher rates of groundwater infiltration than upstream or downstream FST sections. Since 1989, the City of Niagara Falls has undertaken a series of projects that have resulted in a significant reduction in groundwater infiltration in this section (see Section 2.2.2). The SSI does not receive significant groundwater infiltration presumably due to the concrete lining method of construction. The subject of this investigation is the quantification of dry-weather flow within this section of the FST.

The FST crosses over the NYPA conduit right-of-way along the southern edge of Royal Avenue (Figure 4.4.1-1). To either side of the conduit excavation, the FST is an unlined rock tunnel, approximately 6 by 7 feet in cross-section. Where a section of tunnel was removed for installation of the conduits, an 84-inch diameter concrete pipe, installed with internal and external seals in a vault, has been placed. From this replacement section to a point approximately 500 feet west of the conduits, the tunnel has been grouted. As mentioned above, a similar concrete section was put in place as a bypass when conduit excavation was in progress.

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At the FST-conduit crossing, the FST and SSI are joined via two 84-inch diameter pipes (part of original bypass section), located on either side of the NYPA conduits (Figure 4.4.1-1). The pipes are approximately 160 feet long. Under dry-weather conditions, all FST and SSI flow is routed to the treatment plant. Six gates make it possible, however, to divert flow from the treatment plant if necessary. Two of these gates are built into drop shafts within the FST, two are in the SSI, and one is in each of the 84-inch flow diversion pipes constructed as part of the original bypass (Figure 4.4.1-1). Under normal conditions, all but one of these gates are fully open, with all flow through the FST and SSI being gravity-controlled only. (The one gate that is not fully open affects only wet weather flow). Dry-weather flow in the system is controlled by four weirs or stoplog structures within the FST. As shown in Figure 4.4.1-1, they are located as follows:

- in Drop Shaft 12, approximately 300 feet west of the conduits,
- immediately west of the FST junction with the west flow diversion pipe,
- in Drop Shaft 13A, immediately west of the FST junction with the east flow diversion pipe, and
- in Drop Shaft 14B, approximately 1,500 feet east of Drop Shaft 13A.

4.4.2 Dry Weather Flows

Flow direction in tunnel and interceptor is from east to west. While most sanitary sewer input into the FST east of the site has been rerouted into the SSI, a pipe was nevertheless seen (during the field reconnaissance carried out for this investigation, described in Section 4.4.3) discharging directly into the FST at Drop Shaft 14 (Figure 4.4.1-1). The pipe, approximately 2 feet in diameter, appears to be coming from the north side of Royal Avenue, the location of a small industrial/commercial facility. The origin of flow in the pipe is not known. The flow depth in this pipe during the site visit was on the order of 1 inch. The entire manhole into which the pipe discharged was filled with hard deposits thought to be calcium carbonate.

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The section of the FST east of the conduits, between the 84-inch concrete section and Drop Shaft 14, is known to receive infiltration from groundwater. This flow is redirected into the 84-inch diversion pipe and the SSI by the 3-foot-high diversion dam located immediately west of the junction of the tunnel and the east flow diversion pipe (Figure 4.4.1-1). This flow was observed during the site visit. This flow was reportedly measured by the City of Niagara Falls some years ago (one-time instantaneous sample measurement) at 2.9 mgd (2,000 gpm) (verbal communication with Richard Roll, 9/3/03).

Infiltration into the FST's concrete section, reportedly measured at one time to be several mgd, has been reduced through sealing and grouting to approximately 100 gpm (Roll and Lannon 2001). This flow is directed into the SSI by means of the stoplog structure located immediately west of the junction of the tunnel and the west flow diversion pipe (Figure 4.4.1-1).

Infiltration also enters the FST through the section west of the conduits. In spring 2001, infiltration in this area was estimated at 1.6 mgd (Roll and Lannon 2001). A weir structure at Drop Shaft 12 creates a backwater, redirecting flow upgradient, towards the stoplog structure near the west flow diversion pipe. Under design conditions, this flow spills over the stoplog structure and into the SSI via the west flow diversion pipe. During the site visit, however, water was observed also to be flowing over the weir at Drop Shaft 12. Flow passing over this weir continues to the Gorge Pumping Station where it is pumped to the treatment plant.

As a result of the use of weirs and stoplog structures to direct the flow from the FST to the SSI, backwater conditions arise at various locations. These backwater conditions cause significant accumulation of solids, including sediment and debris, in the FST and flow diversion pipes, leading to a reduction in system efficiency.

4.4.3 FST Reconnaissance

On September 22, 2003, a reconnaissance of the FST system in the vicinity of the NYPA conduits was conducted to observe existing conditions and to determine the optimum design of a flow-measuring

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program. Approved confined-space entry procedures were used for all tunnel reconnaissance activities. Confined-space entry procedures employed for this inspection included continual monitoring of tunnel atmospheric conditions; use of standby personnel on the surface, equipped with emergency rescue equipment; and use of constant radio communication between tunnel entrants and surface standby personnel. Moreover, Wastewater Treatment Plant personnel from the Niagara Falls Water Board (NFWB), which owns and operates the wastewater system in the City of Niagara Falls, were notified of all tunnel inspection activities, and were provided with a cell phone number to call in case of any condition that would necessitate the immediate extraction of tunnel inspection personnel.

The FST system reconnaissance involved tunnel entries at several different locations along the tunnel. They were, in order of entry: Drop Shaft 14A, Drop Shaft 12, Drop Shaft 13A, the East Bypass Gate Structure, and Drop Shaft 13.

At each location, observations regarding tunnel flow, groundwater infiltration, inflows, and sediment accumulation were recorded. Observations were made of the FST both up- and downstream of the entrance point as well as within both the east and west SSI bypass tunnels. The inspections were also documented using a digital camera. Results of tunnel reconnaissance, including photographs, are presented in Section 5.4.

4.4.4 Flow Measuring Program

Based on observations recorded during tunnel reconnaissance, URS developed a program to monitor flow rates of groundwater infiltration into the FST. URS determined that, during dry-weather conditions, all groundwater infiltration entering the FST in the vicinity of the NYPA conduits flows to one of three places: (1) over the FST measuring weir located immediately upstream of Drop Shaft 12, (2) through the SSI via the east bypass tunnel, or (3) through the SSI via the west bypass tunnel. The program developed involved placing flow-monitoring equipment at these three locations in order to monitor infiltration rates. The program additionally involved making regular visual observations of inflow at the industrial discharge located at Drop Shaft 14, and of any flow entering the FST at Drop Shaft 14A. Since the above holds true only during dry-weather conditions, data collected during dry-

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weather conditions were used to estimate rates at which groundwater infiltrates into the FST. During wet weather, inflow from other sources, such as backup from the SSI into the FST, precludes the accurate measurement of flows.

The flow-measuring program for all three locations was implemented for a period of approximately one month starting in mid-October. This allowed for measuring groundwater infiltration for approximately 2 weeks before and 2 weeks after November 1. This was done in order to evaluate the groundwater infiltration rates under both tourist season (April 1-October 31) and non-tourist season (November 1-March 31) operating conditions.

4.4.4.1 Drop Shaft 12

An existing measuring weir was used to measure flow in the FST at Drop Shaft 12. The weir at drop Shaft 12 is sharp-crested, with a rectangular opening 60 inches wide and 12 inches high. A Sigma 920 flow meter equipped with a single depth probe was used to continuously record flows at this location. The depth sensor was installed upstream of the weir and set to measure the depth of flow above the weir crest at 5-minute intervals. The flow meter was set up to automatically convert this depth to a flow rate using the equation for a 60-inch rectangular weir with end contractions.

For depths greater than 12 inches above the weir crest, the weir opening is totally submerged and the flow cross section is no longer rectangular. Therefore, calculation of flow for depths greater than 12 inches above the weir crest was not possible. These data; however, correspond to significant wet weather events and are not used in the calculation of groundwater infiltration, which was performed based on dry-weather data. Detailed discussion of the flow monitoring results is presented in Section 5.4 and Appendix H.

4.4.4.2 East and West Bypass Tunnels

It was noted during the tunnel reconnaissance that the bottom of each 84-inch SSI bypass pipe was covered by approximately one foot of sediment. Flow depths over the sediment were observed to be

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approximately one foot. The cross-sectional flow created by the flat sediment surface and the 84-inch pipe walls resembles flow in a trapezoidal channel. In order to obtain flow measurements in both these tunnels, flat, steel-bottom platforms (Figure 4.4.4-1) were designed, fabricated, and installed in both the east and west SSI bypass pipes in order to provide regular flow channels. The flow channel created by the platforms and the tunnel walls measured approximately 60 inches wide at the base, and varied in width at the top depending on the flow depth.

At each tunnel location, a Sigma 920 flow meter equipped with two area-velocity probes was used to measure flow. Each sensor measured the depth of flow above the bottom of the flow channel and the depth-averaged velocity. One sensor was placed at the flow channel centerline and the other was placed approximately 1 foot from the eastern tunnel wall (Figure 4.4.4-1). Data collected over the one-month monitoring period was used to calculate dry-weather flows through the bypass tunnels. Detailed discussion of the flow monitoring results is presented in Section 5.4 and Appendix H.

4.4.4.3 Drop Shafts 14 and 14A

As mentioned previously, the flow-monitoring program also included a component for performing visual spot-checks of flow at drop shafts 14 and 14A. During the tunnel reconnaissance, inflow from an apparent industrial discharge was observed at Drop Shaft 14. Approximately one inch of flow was observed discharging from the 24-inch pipe. The flow monitoring program involved using a 5-gallon bucket and stop watch to measure discharge rates into the FST. The flow-monitoring program also included performing visual spot checks for any possible flow in the FST at Drop Shaft 14A (the most upstream location included in this program). These spot-checks were performed approximately twice weekly. Results of these spot-checks are discussed in Section 5.4.

4.4.4.4 Rain Gauge Installation

The overall purpose of the monitoring program was to estimate groundwater infiltration, which is a long-term phenomenon independent of peak flows that are produced by surface water runoff. To distinguish

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between dry-weather and wet-weather flows, a rain gauge was installed at the Project site. The gauge was mounted on the roof of Pump Station A, located in the area between the NYPA conduits, the FST and the SSI. Rainfall data gathered by the gauge was used to identify wet-weather flow regimes in the monitored sewer system. As mentioned above, wet-weather flows were excluded from the analysis of groundwater infiltration.

4.4.5 Field Activities

Field activities performed as part of this flow-monitoring program included tunnel reconnaissance (discussed above), flow meter installation, routine data downloading, flow meter maintenance, and flow meter removal.

4.4.5.1 Flow Meter Installation

URS installed three flow monitoring meters on October 20, 2003. As discussed previously, flow metering equipment was installed at three locations; the measuring weir at drop shaft 12, the west SSI bypass tunnel, and the east SSI bypass tunnel.

At the measuring weir, the depth probe was securely attached to the weir plate using a vise clamp with a steel rod extending approximately five feet upstream of the weir (Figure 4.4.5-1). The depth probe was mounted on a vertical cross-bar attached to the steel rod and extending downward into the water. The depth probe was installed at a depth of approximately 5.5 inches. This depth was calibrated using the Insight software to read a measurement of 1.25 inches of flow over the weir crest. The depth probe and flow meter were connected using a 50-foot cable. To facilitate downloading of data, the flow meter was mounted on a steel hook located just below ground surface on the inside rim of the manhole.

For both the east and west SSI bypass tunnel flow meter installations, the steel plate assemblies were installed first. To allow for access through the 24-inch manholes, the steel plates were fabricated in four pieces, each measuring approximately 22 inches wide by 60 inches long. The steel plates were

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lowered into the tunnels one piece at a time and assembled at the appropriate location in the tunnel. The plates were designed to fit together smoothly using tongue-and-groove construction. The pieces were then secured together using 3/8-inch U-shaped rods inserted through holes on either side of the joints. The flow measuring assemblies were designed so that the dual area-velocity probes were mounted on the downstream edge of the platform formed by the steel plates. For both the east and west tunnels, the probes were installed with one located at the centerline of the flow area and the other located approximately one foot from the eastern edge of the steel plates. The probes were installed within the tunnel flow approximately 96 feet downstream (in the west tunnel) and 84 feet downstream (in the east tunnel) of the intersection with the FST (Figure 4.4.1-1). Once the platforms were in place, they were checked to ensure a level surface and then each plate was secured to the bypass gate structure using a 1/8-inch stainless steel cable. The area-velocity probe data cables were run from the probes to the flow meters using custom made 175-foot cables. The flow meters were suspended from the manhole ladder rungs just beneath the ground surface. At the time of installation, depth readings recorded by the area-velocity probes were calibrated by comparing the readings to depths measured by hand.

For the east bypass, several sandbags were placed in the tunnel to redistribute flow from the eastern edge toward the center of the channel.

4.4.5.2 Downloading and Maintenance

During the flow measuring program, data downloads were performed approximately every three days. Data was downloaded by accessing the flow meters mounted just below each manhole, and connecting a laptop computer using the appropriate cable. For each downloading event, the following steps were followed:

- Remove manhole covers and access flow meters,
- Confirm proper connection and communication with flow meter,
- Check the current status and record all parameters in the field notebook,
- Initiate data download,

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- Confirm proper download, and
- Return flow meter to manhole and replace cover.

A planned tunnel entrance to inspect the condition of the flow meter installations was conducted on October 30, 2003. This was done to confirm satisfactory condition of the flow meters and to ensure collection of useful data through the transition from tourist to non-tourist season on November 1, 2003. Entries were made at all three flow monitoring locations. Activities completed during these inspections included checking the level of the steel plates, checking for and clearing any sediment accumulation on the steel plates and probes, and checking the depth calibration of each probe.

To provide data for future analysis, a velocity profile was also obtained from collected data in each bypass tunnel. The velocity profile was obtained by detaching the center area-velocity probe and recording velocity and depth readings for different locations across the cross-sectional flow channel. The probe was placed at 6-inch intervals across the back (downstream side) of the steel platform over the entire 60-inch length.

On November 4, 2003, a check of the most recently downloaded data indicated that the flow meters at the east and west bypass tunnels had stopped recording data due to the memory slates being full. The dataloggers at all three monitoring locations were reset to record data in "wrap" mode rather than "slate" mode. In slate mode, the datalogger will stop recording data upon reaching a full memory condition. In wrap mode, when the datalogger memory becomes full, the datalogger will begin overwriting previously recorded data. As a result of the memory filling up and the halt in data recording, there is a data gap of approximately 35 hours for the east and west bypass locations from approximately November 3 to November 4, when the error was discovered.

Once the dataloggers were reset, data for the west bypass tunnel indicated that flow was still not being recorded at this location. A review of the data revealed that a flow reversal had occurred just prior to the loss of flow signal strength. This indicated that sediment may have been deposited on the steel platform and the area-velocity probes when the flow reversal had occurred. To inspect and correct the problem, an unplanned tunnel entrance was completed on November 6. Upon inspection of the steel

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platform and probes, it was revealed that significant quantities of sediment had covered the plate and probes. Once the sediment had been cleared off, signal strength and flow readings returned.

4.4.5.3 Flow Meter Removal

Satisfactory completion of data collection was determined to have occurred by November 20. All flow monitoring equipment, including sandbags, steel plates, and related hardware, was therefore removed from the tunnels on November 25, 2003.

4.5 Water Sampling

Three groundwater/surface water sampling events were performed in 2003/2004. The first sampling event was conducted from September 24 through October 15, 2003 (two surface water sample locations were partially resampled on October 28, 2003), the second from November 24 through December 19, 2003 and the third from February 24 through March 10, 2004. Sampling was carried out in general accordance with the protocols and requirements of the Work Plan – Groundwater and Surface Water Monitoring Program (URS 2003a) and the Health and Safety Plan, Groundwater Investigation Activities (URS 2003b). The goal for each sampling event was the collection of groundwater samples from each of the 91 piezometers within 17 nested groundwater monitoring locations (GW03-001 through GW03-017, installed as part of the NYPA relicensing groundwater investigation), and the collection of surface water samples from 11 locations in and around the NPP. For various reasons, samples could not be collected at all of the locations during either sampling event. Sample collection information for the September-October, November-December and February-March sampling events is summarized on Tables 4.5-1 ,4.5-2, 4.5-3, respectively.

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4.5.1 Surface Water

4.5.1.1 Locations

The surface water study targeted eleven locations (see Figure 4.2.1-1) for sampling and analysis. They are:

- SW03-001: Fish Creek, north and downstream of the Lewiston Reservoir.
- SW03-002: Fish Creek, east and upstream of the Lewiston Reservoir
- SW03-003: Gill Creek, east and upstream of the Lewiston Reservoir
- SW03-004: Gill Creek headwater wetland area, east and upstream of both the Lewiston Reservoir and SW03-003.
- SW03-005: Gill Creek, south and downstream of the Lewiston Reservoir and upstream of the Gill Creek augmentation outflow from the Reservoir.
- SW03-006: Lewiston Reservoir, west end near the Lewiston Pump Generating Plant
- SW03-007: Forebay, west end at the Robert Moses Niagara Power Plant
- SW03-008: Western Conduit (Conduit 2), collected from the west air intake shaft (located approximately 450 feet north of Royal Avenue)
- SW03-009: Eastern Conduit (Conduit 1), collected from the east air intake shaft (located approximately 450 feet north of Royal Avenue)
- SW03-010: Niagara River at Project intakes
- SW03-011: Eastern end of the Lewiston Reservoir.

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These locations are shown on Figure 4.2.1-1. Since, however, no water was flowing at locations SW03-002 and SW3-003 during the September-October sampling event, or at location SW3-003 during the November-December sampling event (i.e., only standing, stagnant water was present at these locations), no samples were collected at these locations (see Tables 4.5-1 and 4.5-2).

The October 2003 event, which was conducted from October 7 through October 9, 2003, included collection of samples at nine locations. No samples were collected at SW03-003 (Gill Creek) and SW03-002 (Fish Creek) since these locations were "dry" (no flow with small amounts of stagnant water in shallow puddles). Due to a sample processing/preparation error at the laboratory, two locations (SW03-001 and SW03-004) were re-sampled for monomethyl mercury on October 28, 2003.

The November 2003 event, conducted on November 24 and 25, 2003, included collection of samples at ten locations. Location SW03-003, upstream of the Lewiston Reservoir in Gill Creek was "dry".

Surface water samples were collected from all 11 locations during the March 2004 sampling event.

For each event, samples were analyzed for VOCs, SVOCs, metals, pesticides, PCBs, bacterial parameters, and miscellaneous water quality parameters as discussed in Section 4.5.1.3 and summarized on Table 4.5-4. For purposes of discussion, the surface water locations were divided into two groups, "river-sourced" water (water derived directly from the Niagara River as part of Project operations) and "local-sourced" water (surface water present in wetlands and streams near the reservoir). The "river-sourced" locations include (in order of distance from river): SW03-010, SW03-009, SW03-008, SW03-007, SW03-006 and SW03-011. The remaining "local-sourced" locations included (in order of distance away from the reservoir); SW03-004, SW03-003, SW03-002, and SW03-001.

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4.5.1.2 Sampling Methods

In accordance with procedures outlined in the Field Sampling Plan (FSP) portion of the Work Plan (URS 2003a), most surface water samples were collected by direct submersion of the sample bottles and capping underwater. The forebay sample (SW03-007), however, due to forebay surface water inaccessibility, was collected from the forebay deck of the RMNPP with a disposable polyethylene bailer with nylon rope. Bailer sampling had not been addressed in the FSP. Samples from the 2 conduits at the pressure relief vents located near Royal Avenue (SW03-008 and SW03-009) were collected through the vent grates using a peristaltic pump with high-density polyethylene and silicone (rotor head) tubing. The use of peristaltic pumps for sample collection had been described in the FSP for groundwater sample collection, but not for surface water sample collection.

4.5.1.3 Parameters

Following sample collection, the sample bottles were placed in coolers, iced, and transported via courier to Severn Trent Laboratories of Buffalo, New York, for analysis. The surface water samples were analyzed for an extensive list of organic, inorganic, and bacteriological parameters. Parameters and analytical methods are summarized on Table 4.5-4.

4.5.2 Groundwater

4.5.2.1 Locations

As part of this investigation, it was proposed that groundwater samples be collected at each of the 91 piezometers located among 17 nested groundwater monitoring points (GW03-001 through GW03-017). The 17 nested groundwater monitoring well locations are shown in Figure 4.2.1-1. Monitoring locations GW03-001 through GW03-011 are located in the vicinity of the Lewiston Reservoir, and monitoring locations GW03-012 through GW03-017 are located adjacent to the NYPA conduits, along their eastern

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side. Multiple piezometers, screened at discrete depth intervals, are present at each monitoring location. Nested well construction details are provided in Appendix C.

During the September-October sampling event, seven piezometers could not be sampled because (1) they were initially dry (GW03-012A-P1 and GW03-012B-P4), (2) they purged to dryness and never recovered (GW-03-002A-P2, GW03-006B-P3, GW03-011B-P5, and GW03-012C-P7), or (3) they had obstructed risers that did not permit sampling with available equipment (GW03-017A-P3) (see Table 4.5-1. At six piezometers (GW03-005A-P2, GW03-010A-P3, GW03-013B-P6, GW03-014A-P1, GW03-014A-P2, and GW03-015A-P3), due to poor groundwater yields, only partial sample volumes could be collected (see Table 4.5-1). Complete sample bottle sets were collected from the other 78 piezometers.

During the November-December sampling event, six piezometers could not be sampled either because they were initially dry (GW03-012A-P1) or they purged to dryness and never recovered (GW03-001A-P2, GW03-006B-P3, GW03-008B-P6, GW03-011B-P5, and GW03-013B-P6) (see Table 4.5-2). Due to poor groundwater yields, only partial sample volumes could be collected at four piezometers (GW03-002A-P2, GW03-012B-P4, GW03-014A-P2, and GW03-017A-P3) (see Table 4.5-2). Complete sample bottle sets were collected from the other 81 piezometers.

During the February-March 04 sampling event, eight piezometers could not be sampled either because they were initially dry (GW03-012-P1 and GW03-012-P4) or an insufficient volume of water was present (GW03-002-P2, GW03-006-P3, GW03-008-P6, GW03-011-P5, and GW03-017-P3) or they purged to dryness and never recovered (GW03-004-P1). Due to poor groundwater yields, only partial sample volumes could be collected at three piezometers (GW03-013-P6, GW03-013-P7, and GW03-015-P3) (see Table 4.5-3).

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4.5.2.2 Sampling Methods

Detailed, step-by-step procedures for the collection of groundwater samples for this project were provided in the FSP. The following paragraphs provide a general discussion of sampling procedures, noting any deviations from the FSP.

Groundwater samples were collected from the piezometers using dedicated and/or disposable sampling equipment. Low-flow purging and sampling techniques, in accordance with USEPA Region II recommended procedures (USEPA 1998), were used to obtain representative groundwater samples and to minimize purge water volumes requiring containerization, characterization, and subsequent disposal. At piezometer locations where depth to groundwater was less than approximately 30 feet below ground surface, purging and groundwater sampling were accomplished using GeoPump 2 peristaltic pumps with dedicated, disposable high-density polyethylene (HDPE) and silicone (rotor head only) tubing. Tubing associated with the peristaltic pumps was removed at the completion of sampling and disposed of.

At piezometers where depth to groundwater was greater than approximately 30 feet below ground surface, purging and groundwater sampling were accomplished using dedicated Proactive Environmental Products submersible pumps with low-flow controllers and dedicated HDPE tubing. The dedicated submersible pumps and associated tubing were left in the piezometers following sampling. The inlet of the submersible pump, or HDPE tubing for the peristaltic pump, was set at the midpoint of the saturated portion of the piezometer screen.

Flow from the purging/sampling pump was routed to a Horiba U-22 multiparameter meter with flow-through cell. Upon initiation of piezometer purging, the time, pump flow rate, depth to water, and field parameter measurements (pH, temperature, specific conductivity, dissolved oxygen, turbidity, and Eh) were recorded. The Low Flow Groundwater Purging/ Sampling Log sheets are provided in Appendix I. Purge water was containerized and later transported to the field staging area for storage and subsequent characterization and disposal. Once field parameter readings had stabilized within specified tolerances and at least one well volume had been purged, the tubing between the pump and flow cell was cut and the sample bottles were filled from the tubing. In a few cases, the "purge at least one well volume" criterion

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was waived for deeper piezometers where field parameters had stabilized but the time necessary to purge one well volume was deemed to be excessive.

During all three sampling events, several piezometers could not be readily sampled with either of the pump types specified in the FSP. This was due to limited water volume within the piezometer (usually less than 3 feet), poor recharge characteristics (i.e., known to purge to dryness), extreme depths to groundwater (beyond the pumping range of submersible pumps), or a combination of these conditions. These piezometers were sampled with dedicated, disposable polyethylene bailers with nylon rope (bailer sampling had not been specified in the FSP). Generally, the piezometers were purged to dryness with the bailer, allowed to recover, and the recovered groundwater was later sampled with the bailer. During the September-October sampling event, three piezometers were sampled with bailers: GW03-013C-P7, GW03-014A-P2, and GW03-015A-P3. During the November-December sampling event, six piezometers were sampled with bailers: GW03-002A-P2, GW03-005A-P2, GW03-012B-P4, GW03-013C-P7, GW03-014A-P2, and GW03-015A-P3. During the February-March 04 sampling event, seven piezometers were sampled with bailers: GW03-005A-P2, GW03-012C-P7, GW03-013B-P6, GW03-013C-P7, GW03-014A-P2, GW03-015A-P2 and GW03-015A-P3

During the September-October sampling event, several methods were attempted to collect a sample from piezometer GW03-017A-P3 (i.e., submersible pump, 1.6-inch OD disposable bailer, and 0.75-inch OD disposable bailer). Due to an obstruction in the piezometer riser pipe located above the water in the piezometer (preventing use of the submersible pump and the larger disposable bailer), and due also to the extreme depth to water in this piezometer (the water leaked out of the smaller bailer before it could be pulled to the surface), none of these methods was successful. During the November-December sampling event, an alternative sampling method not specified in the FSP (manual pumping using HDPE tubing with decontaminated stainless-steel check valve) was employed to attempt sampling at GW03-017A-P3. The yield from this piezometer was poor, however, and only limited sample volume could be collected. This same approach was attempted during the February-March sampling event, however, not enough water was present to bring sample to the surface.

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4.5.2.3 Parameters

Following sample collection, the sample bottles were placed in coolers, iced, and transported via courier to Severn Trent Laboratories of Buffalo, New York, for analysis. The groundwater samples were analyzed for an extensive list of organic, inorganic, and bacteriological parameters. Parameters and analytical methods are summarized on Table 4.5-4. Based upon elevated total coliform levels in the September-October 2003 sampling event, the December 2003 groundwater samples collected from piezometers GW03-005A-P2, GW03-014C-P7, GW03-015A-P1, GW03-015B-P6, and GW03-017C-P7 were also analyzed for fecal coliform. In addition, *E. coli,* which was not analyzed for in the September-October 2003 sampling event, was tested in the subsequent December 2003 and February-March 2004 sampling events. Piezometer locations where only partial sample volumes could be collected for analysis due to poor groundwater yields were noted in the "Comments" columns of Tables 4.5-1 , 4.5-2 and, 4.5-3.

4.5.3 Quality Control Samples

Quality control (QC) procedures during the groundwater/surface water sampling program included use of trip blanks, matrix spike (MS)/matrix spike duplicate (MSD)/matrix duplicate (MS) samples, and sampling equipment rinsate blanks. These QC sample types and their collection frequencies were detailed in the Quality Assurance Project Plan (QAPP) portion of (URS 2003a). Some variations from the QAPP occurred, however, during the sampling events.

The QAPP had specified that one trip blank per day accompany the volatile organic analysis (VOA) sample bottles from the field to the analytical laboratory. However, multiple sampling crews were working at different locations and samples were being shipped to the laboratory twice per day due to bacteriological parameter method holding times. Trip blanks therefore accompanied each separate sampling crew's VOA bottle shipments to the laboratory (up to 6 separate trip blanks per day).

MS/MSD/MD samples were collected at the rate of 1 per 20 groundwater or surface water samples collected, as was specified in the QAPP. Three equipment rinsate blanks were collected during

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the September-October sampling event (peristaltic pump and tubing, submersible pump and tubing, and disposable bailer) and two equipment rinsate blanks were collected during the November-December and February-March sampling events (peristaltic pump and tubing, and disposable bailer). Since the dedicated submersible pumps and tubing were left in the piezometers following the first sampling event, a submersible pump rinsate blank was not collected for the second and third sampling events.

4.6 Well GW03-015 Chloride Monitoring

Based on groundwater sample analytical results from the groundwater monitoring program (as discussed in Sections 5.5.2.1 and 6.3.2.4.1, additional study was performed to focus on the seasonal (tourist/non-tourist season) nature of groundwater flow conditions and the effect seasonal variations may have on groundwater flow and contaminant movement in the vicinity of the conduits and well GW03-015.

To assess the degree of change in water quality caused by daily, operationally induced changes in water levels in the CDS, continuous recording ion specific probes with pressure transducers were installed in each piezometer at monitoring location GW03-015. The probes were deployed between March 25 and April 6, 2004, to monitor the period of one week before the change over from non-tourist to tourist season and one week after. Details of the study are discussed in the following sections.

4.6.1 Probe Calibration

On March 24, 2004, seven In-Situ® Multi-Parameter (MP) Troll 9000 Series® probes were received. Each troll was equipped with the capability of measuring water quality parameters including, conductivity, oxidation/reduction potential (ORP), pH, barometric pressure, dissolved oxygen (DO), temperature, and feet of water (height of water column), and chloride concentration.

To ensure proper data collection and quality control, the probes were calibrated prior to deployment. Calibration solution supplied by In-Situ® was used to calibrate probes for DO, conductivity, pH and ORP. According to manufacturers specifications, recommended recalibration frequencies range

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from 2-4 weeks (for DO) to 2-3 months (for conductivity). Since the trolls were only deployed for a two week period, this calibration was only performed once. The chloride probe calibration was required daily.

A more intensive 'three-point calibration" for the chloride probe was performed once prior to troll deployment. The three-point calibration utilized two different chloride concentration solutions, which included 355 parts per million (ppm) chloride and 3545 ppm chloride. The three point calibration procedure consisted of the following,

- Calibrated probe in 355 ppm solution at room temperature until stable readings were obtained.
- Calibrated probe in 3545 ppm solution at room temperature until stable readings were obtained.
- Calibrated probe in 3545 ppm solution in an ice bath. Chloride solution was chilled in ice bath for at least one hour prior to calibration. Readings were collected until steady and temperature readings were near 0° Celsius (=+ 0.4° Celsius).

Following the three-point and quick-cal calibrations, each probe was fitted with a small battery operated DO stirrer supplied by In-Situ®. The purpose of the stirrers was to gently agitate groundwater (similar to laboratory analysis) for more accurate DO readings. The trolls were deployed in each piezometer at well location GW03-015 on March 26, 2004. Each troll was programmed to collect data every 15 minutes. The trolls were placed on average approximately 2-3 feet from the bottom of the piezometer, except piezometer P3. Due to an insufficient volume of water in P3 (approximately 4-5 feet of water column), the troll was placed directly on the bottom of the well. However, the design of the DO stirrer unit (which is located directly below the probes) is such that approximately one foot of space is between the DO stirrer and the bottom of the troll. Because of this, the probes were still located approximately one foot above the bottom of the well.

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4.6.2 Field Activities

As mentioned above, the trolls collected data from March 25 through April 6, 2004. Site visits were performed on a daily basis (including weekends). Activities performed during each site visit included the following,

- Upon arrival, static water levels and height of water column readings from trolls were collected simultaneously in order to calibrate troll positions in the piezometers. These procedures are identical to those described in Sections 4.3.1 and 4.3.3.
- All data collected between site visits was extracted and downloaded to a computer and saved. Data was collected by the dataloggers every 15 minutes.
- The trolls were then removed from each piezometer and the chloride probes were calibrated with a "one-point" calibration. The difference between the one-point and the three-point calibration is that only one solution at ambient air temperature is used for the one-point calibration. Based on previous groundwater sample analytical data, probes installed in piezometers P1, P4, P5, P6, and P7 were calibrated with the lower concentration of 355 ppm chloride solution. Probes installed in piezometers P2 and P3 were calibrated with the higher concentration of 3545 ppm chloride solution.
- Following chloride calibration, the trolls were reinstalled into each piezometer and a new test was started. A second water level/troll position calibration was performed as outlined above.
- The trolls were removed on April 6, 2004.

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4.6.2.1 Tourist/Non-Tourist Water Quality

Since location GW03-015 exhibited a change toward greater salinity in the samples collected between fall and winter sampling events, a limited groundwater sampling event was conducted on April 12 and 13, 2004, following the change over to tourist season operational mode and removal of MP 9000 Trolls®.

Groundwater samples were collected following guidelines outlined in Section 4.5.2.2. Sample analytical parameters were similar to those described in Section 4.5.2.3 and Table 4.5-4.

4.6.3 Data Management

Electronic water level data quality assurance measures were performed in accordance with those described in Section 4.3.1. After these calculations were completed, the data was imported into a database. Further quality assurance was completed by graphing each piezometer and comparing to the original spreadsheet and field notes to determine whether reference elevations and depth to water calculations were correct.

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TABLE 4.1.1-1

PARAMETERS ESTIMATED DURING CALIBRATION, CALIBRATED USGS 1996 MODEL

Transmissivity [ft^2/d]		
	Weathered bedrock	220
	horizontal fracture zones	99
Vertical Hydraulic Conductivity [ft/d]		
	glacial sediments	$6.6*10^{-3}$
	weathered bedrock	$1.3*10^{-2}$
	unweathered bedrock	$1.1*10^{-3}$
Average Recharge Rate [ft/d]		
	urban areas	$2.5*10^{-3}$
	rural areas	$1.2*10^{-4}$

Source: Yager 1996, Table 5

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TABLE 4.1.1-2

COMPARISON OF MEASURED AND ESTIMATED FLOW RATES, CALIBRATED USGS 1996 MODEL

Discharge Area	Observed Flow [ft^3/d]	Calibrated Model Flow [ft^3/d]
Crossing of Falls Street Tunnel and NYPA conduits	930,000	380,000
Remainder of Falls Street Tunnel[1]	70,000	73,000
Cayuga Creek[2]	40,000	24,000
Bergholtz Creek	32,000	49,000
Redland Quarry	13,000	8,000
Perennial springs	4,000	2,400

[1] Does not include flow entering airshaft near 18th Street. In the 1990's flow was reduced to less than 0.1 mgd at this location (Pers. Comm. NFWB, 2004).

[2] Does not include 70,000 ft^3/d entering creek from sewer lift-station near Lockport Road.

Source: Simulated Three-Dimensional Ground-Water Flow in the Lockport Group, A Fractured–Dolomite Aquifer Near Niagara Falls, New York (Yager 1996), Table 7.

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TABLE 4.1.1-3

WATER BUDGET, CALIBRATED USGS 1996 MODEL

Inflow	**Rate [ft^3/d]**	**Percentage of Total [%]**
Recharge	1,100,000	61
Lewiston Reservoir	280,000	16
Niagara River	270,000	15
Tributaries	130,000	7
Underflow	13,000	1
Outflow	**Rate [ft^3/d]**	**Percentage of Total [%]**
Natural Areas		
Niagara River Gorge	530,000	30
Tributaries	330,000	19
Niagara River	94,000	5
Niagara Escarpment	40,000	2
Manmade Structures		
Falls Street Tunnel at NYPA Conduits	450,000 (3.36 mgd)	25
Industrial Wells	130,000	7
Tunnels	150,000	8
Excavations	67,000	4

Source: Yager 1996, Table 6

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TABLE 4.1.2-1

COMPARISON OF FLOW BUDGETS, GMS MODEL AND 2003 USGS MODEL

Element	Flow Rate 2003 USGS Model[1] [ft^3/d]	GMS Model[2] [ft^3/d]	Discrepancy [%]
Flow In:			
Storage	0.0000	0.0000	0
Constant head	440,038.7190	440,187.7188	0.034
Wells *	462.8400	462.8400	0
Drains	0.0000	0.0000	0
Head dependent boundaries	4,944.1704	4,944.1440	0.00053
Recharge	887,996.1880	887,996.1250	0.000007
Flow Out:			
Storage	0.0000	0.0000	0
Constant head	213,219.7660	213,099.0000	0.056
Wells	134,670.0000	134,670.0000	0
Drains	903,135.4380	903,401.1875	0.029
Head dependent boundaries	82,430.9531	82,422.3359	0.010
Recharge	0.0000	0.0000	0

Maximum discrepancy = 0.056%

[1] Source: output file "modflow.out" of the 2003 USGS model.

[2] Source: output file of the converted GMS model.

* Injection wells used to simulate the inflow of groundwater from the outside of the model domain.

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TABLE 4.1.2-2

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
668	644	626.793	626.83	-0.037
662	637	625.231	625.272	-0.041
632	624	620.317	620.354	-0.037
640	610	605.942	605.893	0.049
629	619	621.551	621.58	-0.029
621	626	629.748	629.711	0.037
622	627	628.724	628.688	0.036
594	598	598.965	598.928	0.037
578	647	622.97	622.97	0
584	619	621.103	621.089	0.014
570	620	626.514	626.486	0.028
566	622	620.6	620.619	-0.019
562	612	622.073	622.177	-0.104
557	619	622.813	622.912	-0.099
563	621	606.489	606.259	0.23
530	620	614.468	614.455	0.013
510	622	611.721	611.654	0.067
496	610	611.178	611.158	0.02
506	607	618.923	618.896	0.027
W2A	611	583.69	583.477	0.213
513	614	618.741	618.692	0.049
W13	599	570.399	570.092	0.307
W3A	605	576.893	576.605	0.288
LW2	618	619.032	618.987	0.045
W7	593	584.909	584.716	0.193
W23	578	547.458	546.795	0.663
487	630	616	615.965	0.035
472	613	615.327	615.233	0.094
471	608	614.056	613.991	0.065
462	617	613.734	613.639	0.095
84-7	582	566.759	567.09	-0.331
LW1	611	605.246	604.852	0.394
448	617	613.831	613.728	0.103
439	614	614.451	614.351	0.1
W167	552	562.356	562.247	0.109

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TABLE 4.1.2-2 (CONT.)

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
W129	606	608.181	607.996	0.185
W126	598	595.167	594.999	0.168
2380	569	566.217	566.08	0.137
28611	576	576.547	576.449	0.098
B10	619	607.112	607.017	0.095
WF3	619	607.051	607.011	0.04
1979	576	570.071	569.944	0.127
B6	612	605.066	604.976	0.09
1479	590	582.42	582.3	0.12
388	585	586.931	586.784	0.147
B4	602	604.817	604.723	0.094
2780	601	593.469	593.463	0.006
2580	610	598.67	598.731	-0.061
W102	583	582.481	582.295	0.186
3280	594	591.233	591.109	0.124
366	608	589.199	589.042	0.157
W162	549	560.797	560.989	-0.192
W105	580	577.475	577.304	0.171
356	584	582.11	581.937	0.173
349	575	586.794	586.561	0.233
341	579	592.394	592.146	0.248
37834	588	590.427	590.312	0.115
85-2	577	572.933	572.683	0.25
37742	589	587.96	587.84	0.12
37681	598	586.977	586.923	0.054
37682	593	585.403	585.341	0.062
NI1	594	588.733	588.659	0.074
37712	594	585.955	585.865	0.09
37626	590	583.209	583.134	0.075
NI69	575	591.603	591.502	0.101
85-1	553	553.284	552.562	0.722
37803	584	581.28	581.16	0.12
37865	579	584.892	584.848	0.044
262	577	577.312	577.166	0.146
84-1	584	579.962	579.766	0.196
W152	552	553.114	553.063	0.051

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TABLE 4.1.2-2 (CONT.)

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
8715	580	577.383	577.339	0.044
229	574	579.185	579.146	0.039
89-1	576	575.816	575.76	0.056
8710	575	575.783	575.74	0.043
400	579	581.154	581.071	0.083
250	574	581.931	581.947	-0.016
89-4	573	572.906	572.885	0.021
8712	571	574.168	574.134	0.034
8718	570	574.156	574.109	0.047
REIC	590	561.79	561.569	0.221
8719	569	574.96	575.026	-0.066
8921	569	573.159	573.216	-0.057
WF1	579	584.863	584.824	0.039
84-2	581	593.397	593.378	0.019
315	574	577.561	577.463	0.098
156B	582	555.091	554.949	0.142
142B	572	572.292	572.082	0.21
143B	578	563.261	563.05	0.211
89-5	569	574.777	574.801	-0.024
185	547	567.17	567.38	-0.21
147B	566	553.612	553.453	0.159
153B	569	571.318	571.214	0.104
51	570	567.491	567.313	0.178
149B	567	560.565	560.407	0.158
NF1	539	567.33	567.412	-0.082
89-6	569	575.279	575.27	0.009
15A	567	574.818	574.79	0.028
89-7	569	575.135	575.129	0.006
89-8	569	575.111	575.109	0.002
MW3C	562	560.754	560.62	0.134
MW1C	564	566.649	566.537	0.112
MW3	559	548.1	547.943	0.157
40A	566	573.842	573.813	0.029
162	557	567.172	567.017	0.155
82-3	567	564.823	564.799	0.024
82-1	518	519.688		(*)

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TABLE 4.1.2-2 (CONT.)

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
W139	548	543.319	543.338	-0.019
MW13	544	545.712	545.588	0.124
150	546	547.043	546.911	0.132
4215	566	573.633	573.601	0.032
135	562	561.815	561.714	0.101
133	566	557.966	558.391	-0.425
17B	549	547.66	547.851	-0.191
OC26	552	545.801	545.704	0.097
19B	557	543.583	543.962	-0.379
W410	555	557.31	557.272	0.038
6211	567	571.088	571.045	0.043
99A	565	569.112	569.069	0.043
1B	560	555.948		(*)
SP5	554	549.14	549.568	-0.428
6209	565	569.117	569.067	0.05
PA1D	563	560.714	560.659	0.055
OC16	562	559.708	559.721	-0.013
OW52	564	566.967	566.913	0.054
WF2	565	568.818	568.77	0.048
NR5B	560	562.367	562.364	0.003
NR1B	566	565.146	565.182	-0.036
NR2B	564	564.477	564.491	-0.014
NR3B	564	565.558	565.583	-0.025
CNI2	564	562.277	562.28	-0.003
GW1D	564	568.608	568.549	0.059
GW2D	564	567.229	567.157	0.072
NR4B	564	566.696	566.711	-0.015
PN1	567	569.606	569.597	0.009
GW6D	564	566.154	566.077	0.077
NR6B	562	564.133	564.124	0.009
DW12	566	573.435	573.426	0.009
1793	564	569.764	569.77	-0.006
DW7	566	573.656	573.654	0.002
DW17	566	573.546	573.539	0.007
GI2	564	575.783	575.799	-0.016
NR7B	565	564.351	564.309	0.042

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TABLE 4.1.2-2 (CONT.)

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
1749	596	577.633	577.618	0.015
NR8B	567	568.565	568.537	0.028
GI2	564	574.682	574.693	-0.011
PN1	566	570.441	570.438	0.003
GI2	565	568.401	568.404	-0.003
PN1	568	573.49	573.491	-0.001
CNI2	564	561.482	561.487	-0.005
GI2	565	568.293	568.306	-0.013
PN1	566	573.623	573.623	0
WF1	579	584.501	584.462	0.039
CNF2	559	559.566	559.565	0.001
CNI2	564	560.614	560.607	0.007
GI2	568	568.533	568.546	-0.013
NF1	539	554.086	554.006	0.08
NI1	590	588.168	588.088	0.08
PN1	580	573.661	573.661	0
153C	563	566.82	566.724	0.096
156B	553	550.262	550.163	0.099
WF1	579	584.976	584.94	0.036
CNF2	559	553.518	553.517	0.001
CNI2	564	559.863	559.857	0.006
GI2	568	568.571	568.584	-0.013
NF1	541	550.694	550.57	0.124
NI1	591	587.993	587.909	0.084
PN1	580	573.667	573.667	0
153E	559	565.996	565.903	0.093
156E	554	551.776	551.672	0.104
WF1	579	585.168	585.129	0.039
WF2	565	572.88	572.861	0.019
CNF2	559	543.873	543.872	0.001
CNI2	564	559.183	559.175	0.008
GI2	568	568.604	568.617	-0.013
LW1	614	593.358	593.056	0.302
NF1	543	546.646	546.529	0.117
NI1	592	587.845	587.758	0.087
PN1	579	573.673	573.672	0.001

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TABLE 4.1.2-2 (CONT.)

COMPARISON OF HYDRAULIC HEADS AT MONITORING LOCATIONS, GMS MODEL AND 2003 USGS MODEL

Observation Point	Observed Head [ft]	Calculated Head		Difference USGS GMS [ft]
		USGS Model [ft]	GMS Model [ft]	
153F	555	565.461	565.368	0.093
156F	556	552.457	552.345	0.112
WF1	579	585.47	585.42	0.05
WF2	565	573.275	573.258	0.017
WF3	617	605.35	605.308	0.042
CNF2	531	538.105	537.964	0.141
CNI2	565	558.645	558.635	0.01
GI2	568	568.628	568.64	-0.012
LW1	589	589.137	588.858	0.279
LW2	625	615.833	615.775	0.058
NF1	549	544.757	544.646	0.111
NI1	575	587.708	587.62	0.088
PN1	576	573.677	573.676	0.001
153F	555	565.394	565.272	0.122
156G	554	552.546	552.43	0.116
WF1	579	585.433	585.389	0.044
WF2	566	573.491	573.473	0.018
WF3	612	604.97	604.926	0.044
CNF2	533	526.646	526.459	0.187
GI2	572	568.655	568.668	-0.013
LW1	555	583.173	582.927	0.246
LW2	626	614.755	614.699	0.056
NF1	551	543.219	543.116	0.103
NI1	559	587.463	587.379	0.084
PN1	576	573.682	573.681	0.001
153G	558	564.548	564.46	0.088
156G	554	553.118	553.008	0.11
WF1	579	585.366	585.333	0.033
WF2	570	573.918	573.901	0.017
Maximum discrepancy				0.722

(*) - Point located at the model boundary. GMS considered it as an outside point.

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TABLE 4.2.5-1

SURVEY DATA FOR NESTED GROUNDWATER MONITORING LOCATIONS

Well	Northing	Easting	Elevation of		
			Ground	Casing	Riser
GW 03-001A	1152369.4	389970.9	614.2	617.00	
RISER P1					616.79
RISER P2					616.66
GW 03-002A	1152935.0	389884.9	618.5	620.28	
RISER P1					620.10
RISER P2					619.92
GW 03-003A	1154579.8	389653.9	635.2	638.06	
RISER P1					637.81
RISER P2					637.83
GW 03-004A	1155690.7	389471.9	620.6	623.42	
RISER P1					623.24
RISER P2					623.08
GW 03-005A	1152022.8	395642.7	612.6	615.42	
RISER P1					615.27
RISER P2					615.12
GW 03-006A	1149600.9	395389.5	628.9	631.12	
RISER P1					630.85
RISER P5					630.82
GW 03-006B	1149591.4	395405.2	628.9	631.16	
RISER P2					630.74
RISER P3					630.67
RISER P4					630.87
GW 03-007A	1147724.8	397715.2	624.4	627.37	
RISER P1					627.22
RISER P2					627.24
RISER P3					627.22
GW 03-007B	1147742.0	397713.1	624.4	627.30	
RISER P4					627.15

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TABLE 4.2.5-1 (CONT.)

PIEZOMETER LOCATIONS AND ELEVATIONS

Well	Northing	Easting	Elevation of		
			Ground	Casing	Riser
RISER P5					627.10
GW 03-008A	1145673.3	398385.6	625.8	627.89	
RISER P1					627.74
RISER P2					627.67
RISER P3					627.61
GW 03-008B	1145672.9	398366.9	626.1	628.08	
RISER P4					627.94
RISER P5					627.88
RISER P6					627.76
GW 03-009A	1145373.7	396489.0	634.5	636.83	
RISER P1					636.69
RISER P2					636.59
RISER P3					636.45
GW 03-009B	1145387.6	396481.1	635.0	637.43	
RISER P4					637.21
RISER P5					637.13
RISER P6					637.07
GW 03-010A	1142036.0	395989.2	630.6	630.29	
RISER P1					629.98
RISER P2					629.93
RISER P3					629.84
GW 03-010B	1142017.8	395989.5	630.6	630.28	
RISER P4					630.00
RISER P5					630.00
RISER P6					630.00
GW 03-010C	1142026.3	396001.2	630.7	630.37	
RISER P7					630.00
GW 03-011A	1141170.0	391139.9	617.7	617.40	

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TABLE 4.2.5-1 (CONT.)

PIEZOMETER LOCATIONS AND ELEVATIONS

Well	Northing	Easting	Elevation of		
			Ground	Casing	Riser
RISER P1					617.14
RISER P2					617.10
RISER P3					617.07
GW 03-011B	1141169.4	391124.3	617.7	617.63	
RISER P4					617.25
RISER P5					617.22
GW 03-011C	1141169.9	391104.0	617.8	617.53	
RISER P7					617.19
RISER P8					617.13
GW 03-012A	1142717.5	383378.3	622.7	624.67	
RISER P1					624.43
RISER P2					624.51
RISER P3					624.41
GW 03-012B	1142701.5	383380.2	622.7	625.39	
RISER P4					625.13
RISER P5					625.03
RISER P6					624.97
GW 03-012C	1142735.0	383377.0	622.7	624.74	
RISER P7					624.51
GW 03-013A	1137964.6	384524.0	599.5	601.83	
RISER P1					601.61
RISER P2					601.47
RISER P3					601.43
GW 03-013B	1137975.8	384514.8	599.3	601.99	
RISER P4					601.72
RISER P5					601.63
RISER P6					601.57

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TABLE 4.2.5-1 (CONT.)

PIEZOMETER LOCATIONS AND ELEVATIONS

Well	Northing	Easting	Elevation of		
			Ground	Casing	Riser
GW 03-013C	1137953.2	384533.2	599.3	601.63	
RISER P7					601.31
GW 03-014A	1132067.5	385243.7	585.1	584.96	
RISER P1					584.65
RISER P2					584.62
RISER P3					584.53
GW 03-014B	1132078.8	385250.6	585.1	584.74	
RISER P4					584.37
RISER P5					584.28
RISER P6					584.20
GW 03-014C	1132079.3	385238.3	584.7	584.37	
RISER P7					584.01
GW 03-015A	1129033.9	384948.1	580.4	582.75	
RISER P1					582.53
RISER P2					582.49
RISER P3					582.41
GW 03-015B	1129033.0	384968.0	580.9	582.85	
RISER P4					582.53
RISER P5					582.51
RISER P6					582.41
GW 03-015C	1129033.1	384986.9	581.0	583.47	
RISER P7					583.25
GW 03-016A	1125189.7	384494.8	569.5	571.59	
RISER P1					571.43
RISER P2					571.31
RISER P3					571.23
GW 03-016B	1125211.5	384498.2	569.5	571.70	
RISER P4					571.55

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TABLE 4.2.5-1 (CONT.)

PIEZOMETER LOCATIONS AND ELEVATIONS

Well	Northing	Easting	Elevation of		
			Ground	Casing	Riser
RISER P5					571.48
RISER P6					571.29
GW 03-016C	1125230.9	384497.8	569.1	571.77	
RISER P7					571.52
RISER P8					571.41
GW 03-017A	1122542.2	384198.2	569.3	569.03	
RISER P1					568.70
RISER P2					568.62
RISER P3					568.50
GW 03-017B	1122531.2	384211.1	569.1	568.66	
RISER P4					568.37
RISER P5					568.25
RISER P6					568.19
GW 03-017C	1122523.1	384220.9	569.2	568.86	
RISER P7					568.64
RISER P8					568.63
RISER P9					568.55
GW03-018A-P1	1146179	399619	622.96	NA	626.8
GW03-018A-P2	1146184	399619	622.96	NA	624.7
OW-139	1125060.7	384466.9	569.4	569.24	568.98

1) Vertical Datum shown is USLSD 1935
2) Coordinates shown are New York State Plane Coordinates NY West 3103
NAD 1927, in feet
3) Site Combined Factor is 0.999930091990
4) NA – not applicable
Conversions:
1) Grid Coordinates= Ground Coordinates X Combined Factor
2) USLSD 1935 = NGVD 1929 + 0.51’

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TABLE 4.3.1-1

SURVEY DATA FOR CONDUIT AND RESERVOIR WELLS

Well No.	Northing	Easting	Elevation of		
			Ground	Casing	Riser
NW-01	1148800.00	383746.00	625.0		627.77
NW-05	1148908.00	394950.00	620.8		623.63
NW-07	1145580.00	395995.00	637.4		634.80
NW-09	1143370.00	391900.00	609.6		612.77
NW-10	1143375.00	387100.00	608.0		610.39
NW-11	1142855.00	387100.00	610.5		613.28
NW-13	1143395.00	386120.00	609.6		612.27
NW-16	1143206.00	3847980.00	613.5		616.06
NW-17	1143180.00	384798.00	613.5		615.95
NW-18	1149399.00	382860.00	621.3		624.27
NW-19	1149952.00	385225.00	624.9		627.88
NW-20	1150227.00	384924.00	627.4		624.60
OW-104	114322.51	389203.95	605.5		609.02
OW-111	1149951.96	385194.47			628.29
OW-112	1150226.99	384893.76	623.8		627.17
OW-139	1125060.70	3844766.90		569.44	568.98
OW-179	1143287.10	385247.92	613.4		616.68
OW-180	1143347.00	385173.00	613.3		616.08
OW-181	1143473.05	384054.70	623.9		623.67
OW-189	1143451.78	385627.96	613.3		616.64
OW-193	1147008.90	395585.09	620.8		624.58
OW-206	1148646.00	3949260.00	620.7		623.60
OW-207	1149153.00	394725.00	624.4		627.48
OW-209	1147838.00	395255.00	626.6		623.60
OW-210	1151898.20	393645.80	613.1		616.95
OW-212	1151823.40	393629.90	613.3		616.80
OW-650D	1124325.65	384080.50			569.81

Survey data obtained from Drawing No. 7G-202, LPGP Reservoir Dike Observation Wells Rehabilitation Schedule, July 19, 1991

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TABLE 4.3.2-1

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-001A P1	611.97	611.01			611.04			611.45	610.84				610.38	610.63	610.17	610.88	
GW03-001A P2	609.86	569.71			579.26			584.92	591.45				603.45	605.52	606.88	607.55	
GW03-002A P1	612.32	611.36			611.20			610.69	610.97				610.53	610.64	610.34	610.89	
GW03-002A P2	611.37	576.48			576.59			576.56	576.59				576.60	576.56	576.62	576.62	
GW03-003A P1	626.01	625.05	624.90	624.84	624.45			624.18	623.99				623.75	623.65	623.66	624.42	
GW03-003A P2	625.93	624.96	624.80	624.74	624.35			624.09	623.89				623.67	623.57	623.58	624.31	
GW03-004A P1	614.92	614.13	614.44	614.52	614.43			614.32	614.30				614.20	614.20	614.22	612.34	
GW03-004A P2	611.31	611.41	611.43	611.52	611.50			611.48	611.31				611.43	611.38	611.50	606.18	
GW03-005A P1	614.07	612.54	612.32	611.62	611.18			610.79	610.48				609.38	609.33	609.01	609.24	
GW03-005A P2	610.75	571.28	571.62	571.94	572.16			572.37	572.55				573.17	573.66	574.21	574.41	
GW03-006A P1	618.96	617.40	617.31	616.57	614.87			616.31	616.22				615.44	615.56	615.35	615.41	
GW03-006B P2	614.90	613.35	613.23	612.32	611.89			611.57	611.25				610.14	610.23	609.83	610.21	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-006B P3	617.32	556.61	556.70	556.74	556.79			556.80	556.88				556.95	556.98	557.02	556.83	
GW03-006B P4	618.91	617.53	617.46	616.56	616.66			616.37	616.30				615.77	615.71	615.47	615.59	
GW03-006A P5	614.50	612.45	612.66	611.44	611.38			610.56	610.60				609.49	609.69	609.00	609.53	
GW03-007A P1	618.69	617.09	616.92	616.25	616.13			615.91	615.75				615.14	615.04	614.84	614.87	
GW03-007A P2	610.49	606.51	605.79	605.20	604.67			604.49	603.68				601.82	601.67	601.54	603.28	
GW03-007A P3	604.42	550.48	577.36	590.83	596.83			599.25	600.97				603.07	603.60	604.04	604.36	
GW03-007B P4	618.84	617.25	617.07	616.21	616.29			616.07	615.93				615.38	615.26	615.05	615.02	
GW03-007B P5	616.71	608.29	607.64	606.90	606.51			606.32	605.62				603.81	603.67	603.54	604.98	
GW03-008A P1	618.89	617.22	617.01	616.48	616.24			616.05	615.86				615.26	615.14	614.94	614.99	
GW03-008A P2	610.44	606.25	605.49	604.94	604.42			604.26	603.41				601.54	601.38	601.28	603.12	
GW03-008A P3	619.04	618.05	618.02	618.00	617.74			617.74	617.69				617.52	617.82	617.76	617.88	
GW03-008B P4	618.62	617.00	616.80	616.46	616.08			615.87	615.69				615.07	614.94	614.73	614.70	614.63
GW03-008B P5	618.72	617.13	616.93	616.38	616.17			615.97	615.81				615.21	615.12	614.91	614.98	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-008B P6	617.89	567.15	567.30	567.46	567.62			567.72	567.87				568.25	568.39	568.54	568.65	
GW03-009A P1	618.00	616.61	616.64	615.89		615.94		615.55	615.59		615.26		615.01	614.97	614.78	614.94	
GW03-009A P2	610.38	606.25	605.49	604.98		604.55		604.41	603.44		602.77		601.58	601.42	601.32	603.30	
GW03-009A P3	610.22	577.59	582.11	584.46		586.08		586.57	587.20		588.33		588.44	589.03	589.50	589.85	
GW03-009B P4	620.01	619.03	618.90	618.72		618.48		618.32	618.15		617.85		617.63	617.31	617.49	617.80	617.70
GW03-009B P5	618.76	616.47	618.46	618.16		618.42		617.76	617.58		617.00		616.31	616.12	615.50	616.54	
GW03-009B P6	620.04	618.96	618.86	618.69		618.49		618.29	618.13		617.81		617.62	617.54	617.45	617.75	
GW03-010A P1		593.45	593.11	592.68		592.63		592.13	591.86		591.50		590.88	590.90	590.90	592.13	
GW03-010A P2		606.19	605.37	604.95		604.49		604.42	603.40		602.78		601.50	601.36	601.36	603.42	
GW03-010A P3		603.96	604.22	604.19		604.14		604.11	604.04		603.74		602.90	602.73	602.58	602.44	
GW03-010B P4		610.84	610.74	610.56		610.34		610.23	610.12		609.82		609.73	609.61	609.57	609.80	
GW03-010B P5		606.93	606.51	606.18		605.76		605.55	605.28		605.01		604.78	604.65	604.75	605.79	
GW03-010B P6		598.36	597.70	597.22		596.83		596.64	595.91		595.39		594.43	594.26	594.23	595.85	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-010C P7		610.86	610.75	610.58		610.36		610.24	610.22		609.82		609.74	609.62	609.58	609.79	596.96
GW03-011A P1		580.76	581.05	580.85		581.08		580.61	581.11		581.30		581.07	581.40	581.25	582.34	
GW03-011A P2		595.81	595.80	594.74		594.19		593.55	593.75		593.17		592.64	592.73	592.08	592.36	
GW03-011A P3		593.61	593.60	592.60		592.10		591.47	591.68		591.12		590.61	590.66	590.06	590.34	
GW03-011B P4		604.18	604.02	603.85		603.62		603.41	603.22		603.08		602.91	602.96	603.05	603.63	
GW03-011B P5		530.79	530.83	530.89		530.98		530.98	531.01		531.04		531.04	531.06	531.07	531.09	
GW03-011C P7		604.16	604.03	603.85		603.61		603.40	603.21		603.08		602.90	602.96	603.04	603.62	
GW03-011C P8		601.73	601.52	601.27		601.76		600.82	600.67		600.51		600.35	600.34	600.80	601.40	
GW03-012A P1 [1]																	
GW03-012A P2		556.44	556.44	556.77		557.99	557.56	557.27	558.92	558.35	558.60		558.69	559.12	559.19	558.30	
GW03-012A P3		516.03	530.05	540.75		558.48	549.34	549.81	551.09	552.53	553.33		553.14	553.56	552.71	552.80	
GW03-012B P4			584.03	584.03		584.01		584.03	584.03	584.04	584.01		584.02	584.03	584.02		
GW03-012B P5		564.74	564.82	564.85		564.84		564.62	564.57	564.55	564.62		564.42	564.58	564.35	564.27	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-012B P6		556.47	556.22	556.63		558.38	557.79	557.03	558.68	558.17	558.41		558.34	559.00	558.95	558.07	
GW03-012C P7		597.80	597.78	597.79		597.83		597.82	597.83	597.83	597.80		597.79	597.80	597.80	597.77	
GW03-013A P1		558.13	557.53	558.36					558.91		559.95		560.35	560.17	560.19	559.43	
GW03-013A P2		556.60	556.41	556.56					557.66		558.67		559.21	559.36	558.86	558.35	
GW03-013A P3		556.49	556.33	556.48					557.61		558.55		559.12	559.29	558.76	558.25	
GW03-013B P4		558.83	558.81	558.77					558.78		559.21		559.65	559.51	559.26	558.93	
GW03-013B P5		556.53	556.18	556.37					557.33		558.71		559.32	559.26	558.88	558.30	
GW03-013B P6		551.56	551.62	551.66					551.83		552.10		552.12	552.18	552.22	552.26	
GW03-013C P7		565.58	565.59	565.61					565.58		565.56		565.48	565.48	565.41	565.36	
GW03-014A P1		515.53	499.69	526.82					540.37		546.72			550.39	551.86	552.79	
GW03-014A P2		464.34	464.56	464.72					465.15		465.43			465.65	465.88	466.23	
GW03-014A P3		546.99	547.02	546.95					547.00		547.45			547.54	547.41	547.35	
GW03-014B P4		557.13	557.54	557.22					557.52		558.52			558.53	558.19	558.24	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-014B P5		558.08	558.40	557.62					558.59		559.09			560.00	559.38	559.17	
GW03-014B P6		558.09	558.40	557.68					558.64		559.15			559.99	559.45	559.23	
GW03-014C P7		557.27	557.58	557.20					557.54		558.53			558.48	558.22	558.40	
GW03-015A P1		558.62	559.23	558.18					559.36	560.01	559.69		559.92	560.24	560.17	559.63	
GW03-015A P2		507.71	533.84	547.98					554.84	555.53	556.57		555.94	556.31	556.01	556.00	
GW03-015A P3		435.16	435.41	435.63					436.17	436.38	436.55		436.69	436.88	437.08	437.20	
GW03-015B P4		558.49	559.71	559.05					559.63	560.48	560.45		560.26	560.67	560.49	560.09	
GW03-015B P5		559.01	559.21	557.85					559.38	557.97	559.77		559.90	560.22	560.23	559.60	
GW03-015B P6		558.99	559.19	557.74					559.35	559.92	559.67		559.94	560.18	560.16	559.52	
GW03-015C P7		558.21	558.58	557.85					558.46	559.35	559.34		559.42	559.68	559.45	559.17	
GW03-016A P1		558.92	559.30	558.82					558.98	559.81				559.86	559.99	559.63	
GW03-016A P2		558.63	558.96	558.55					558.70	559.55		558.98		559.62	559.73	559.38	
GW03-016A P3		536.23	559.18	558.78					558.91	559.67				559.81	559.76		

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-016B P4		558.09	558.39	557.95					558.10	558.88				559.02	559.08	558.78	
GW03-016B P5		558.36	558.66	558.11					558.31	559.12				559.40	559.43	559.21	
GW03-016B P6		558.98	559.37	558.86					559.10	559.97				560.02	560.14	559.72	
GW03-016C P7		557.77	558.07	557.61					557.75	558.49		557.98		558.59	558.66	558.36	
GW03-016C P8		558.94	559.29	558.82					559.05	559.88				559.94	560.05	559.68	
GW03-017A P1		519.04	559.83	558.63					559.16	560.08				560.63	560.53	560.43	
GW03-017A P2		559.93	560.37	559.75					559.89	560.76				561.23	560.77	560.72	
GW03-017A P3																	
GW03-017B P4		560.30	560.75	560.07					560.23	561.06				561.25	561.13	561.11	
GW03-017B P5		560.12	560.58	559.90					560.06	560.90				561.08	560.93	560.95	
GW03-017B P6		559.99	560.44	559.84					559.96	560.83				560.95	560.79	560.71	
GW03-017C P7		560.23	560.68	559.95					560.13	560.95				561.17	561.06	561.02	
GW03-017C P8		560.32	560.75	559.99					560.21	561.05				561.28	561.12	561.14	

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TABLE 4.3.2-1 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, JULY THROUGH SEPTEMBER 2003

Location	7/24/03	8/22/03	8/24/03	8/29/03	9/2/03	9/3/03	9/4/03	9/5/03	9/8/03	9/12/03	9/15/03	9/17/03	9/18/03	9/22/03	9/26/03	9/29/03	9/30/03
GW03-017C P9		532.33	559.07	558.99					559.35	559.54				559.66	559.28	559.97	
OW-650D										558.59				558.69	558.69		
OW-139										558.5				558.62	558.72		
GW03-018A P1																	
GW03-018A P2																	

All data recorded in feet elevation.
Vertical Datum shown is USLSD 1935.
[1]No water observed in well (persistently dry). Consequently no measurements recorded.

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TABLE 4.3.2-2

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-001A P1	610.26		609.81	609.81	610.01	610.71	611.18	611.96		611.83				612.85		
GW03-001A P2	589.15		549.45	549.45	583.13	590.94	606.38	608.32		609.31				610.01		
GW03-002A P1	610.51	610.75	610.12	610.12	610.32	610.83	611.40	612.18		612.18				613.13		
GW03-002A P2	576.63	576.66								572.77				572.87		
GW03-003A P1	624.28	624.07	623.77	623.57	623.08	624.27	625.21	625.53		625.49				626.61		
GW03-003A P2	624.15	623.95	623.64	623.43	623.95	624.13	625.05	625.39		625.31				626.18		
GW03-004A P1	611.47		614.26	614.27	614.58	614.63	616.14	615.67		615.53				616.10		
GW03-004A P2	601.65		611.58	611.59	611.83	611.85	612.09	612.07		611.87				612.10		
GW03-005A P1	609.16	609.23	611.96	609.33	608.87	609.23	609.87	610.62		610.98			611.93			
GW03-005A P2	574.86	575.20		570.36	571.45	572.19	590.40	597.70		600.67			603.19			
GW03-006A P1	615.35	615.30	614.86	615.11	614.96	615.10	616.47	616.79		616.70			617.78			
GW03-006B P2	609.86	610.16	609.56	609.30	609.46	609.96	610.64	611.44		611.74			612.75			

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-006B P3	557.08	557.10	555.82	555.89	555.91	555.99	556.03	556.08		556.13			556.18			
GW03-006B P4	615.54	615.50	614.93	615.30	615.12	615.31	616.65	617.15		617.01			618.22			
GW03-006A P5	608.99	609.31	608.20	609.40	608.41	609.19	609.91	610.56		610.54			611.75			
GW03-007A P1	614.82	614.76	614.39	614.52	614.44	614.53	616.35	616.31		616.29			617.36			
GW03-007A P2	602.30	601.70	600.90	600.70	599.08	600.92	602.49	602.72		601.89			603.95			
GW03-007A P3	546.88	569.36	564.67	577.60	586.94	589.74	593.62	593.74		595.06			595.98			
GW03-007B P4	615.04	614.92	614.72	614.74	614.68	614.77	616.37	616.47		616.46			617.53			
GW03-007B P5	599.63	603.29	599.29	587.30	595.52	601.26	603.70	604.82		604.04			605.93			
GW03-008A P1		614.89	614.66	614.69	614.61	614.68	616.14	616.45		616.47			617.50			
GW03-008A P2	602.08	601.43	600.63	600.44	600.77	600.68	602.37	602.44		601.62			603.67			
GW03-008A P3	617.80	617.56	617.51	617.65	617.51	617.64	617.48	617.16		617.32			618.01			
GW03-008B P4	614.68	614.57	614.45	614.38	614.31	614.33	614.99	616.13		616.16			617.11			
GW03-008B P5	614.93	614.87	614.63	614.69	614.58	614.66	616.08	616.39		616.39			617.41			

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-008B P6	568.81	568.90						566.73		567.01			567.27			
GW03-009A P1	614.86	615.11	614.51	614.71	614.34	614.58	615.83	616.16		616.06				616.84		
GW03-009A P2	602.15	601.47	600.70	600.47	600.79	600.74	602.73	602.52		601.68				603.55		
GW03-009A P3	590.08	590.31	590.44	590.75	554.07	554.97	558.00	558.82		559.59				560.42		
GW03-009B P4	617.83	617.79	617.62	617.48	617.59	617.61	618.09	618.92		618.80				619.23		
GW03-009B P5	616.88	616.80	616.33	616.21	616.24	616.42	617.56	618.34		618.22				618.74		
GW03-009B P6	617.74	617.72	617.57	617.44	617.53	617.56	618.04	618.86		618.75				619.18		
GW03-010A P1	591.76	591.53	590.28	590.38	590.44	590.52	591.44	591.84		590.88			592.03			
GW03-010A P2	602.08	601.40	600.62	600.38	600.73	600.72	602.80	602.47		601.59			603.72			
GW03-010A P3	602.41	602.32	600.62	600.64	513.39	516.77	531.38	537.97		544.10			549.57			
GW03-010B P4	609.79	609.79	609.69	609.65	609.65	609.65	610.03	610.32		610.21			610.50			
GW03-010B P5	605.59	605.45	605.06	604.88	605.24	605.24	606.53	606.63		606.15			606.98			
GW03-010B P6	595.16	594.67	594.03	593.85	594.10	594.12	595.58	595.97		594.99			596.70			

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-010C P7	609.81	609.80	609.68	609.63	609.65	609.65	610.01	610.32		610.23			610.49			
GW03-011A P1	582.15	582.21	581.59	582.24	581.83	582.49	583.11	583.28			582.15		583.33			
GW03-011A P2	591.71	591.55	590.72	591.57	590.80	591.11	590.63	590.05			589.69		590.34			
GW03-011A P3	589.66	589.53	596.77	589.58	588.82	589.15	588.67	588.13			587.81		588.44			
GW03-011B P4	603.60	603.48	603.24	603.12	603.40	603.47	604.40	604.32			604.31		604.92			
GW03-011B P5	531.11	531.14	530.34	530.40	530.42	530.45	530.53	530.59			530.63		530.68			
GW03-011C P7	603.63	603.47	603.24	603.13	602.37	603.45	604.39	604.30			604.31		604.91			
GW03-011C P8	601.36	601.22	600.76	600.56	600.85	600.92	601.60	601.67			601.70		602.25			
GW03-012A P1 [1]																
GW03-012A P2	556.51	559.70	559.04	558.78	558.51	557.29	553.00	554.41		550.47				549.03		
GW03-012A P3	552.70	552.18	500.56		501.00	510.40	547.12	548.36		546.58				545.47		
GW03-012B P4	584.02	584.10	584.09	584.12	578.67	584.67	584.67	584.67		585.03				585.18		
GW03-012B P5	564.43	564.19	560.48	564.28	564.18	564.22	564.43	564.47		564.28				564.42		

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-012B P6	555.04	559.44	559.46	558.55	558.24	556.95	552.48	553.91		549.88				548.52		
GW03-012C P7	597.77	598.49	598.43	597.62	597.63	597.63	597.63	598.70		598.46				598.62		
GW03-013A P1		560.43	561.89	561.75	561.62	561.22	559.49	560.47		558.56				554.30		
GW03-013A P2		559.26	559.00	558.76	558.64	557.61	553.22	554.23		549.69				548.94		
GW03-013A P3		559.16	558.95	558.66	558.55	557.50	553.12	554.12		549.56				548.80		
GW03-013B P4		559.46	559.14	559.19	558.97	558.78	558.26	558.54		558.22				558.18		
GW03-013B P5		559.20	558.77	558.71	558.54	557.57	553.23	554.22		549.69				548.65		
GW03-013B P6		552.16	552.27	520.66										519.08		
GW03-013C P7		565.34	565.34	565.36	565.33	565.35	565.58	565.89		565.96				566.02		
GW03-014A P1		553.74	554.39		518.40	524.47	542.89		547.90	550.21				552.12		
GW03-014A P2		466.25	466.41		464.54	464.69	465.40		465.69	465.99				466.31		
GW03-014A P3		547.20	547.12		547.21	547.30	547.31		547.39	546.72				546.74		
GW03-014B P4			557.98		557.92	557.95	556.58		556.21	554.84				553.70		

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-014B P5		559.57	559.65		559.37	558.42	555.32		555.17	552.53				553.37		
GW03-014B P6		559.57	559.71		559.39	558.44	555.35		555.22	552.63				553.42		
GW03-014C P7		558.17	557.96		557.99	558.03	557.69		554.04	554.76				553.28		
GW03-015A P1		559.75	560.48		559.96	559.10	556.56		556.74	554.34				555.18		
GW03-015A P2		555.77	555.64		547.89	551.50	554.86		554.71	553.29				553.45		
GW03-015A P3		437.68	437.05		435.91	436.09	437.20		437.83	438.31				438.93		
GW03-015B P4		560.33	560.85		560.37	559.75	557.05		557.31	554.54				555.72		
GW03-015B P5		559.76	560.46		559.93	558.93	556.51		556.72	554.16				555.13		
GW03-015B P6		559.78	560.49		559.91	558.82	556.41		556.56	553.96				555.06		
GW03-015C P7		559.24	559.28		559.04	558.59	556.77		556.68	554.77				554.41		
GW03-016A P1		559.68	559.90		558.73	559.36	557.05		557.24	555.16				555.89	554.79	556.58
GW03-016A P2		559.45	559.67		559.50	559.10	556.78		556.94	554.94				555.50	554.48	556.28
GW03-016A P3		559.42	559.31		558.81	558.65	556.91		556.65	555.21		555.71		554.74	553.70	555.59

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-016B P4		558.84	558.95		558.79	558.42	556.30		556.47	554.67		554.98		555.18	554.19	555.82
GW03-016B P5		559.27	559.19		559.18	558.75	556.58		556.76	555.40		556.39		555.05	554.43	555.86
GW03-016B P6		559.76	560.08		559.87	559.49	556.92		557.16	554.87		555.39		555.76	554.55	556.61
GW03-016C P7		558.44	558.54		558.41	558.05	556.02		556.17	554.45				554.94	553.96	555.98
GW03-016C P8		559.71	559.96		559.78	559.43	556.99		557.16	555.11		555.57		555.93	554.80	556.61
GW03-017A P1		560.43	559.87		560.07	559.63	557.72		558.01	557.16				556.67	555.68	557.28
GW03-017A P2		560.61	560.87		561.13	560.27	558.03		558.02	557.01				557.58	556.21	557.85
GW03-017A P3									421.46	424.48				430.02	433.43	436.19
GW03-017B P4		560.95	561.06		560.96	560.48	558.54		558.56	557.51				557.92	556.74	558.24
GW03-017B P5		560.78	560.92		560.90	560.32	558.37		558.38	557.31				557.77	556.62	558.11
GW03-017B P6		560.61	560.90		560.83	560.27	558.10		558.11	556.94				557.64	556.38	557.99
GW03-017C P7		560.87	560.86		560.89	560.38	558.42		558.50	557.50				557.79	556.70	558.15
GW03-017C P8		560.98	560.98		560.92	560.49	558.60		558.67	557.64				557.92	556.82	558.30

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TABLE 4.3.2-2 (CONT.)

MANUAL GROUNDWATER ELEVATIONS, OCTOBER THROUGH DECEMBER 2003

Location	10/3/03	10/6/03	10/10/03	10/13/03	10/17/03	10/20/03	11/3/03	11/10/03	11/11/03	11/18/03	11/19/03	11/21/03	11/24/03	11/25/03	12/1/03	12/8/03
GW03-017C P9		558.63	558.87		564.07	559.24			558.52	557.91				557.34	556.15	557.15
OW-650D		558.42	558.59		558.08	557.76	554.07		556.30	555.19				555.57		555.87
OW-139		558.45	558.59		558.44	558.03	555.90		556.08	554.32				554.89		555.53
GW03-018A P1	622.81	622.85		622.75	622.91	622.96	623.24	623.18		623.26			623.31			
GW03-018A P2	622.33	622.47		622.75	622.92	622.97	623.23	623.18		623.26			623.32			

All data recorded in feet elevation.
Vertical Datum shown is USLSD 1935.
[1]No water observed in well (persistently dry). Consequently no measurements recorded

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TABLE 4.3.3-1

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-001A P1	X	X	X															
GW03-001A P2	X	X	X															
GW03-002A P1	X	X	X															
GW03-002A P2	X	X	X															
GW03-003A P1	X	X	X															
GW03-003A P2	X	X	X															
GW03-004A P1	X	X	X															
GW03-004A P2	X	X	X															
GW03-005A P1		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-005A P2		X	X															
GW03-006A P1		X	X															
GW03-006B P2		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-006B P3																		
GW03-006B P4		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-006A P5		X	X															
GW03-007A P1		X	X															
GW03-007A P2		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-007A P3																		

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TABLE 4.3.3-1 (CONT.)

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-007B P4		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-007B P5		X	X															
GW03-008A P1		X	X															
GW03-008A P2		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-008A P3		X	X															
GW03-008B P4		X	X					X	X	X	X	X	X	X	X	X	X	X
GW03-008B P5		X	X															
GW03-008B P6		X	X															
GW03-009A P1				X	X													
GW03-009A P2				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-009A P3				X	X													
GW03-009B P4				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-009B P5				X	X													
GW03-009B P6				X	X													
GW03-010A P1				X	X													
GW03-010A P2				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-010A P3				X	X													
GW03-010B P4				X	X													
GW03-010B P5				X	X													

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TABLE 4.3.3-1 (CONT.)

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-010B P6				X	X													
GW03-010C P7				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-011A P1				X	X													
GW03-011A P2				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-011A P3				X	X													
GW03-011B P4				X	X													
GW03-011B P5				X	X													
GW03-011C P7				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-011C P8				X	X													
GW03-012A P1																		
GW03-012A P2				X	X			X	X	X	X	X	X	X	X	X	X	X
GW03-012A P3				X	X													
GW03-012B P4				X	X													
GW03-012B P5																		
GW03-012B P6				X	X													
GW03-012C P7				X	X													
GW03-013A P1						X	X											
GW03-013A P2						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-013A P3						X	X											

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TABLE 4.3.3-1 (CONT.)

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-013B P4						X	X											
GW03-013B P5						X	X											
GW03-013B P6						X	X											
GW03-013C P7						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-014A P1						X	X											
GW03-014A P2																		
GW03-014A P3						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-014B P4						X	X											
GW03-014B P5						X	X											
GW03-014B P6						X	X											
GW03-014C P7						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-015A P1						X	X											
GW03-015A P2						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-015A P3																		
GW03-015B P4						X	X											
GW03-015B P5						X	X											
GW03-015B P6						X	X											
GW03-015C P7						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-016A P1															X	X	X	X

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TABLE 4.3.3-1 (CONT.)

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-016A P2						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-016A P3															X	X	X	X
GW03-016B P4															X	X	X	X
GW03-016B P5															X	X	X	X
GW03-016B P6															X	X	X	X
GW03-016C P7						X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-016C P8															X	X	X	X
GW03-017A P1															X	X	X	X
GW03-017A P2															X	X	X	X
GW03-017A P3																		
GW03-017B P4															X	X	X	X
GW03-017B P5															X	X	X	X
GW03-017B P6															X	X	X	X
GW03-017C P7															X	X	X	X
GW03-017C P8															X	X	X	X
GW03-017C P9															X	X	X	X
OW-650D		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
OW-139				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
GW03-018A P1						X	X	X	X	X	X	X	X	X	X	X	X	X

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TABLE 4.3.3-1 (CONT.)

WELL AND PIEZOMETER MONITORING, DATALOGGER ROTATION SCHEDULE

Location	Comprehensive Intra-Nest Monitoring							Comprehensive Monitoring (Model Layers 2 & 10)								FST Investigation /Comprehensive Intra-Nest Monitoring		
	08/14/03	08/18/03	08/25/03	09/01/03	09/08/03	09/15/03	09/22/03	09/29/03	10/06/03	10/13/03	10/20/03	10/27/03	11/03/03	11/10/03	11/17/03	11/24/03	12/01/03	12/08/03
	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03
GW03-018A P2								X	X	X	X	X	X	X	X	X	X	X
Pump Station B CDS		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pump Station B Conduit #1		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pump Station A CDS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pump Station A Conduit #1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

1) No dataloggers were installed in wells GW03-006-P3 and GW03-012-P5 due to insufficient water levels.
2). No dataloggers were installed in GW03-012-P1 because the well was dry.
3) No dataloggers were installed in GW03-014-P2, GW03-015-P3 and GW03-017-P3 because water levels were greater than 100+feet below the surface which exceeded available cable lengths. In addition, these piezometers were out of the model.
4) No datalogger was installed in GW03-007-P3 due to a scheduling oversight.

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TABLE 4.5-1

SEPTEMBER - OCTOBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-001A-P1	10/02/03	Low-flow Peristaltic Pump		
GW03-001A-P2	10/7/03 & 10/8/03	Low-flow Submersible Pump	Took 2 days to collect total sample volume	
GW03-002A-P1	10/02/03	Low-flow Peristaltic Pump		
GW03-002A-P2	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-003A-P1	09/26/03	Low-flow Peristaltic Pump		
GW03-003A-P2	09/26/03	Low-flow Peristaltic Pump		
GW03-004A-P1	09/29/03	Low-flow Peristaltic Pump	Well purged dry on 9/26/03, sampled on 9/29/03	
GW03-004A-P2	09/29/03	Low-flow Peristaltic Pump		
GW03-005A-P1	10/06/03	Low-flow Peristaltic Pump		
GW03-005A-P2	10/08/03	Low-flow Submersible Pump	Well purged dry on 10/7/03, sampled on 10/8/03; limited sample volume (no SVOCs, pesticides, PCBs, or TCDD)	
GW03-006A-P1	10/01/03	Low-flow Peristaltic Pump	Sample labeled GW03-006B-P1	
GW03-006B-P2	10/01/03	Low-flow Peristaltic Pump	Sample labeled GW03-006A-P2	
GW03-006B-P3	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-006B-P4	10/3/03 & 10/8/03	Low-flow Peristaltic Pump	Well purged dry on 10/1/03; sampled on 10/3/03 and 10/8/03; labeled GW03-006A-P4	
GW03-006A-P5	10/01/03	Low-flow Peristaltic Pump	Sample labeled GW03-006B-P5	MS/MSD/MD (10/1/03)
GW03-007A-P1	10/01/03	Low-flow Peristaltic Pump		
GW03-007A-P2	10/02/03	Low-flow Peristaltic Pump		

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TABLE 4.5-1 (CONT.)

SEPTEMBER – OCTOBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-007A-P3	10/3/03 & 10/8/03	Low-flow Submersible Pump	Well purged dry on 10/2/03 and 10/7/03; sampled on 10/3/03 and 10/8/03	
GW03-007B-P4	10/01/03	Low-flow Peristaltic Pump		
GW03-007B-P5	10/14/03	Low-flow Peristaltic & Submersible Pumps	Well purged dry on 10/13/03, sampled on 10/14/03	
GW03-008A-P1	09/30/03	Low-flow Peristaltic Pump		
GW03-008A-P2	10/08/03	Low-flow Peristaltic Pump		
GW03-008A-P3	10/08/03	Low-flow Peristaltic Pump		
GW03-008B-P4	09/29/03	Low-flow Peristaltic Pump		
GW03-008B-P5	09/30/03	Low-flow Peristaltic Pump		
GW03-008B-P6	10/09/03	Low-flow Submersible Pump	Well purged dry on 10/8/03, sampled on 10/9/03	
GW03-009A-P1	09/29/03	Low-flow Peristaltic Pump		
GW03-009A-P2	10/09/03	Low-flow Submersible Pump		
GW03-009A-P3	10/13/03	Low-flow Submersible Pump		
GW03-009B-P4	09/29/03	Low-flow Peristaltic Pump		
GW03-009B-P5	09/29/03	Low-flow Peristaltic Pump		
GW03-009B-P6	09/30/03	Low-flow Peristaltic Pump		
GW03-010A-P1	10/09/03	Low-flow Submersible Pump		
GW03-010A-P2	10/13/03	Low-flow Submersible Pump		
GW03-010A-P3	10/14/03	Low-flow Submersible Pump	Well purged dry on 10/13/03; sampled on 10/14/03; limited volume (VOCs and TOC only)	
GW03-010B-P4	09/26/03	Low-flow Peristaltic Pump		
GW03-010B-P5	10/08/03	Low-flow Peristaltic Pump		
GW03-010B-P6	10/09/03	Low-flow Submersible Pump		
GW03-010C-P7	09/26/03	Low-flow Peristaltic Pump		
GW03-011A-P1	10/09/03	Low-flow Submersible Pump		

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TABLE 4.5-1 (CONT.)

SEPTEMBER – OCTOBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-011A-P2	10/14/03	Low-flow Submersible Pump		MS/MSD/MD (10/14/03)
GW03-011A-P3	10/13/03	Low-flow Submersible Pump		
GW03-011B-P4	09/25/03	Low-flow Peristaltic Pump		
GW03-011B-P5	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-011C-P7	09/25/03	Low-flow Peristaltic Pump		MS/MSD/MD (9/25/03)
GW03-011C-P8	09/25/03	Low-flow Peristaltic Pump		
GW03-012A-P1	NOT SAMPLED	----------	Well was dry	
GW03-012A-P2	10/10/03	Low-flow Submersible Pump		
GW03-012A-P3	10/15/03	Low-flow Submersible Pump	Well purged dry on 10/9/03 and 10/14/03	
GW03-012B-P4	NOT SAMPLED	----------	Well was essentially dry	
GW03-012B-P5	10/09/03	Low-flow Submersible Pump		
GW03-012B-P6	10/09/03	Low-flow Submersible Pump		
GW03-012C-P7	NOT SAMPLED	Bailer	Well purged dry and did not recover	
GW03-013A-P1	10/08/03	Low-flow Submersible Pump		
GW03-013A-P2	10/14/03	Low-flow Submersible Pump		MS/MSD/MD (10/14/03)
GW03-013A-P3	10/13/03	Low-flow Submersible Pump		
GW03-013B-P4	10/08/03	Low-flow Submersible Pump		
GW03-013B-P5	10/08/03	Low-flow Submersible Pump		
GW03-013B-P6	10/15/03	Low-flow Submersible Pump	Well purged dry on 10/10/03; sampled on 10/15/03; limited volume (VOCs, TOC, SVOCs, pesticides, metals, total hardness only)	
GW03-013C-P7	10/8/03 & 10/9/03 & 10/15/03	Bailer	Well purged dry on 10/8/03; then sampled recovery on 10/8/03, 10/9/03, and 10/15/03	

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TABLE 4.5-1 (CONT.)

SEPTEMBER – OCTOBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-014A-P1	10/14/03	Low-flow Submersible Pump	Well purged dry on 10/13/03; sampled on 10/14/03; limited volume (no bacteriological parameters or methyl mercury)	
GW03-014A-P2	10/14/03	Bailer	Well purged dry on 10/13/03; sampled on 10/14/03; limited volume (VOCs, SVOCs, metals, alkalinity, and total hardness only); lab missed total mercury analysis	
GW03-014A-P3	10/07/03	Low-flow Submersible Pump		
GW03-014B-P4	10/06/03	Low-flow Peristaltic Pump		
GW03-014B-P5	10/06/03	Low-flow Peristaltic Pump		
GW03-014B-P6	10/07/03	Low-flow Peristaltic Pump		
GW03-014C-P7	10/06/03	Low-flow Peristaltic Pump		
GW03-015A-P1	10/03/03	Low-flow Peristaltic Pump		
GW03-015A-P2	10/13/03	Low-flow Submersible Pump		
GW03-015A-P3	10/14/03	Bailer	Well purged dry on 10/14/03; then sampled recovery; limited volume (VOCs only)	
GW03-015B-P4	10/03/03	Low-flow Peristaltic Pump		
GW03-015B-P5	10/06/03	Low-flow Peristaltic Pump		
GW03-015B-P6	10/06/03	Low-flow Peristaltic Pump		
GW03-015C-P7	10/02/03	Low-flow Peristaltic Pump		
GW03-016A-P1	09/29/03	Low-flow Peristaltic Pump		
GW03-016A-P2	09/30/03	Low-flow Peristaltic Pump		
GW03-016A-P3	09/29/03	Low-flow Peristaltic Pump		
GW03-016B-P4	09/29/03	Low-flow Peristaltic Pump		
GW03-016B-P5	09/30/03	Low-flow Peristaltic Pump		

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TABLE 4.5-1 (CONT.)

SEPTEMBER – OCTOBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-016B-P6	09/30/03	Low-flow Peristaltic Pump		
GW03-016C-P7	09/30/03	Low-flow Peristaltic Pump		
GW03-016C-P8	09/30/03	Low-flow Peristaltic Pump		
GW03-017A-P1	10/02/03	Low-flow Submersible Pump		
GW03-017A-P2	09/24/03	Low-flow Peristaltic Pump		
GW03-017A-P3	NOT SAMPLED	----------	Low volume/not sampleable due to riser obstruction	
GW03-017B-P4	09/24/03	Low-flow Peristaltic Pump		
GW03-017B-P5	09/25/03	Low-flow Peristaltic Pump		
GW03-017B-P6	09/25/03	Low-flow Peristaltic Pump		
GW03-017C-P7	09/24/03	Low-flow Peristaltic Pump		MS/MSD/MD (9/24/03)
GW03-017C-P8	09/24/03	Low-flow Peristaltic Pump		
GW03-017C-P9	10/02/03	Low-flow Submersible Pump	Well pumped down to pump limit on 10/1/03, sampled on 10/2/03	
SW03-001	10/8/03 (10/28/03 resample)	Direct Submersion of Sample Bottles	Resampled for methyl mercury analysis on 10/28/03	
SW03-002	NOT SAMPLED	----------	No flowing water	
SW03-003	NOT SAMPLED	----------	No flowing water	
SW03-004	10/8/03 (10/28/03 resample)	Direct Submersion of Sample Bottles	Resampled for methyl mercury analysis on 10/28/03	
SW03-005	10/09/03	Direct Submersion of Sample Bottles		
SW03-006	10/07/03	Direct Submersion of Sample Bottles		
SW03-007	10/07/03	Bailer		
SW03-008	10/07/03	Peristaltic Pump		
SW03-009	10/07/03	Peristaltic Pump		
SW03-010	10/07/03	Direct Submersion of Sample Bottles		
SW03-011	10/09/03	Direct Submersion of Sample Bottles		MS/MSD/MD (10/9/03)

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TABLE 4.5-2

NOVEMBER-DECEMBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-001A-P1	12/08/03	Low-flow Peristaltic Pump		
GW03-001A-P2	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-002A-P1	12/09/03	Low-flow Peristaltic Pump		
GW03-002A-P2	12/12/03	Bailer	Well purged dry on 12/11/03, sampled on 12/12/03; limited sample volume (VOCs, TOC, metals, and bacteriological parameters only)	
GW03-003A-P1	12/02/03	Low-flow Peristaltic Pump		
GW03-003A-P2	12/02/03	Low-flow Peristaltic Pump		
GW03-004A-P1	12/03/03	Low-flow Peristaltic Pump	Well purged dry on 12/2/03, sampled on 12/3/03	
GW03-004A-P2	12/03/03	Low-flow Peristaltic Pump	Well purged dry on 12/2/03, sampled on 12/3/03	
GW03-005A-P1	12/04/03 (12/8/03)	Low-flow Peristaltic Pump	Resampled for bacteriological parameters on 12/8/03	MS/MSD/MD (12/2/03)
GW03-005A-P2	12/10/03	Low-flow Submersible Pump/Bailer	Well purged dry on 12/9/03; one of five wells to be analyzed for fecal coliform	
GW03-006A-P1	12/02/03	Low-flow Peristaltic Pump		
GW03-006B-P2	12/08/03	Low-flow Peristaltic Pump		
GW03-006B-P3	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-006B-P4	12/08/03	Low-flow Peristaltic Pump		
GW03-006A-P5	12/03/03	Low-flow Peristaltic Pump		
GW03-007A-P1	12/04/03	Low-flow Peristaltic Pump		
GW03-007A-P2	12/10/03	Low-flow Peristaltic Pump		
GW03-007A-P3	12/11/03	Low-flow Submersible Pump	Well purged dry on 12/10/03, sampled on 12/11/03	
GW03-007B-P4	12/04/03	Low-flow Peristaltic Pump		
GW03-007B-P5	12/11/03	Low-flow Submersible Pump	Well purged dry on 12/10/03, sampled on 12/11/03	
GW03-008A-P1	12/03/03	Low-flow Peristaltic Pump		
GW03-008A-P2	12/04/03	Low-flow Peristaltic Pump		

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TABLE 4.5-2 (CONT.)

NOVEMBER-DECEMBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-008A-P3	12/03/03	Low-flow Peristaltic Pump		
GW03-008B-P4	12/03/03	Low-flow Peristaltic Pump		
GW03-008B-P5	12/03/03	Low-flow Peristaltic Pump		
GW03-008B-P6	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-009A-P1	12/05/03	Low-flow Peristaltic Pump		
GW03-009A-P2	12/05/03	Low-flow Submersible Pump		
GW03-009A-P3	12/16/03	Low-flow Submersible Pump		
GW03-009B-P4	12/05/03	Low-flow Peristaltic Pump		
GW03-009B-P5	12/05/03	Low-flow Peristaltic Pump		
GW03-009B-P6	12/08/03	Low-flow Peristaltic Pump		
GW03-010A-P1	12/04/03	Low-flow Submersible Pump		
GW03-010A-P2	12/03/03	Low-flow Submersible Pump		
GW03-010A-P3	12/19/03	Low-flow Submersible Pump	Well purged dry on 12/18/03, sampled on 12/19/03	
GW03-010B-P4	12/02/03	Low-flow Peristaltic Pump		
GW03-010B-P5	12/03/03	Low-flow Peristaltic Pump		
GW03-010B-P6	12/03/03	Low-flow Submersible Pump		
GW03-010C-P7	12/02/03	Low-flow Peristaltic Pump		
GW03-011A-P1	12/02/03	Low-flow Submersible Pump		
GW03-011A-P2	12/02/03	Low-flow Submersible Pump		
GW03-011A-P3	12/03/03	Low-flow Submersible Pump		
GW03-011B-P4	12/02/2003 (12/3/03)	Low-flow Peristaltic Pump	Resampled for SVOC, pesticide, PCB, and TCDD fractions on 12/3/03	
GW03-011B-P5	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-011C-P7	12/02/03	Low-flow Peristaltic Pump		
GW03-011C-P8	12/03/03	Low-flow Peristaltic Pump		
GW03-012A-P1	NOT SAMPLED	----------	Well was dry	
GW03-012A-P2	12/16/03	Low-flow Submersible Pump		
GW03-012A-P3	12/19/03	Low-flow Submersible Pump		

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TABLE 4.5-2 (CONT.)

NOVEMBER-DECEMBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-012B-P4	12/17/03	Bailer	Well purged dry on 12/16/03, sampled on 12/17/03; limited sample volume (VOCs, TOC, alkalinity, and hardness only)	
GW03-012B-P5	12/16/03	Low-flow Submersible Pump	Well purged dry on 12/15/03, sampled on 12/16/03	
GW03-012B-P6	12/16/03	Low-flow Submersible Pump		
GW03-012C-P7	12/15/03	Low-flow Peristaltic Pump		
GW03-013A-P1	12/04/03	Low-flow Submersible Pump		
GW03-013A-P2	12/04/03	Low-flow Submersible Pump		
GW03-013A-P3	12/08/03	Low-flow Submersible Pump		
GW03-013B-P4	12/04/03	Low-flow Submersible Pump		
GW03-013B-P5	12/04/03	Low-flow Submersible Pump		
GW03-013B-P6	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-013C-P7	12/05/03	Bailer		
GW03-014A-P1	12/15/03	Low-flow Submersible Pump	Well purged dry on 12/9/03, sampled on 12/15/03	
GW03-014A-P2	12/18/03	Bailer	Well purged dry on 12/9/03, sampled on 12/18/03; limited sample volume (no SVOCs, pesticides, PCBs, or TCDD)	
GW03-014A-P3	12/18/03	Low-flow Submersible Pump		
GW03-014B-P4	12/05/03	Low-flow Peristaltic Pump		
GW03-014B-P5	12/08/03	Low-flow Submersible Pump		MS/MSD/MD (12/3/03)
GW03-014B-P6	12/08/03	Low-flow Submersible Pump		
GW03-014C-P7	12/04/03	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015A-P1	12/08/03	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015A-P2	12/10/03	Low-flow Submersible Pump		
GW03-015A-P3	12/09/03	Bailer		
GW03-015B-P4	12/08/03	Low-flow Peristaltic Pump		
GW03-015B-P5	12/10/03	Low-flow Peristaltic Pump		

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TABLE 4.5-2 (CONT.)

NOVEMBER-DECEMBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-015B-P6	12/09/03	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015C-P7	12/09/03	Low-flow Peristaltic Pump		
GW03-016A-P1	12/12/03	Low-flow Peristaltic Pump		
GW03-016A-P2	12/16/03	Low-flow Peristaltic Pump		MS/MSD/MD (12/16/03)
GW03-016A-P3	12/11/03	Low-flow Peristaltic Pump		
GW03-016B-P4	12/12/03	Low-flow Peristaltic Pump		
GW03-016B-P5	12/17/03	Low-flow Peristaltic Pump		
GW03-016B-P6	12/15/03	Low-flow Peristaltic Pump		
GW03-016C-P7	12/15/03	Low-flow Peristaltic Pump		MS/MSD/MD (12/12/03)
GW03-016C-P8	12/17/03	Low-flow Peristaltic Pump		
GW03-017A-P1	12/17/03	Low-flow Submersible Pump		
GW03-017A-P2	12/12/03	Low-flow Peristaltic Pump		MS/MSD/MD (12/8/03)
GW03-017A-P3	12/18/03	HDPE tubing with check valve	Limited volume (VOCs only)	
GW03-017B-P4	12/10/03	Low-flow Peristaltic Pump		
GW03-017B-P5	12/11/03	Low-flow Peristaltic Pump		
GW03-017B-P6	12/11/03	Low-flow Peristaltic Pump		
GW03-017C-P7	12/10/03	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-017C-P8	12/15/03	Low-flow Peristaltic Pump		
GW03-017C-P9	12/18/03	Low-flow Submersible Pump	Well purged dry on 12/17/03, sampled on 12/18/03	
SW03-001	11/24/03	Direct Submersion of Sample Bottles		
SW03-002	11/25/03	Direct Submersion of Sample Bottles		
SW03-003	NOT SAMPLED	----------	No flowing water	
SW03-004	11/25/03	Direct Submersion of Sample Bottles		
SW03-005	11/24/03	Direct Submersion of Sample Bottles		

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TABLE 4.5-2 (CONT.)

NOVEMBER-DECEMBER 2003 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
SW03-006	11/24/03	Direct Submersion of Sample Bottles		
SW03-007	11/24/03	Bailer		
SW03-008	11/25/03	Peristaltic Pump		
SW03-009	11/25/03	Peristaltic Pump		
SW03-010	11/25/03	Direct Submersion of Sample Bottles		MS/MSD/MD (11/25/03)
SW03-011	11/24/03	Direct Submersion of Sample Bottles		
GW03-001A-P1	12/08/03	Low-flow Peristaltic Pump		
GW03-001A-P2	NOT SAMPLED	Low-flow Submersible Pump	Well purged dry and did not recover	
GW03-002A-P1	12/09/03	Low-flow Peristaltic Pump		
GW03-002A-P2	12/12/03	Bailer	Well purged dry on 12/11/03, sampled on 12/12/03; limited sample volume (VOCs, TOC, metals, and bacteriological parameters only)	

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TABLE 4.5-3

MARCH 2004 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-001A-P1	2/26/04	Low-flow Peristaltic Pump		
GW03-001A-P2	2/27/04	Low-flow Submersible Pump		
GW03-002A-P1	2/26/04	Low-flow Peristaltic Pump		
GW03-002A-P2	NOT SAMPLED	----------		
GW03-003A-P1	3/1/04	Low-flow Peristaltic Pump		
GW03-003A-P2	3/2/04	Low-flow Peristaltic Pump		
GW03-004A-P1	3/1/04 (3/8/04 & 3/9/04)	Low-flow Peristaltic Pump	Sampled on 3/1/04 (insufficient volume to collect samples for pesticides or dioxin). Purged dry on 3/8/04, returned 3/9/04 however not enough volume to collect sample.	
GW03-004A-P2	3/1/04	Low-flow Peristaltic Pump		
GW03-005A-P1	3/10/04	Low-flow Peristaltic Pump		MS/MSD/MD
GW03-005A-P2	3/11/04	Bailer	Well purged on 3/10/04, sampled 3/11/04. One of five wells to be analyzed for fecal coliform	
GW03-006A-P1	3/2/04	Low-flow Peristaltic Pump		
GW03-006B-P2	3/3/04	Low-flow Peristaltic Pump		
GW03-006B-P3	NOT SAMPLED	----------	Water level below pump. Unable to purge.	
GW03-006B-P4	3/3/04	Low-flow Peristaltic Pump		
GW03-006A-P5	3/3/04	Low-flow Peristaltic Pump		
GW03-007A-P1	2/24/04	Low-flow Peristaltic Pump		
GW03-007A-P2	3/1/04	Low-flow Peristaltic Pump		
GW03-007A-P3	2/27/04	Low-flow Submersible Pump	Well purged to level below pump on 2/25/04. Returned 2/26/04, insufficient water. Sampled on 2/27/04.	
GW03-007B-P4	2/26/04	Low-flow Peristaltic Pump		
GW03-007B-P5	2/26/04	Low-flow Submersible Pump	Well purged on 2/25/04, battery failed on pump. Returned and sampled 2/26/04.	

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TABLE 4.5-3 (CONT.)

MARCH 2004 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-008A-P1	3/2/04	Low-flow Peristaltic Pump		
GW03-008A-P2	3/2/04	Low-flow Peristaltic Pump		
GW03-008A-P3	3/2/04	Low-flow Peristaltic Pump		
GW03-008B-P4	3/1/04	Low-flow Peristaltic Pump		
GW03-008B-P5	3/2/04	Low-flow Peristaltic Pump		
GW03-008B-P6	NOT SAMPLED	----------	Water level below pump.	
GW03-009A-P1	3/5/04	Low-flow Peristaltic Pump		MS/MSD/MD
GW03-009A-P2	3/8/04	Low-flow Submersible Pump		
GW03-009A-P3	3/10/04	Low-flow Submersible Pump		
GW03-009B-P4	3/3/04	Low-flow Peristaltic Pump		
GW03-009B-P5	3/3/04	Low-flow Peristaltic Pump		
GW03-009B-P6	3/3/04	Low-flow Peristaltic Pump		MS/MSD/MD
GW03-010A-P1	2/25/04	Low-flow Submersible Pump		
GW03-010A-P2	2/27/04	Low-flow Submersible Pump		
GW03-010A-P3	3/2/04	Low-flow Submersible Pump	Well purged dry on 3/1/04, sampled on 3/2/04	
GW03-010B-P4	3/1/04	Low-flow Peristaltic Pump		
GW03-010B-P5	3/1/04	Low-flow Peristaltic Pump		
GW03-010B-P6	3/1/04	Low-flow Submersible Pump		
GW03-010C-P7	3/1/04	Low-flow Peristaltic Pump		
GW03-011A-P1	3/4/04	Low-flow Submersible Pump		
GW03-011A-P2	3/4/04	Low-flow Submersible Pump		
GW03-011A-P3	3/4/04	Low-flow Submersible Pump		
GW03-011B-P4	3/3/04	Low-flow Peristaltic Pump		MS/MSD/MD
GW03-011B-P5	NOT SAMPLED	----------	Well pumped dry on 3/3/04. Bailed approximately 2 liters on 3/4/04. Returned on 3/5/04 bailer would not hold water.	
GW03-011C-P7	3/4/04	Low-flow Peristaltic Pump		
GW03-011C-P8	3/3/04	Low-flow Peristaltic Pump		
GW03-012A-P1	NOT SAMPLED	----------	Well was dry on 3/4/04.	
GW03-012A-P2	3/3/04	Low-flow Submersible Pump		
GW03-012A-P3	3/4/04	Low-flow Submersible Pump		

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TABLE 4.5-3 (CONT.)

MARCH 2004 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-012B-P4	NOT SAMPLED		Well was dry on 3/3/04.	
GW03-012B-P5	3/3/04	Low-flow Submersible Pump		
GW03-012B-P6	3/3/04	Low-flow Submersible Pump		
GW03-012C-P7	3/3/04	Bailer		
GW03-013A-P1	2/26/04	Low-flow Submersible Pump		
GW03-013A-P2	2/25/04	Low-flow Submersible Pump		MS/MSD/MD
GW03-013A-P3	2/26/04	Low-flow Submersible Pump		
GW03-013B-P4	2/24/04	Low-flow Submersible Pump		
GW03-013B-P5	2/26/04	Low-flow Submersible Pump		
GW03-013B-P6	2/27/04	Bailer	Well purged dry on 2/26/04. Limited sample volume (analyzed for VOCs, alkalinity, and TOC) on 2/27/04.	
GW03-013C-P7	2/26/04	Bailer	Limited sample volume (no SVOCs, pesticides, PCBs, dioxin).	
GW03-014A-P1	2/27/04	Low-flow Submersible Pump	Well purged dry on 2/26/04, sampled on 2/27/04.	
GW03-014A-P2	3/4/04	Bailer	Well purged dry on 3/2/04, sampled on 3/4/04.	
GW03-014A-P3	3/1/04	Low-flow Submersible Pump		
GW03-014B-P4	2/27/04	Low-flow Peristaltic Pump		MS/MSD/MD
GW03-014B-P5	2/25/04	Low-flow Submersible Pump		
GW03-014B-P6	2/25/04	Low-flow Submersible Pump		MS/MSD/MD
GW03-014C-P7	2/26/04	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015A-P1	3/5/04	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015A-P2	3/10/04	Low-flow Submersible Pump and Bailer	Pump malfunctioned on 3/5/04, bailed dry. Bailed dry on 3/904, sampled 3/10/04.	

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TABLE 4.5-3 (CONT.)

MARCH 2004 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
GW03-015A-P3	3/9/04	Bailer	Well bailed dry on 3/8/04, sampled 3/9/04. Limited volume (no pesticides and dioxin).	
GW03-015B-P4	3/4/04	Low-flow Peristaltic Pump		
GW03-015B-P5	3/8/04	Low-flow Peristaltic Pump		
GW03-015B-P6	3/9/04	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-015C-P7	3/8/04	Low-flow Peristaltic Pump		
GW03-016A-P1	3/4/04	Low-flow Peristaltic Pump		
GW03-016A-P2	3/5/04	Low-flow Peristaltic Pump		
GW03-016A-P3	3/8/04	Low-flow Peristaltic Pump		
GW03-016B-P4	3/4/04	Low-flow Peristaltic Pump		
GW03-016B-P5	3/5/04	Low-flow Peristaltic Pump		
GW03-016B-P6	3/9/04	Low-flow Peristaltic Pump		
GW03-016C-P7	3/4/04	Low-flow Peristaltic Pump		
GW03-016C-P8	3/4/04	Low-flow Peristaltic Pump		
GW03-017A-P1	2/24/04	Low-flow Submersible Pump		
GW03-017A-P2	3/1/04	Low-flow Peristaltic Pump		
GW03-017A-P3	NOT SAMPLED	----------	Purged on 3/4/04, returned 3/5/04, insufficient volume of water to sample.	
GW03-017B-P4	2/24/04	Low-flow Peristaltic Pump		
GW03-017B-P5	2/24/04	Low-flow Peristaltic Pump		
GW03-017B-P6	2/26/04	Low-flow Peristaltic Pump		
GW03-017C-P7	2/24/04	Low-flow Peristaltic Pump	One of five wells to be analyzed for fecal coliform	
GW03-017C-P8	2/24/04	Low-flow Peristaltic Pump		
GW03-017C-P9	2/26/04	Low-flow Submersible Pump	Pump failed, replaced, purged on 2/24- and 2/25/04.	
SW03-001	3/8/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	
SW03-002	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	MS/MSD/MD
SW03-003	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	

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TABLE 4.5-3 (CONT.)

MARCH 2004 GROUNDWATER/SURFACE WATER SAMPLING EVENT SAMPLE SUMMARY

Sample ID	Date Sampled	Purging/Sampling Method	Comments	QA/QC Samples
SW03-004	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	
SW03-005	3/8/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	
SW03-006	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	
SW03-007	3/9/04	Bailer	Analyzed for fecal coliform	
SW03-008	3/9/04	Peristaltic Pump	Analyzed for fecal coliform	
SW03-009	3/9/04	Peristaltic Pump	Analyzed for fecal coliform	
SW03-010	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	
SW03-011	3/9/04	Direct Submersion of Sample Bottles	Analyzed for fecal coliform	

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TABLE 4.5-4

SUMMARY OF GROUNDWATER/SURFACE WATER SAMPLE ANALYTICAL PARAMETERS

Parameter	Method Number Reference
Target Compound List (TCL) Volatile Organic Compounds (VOCs)	SW8260B[1]
TCL Semivolatile Organic Compounds (SVOCs)	SW8270C[1]
TCL Pesticides	SW8081A[1]
TCL Polychlorinated Biphenyls (PCBs)	SW8082[1]
Total Arsenic, Cadmium, Calcium, Lead, Magnesium, Potassium, and Sodium	SW6010[1]
Total Mercury	SW7470A[1]
Methyl Mercury*	USEPA 1630, Modified[2]
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	SW8290[1]
Total Organic Carbon (TOC)	USEPA 415.1[3]
Total Dissolved Solids (TDS)	USEPA 160.1[3]
Total Suspended Solids (TSS)	USEPA 160.2[3]
Total Hardness	USEPA 130.2[3]
Inorganic Ions (chloride and sulfate)	USEPA 300.0[3]
Alkalinity (carbonate and bicarbonate)	USEPA 310.1[3]
Total Coliforms	SM 9222B[4]
E. coli	SM 9222B[4]
Heterotrophic Plate Count	SM 9215B[4]
Fecal Coliform**	SM 9222D[4]

*Not all groundwater samples were analyzed for methyl mercury.
**Fecal coliform analyses were only performed on five of the December 2003 groundwater samples.

References:

[1]NYSDEC Analytical Services Protocol, June 2000 Edition, which contains *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW846)*, Third Edition, Final Update III, USEPA, June 1997.

[2]Modified *Method 1630, Methyl Mercury in Water by Distillation, Aqueous Ethylation, Purge and Trap, and CVAFS, Draft,* USEPA, August 1998.

[3]*Methods for the Chemical Analysis of Water and Wastes* (MCAWW), EPA/600/4-79/020, revised March 1983.

[4]*Standard Methods for the Examination of Water and Wastewater, 20th Edition, APHA/AWWA/WEF, 1998.*

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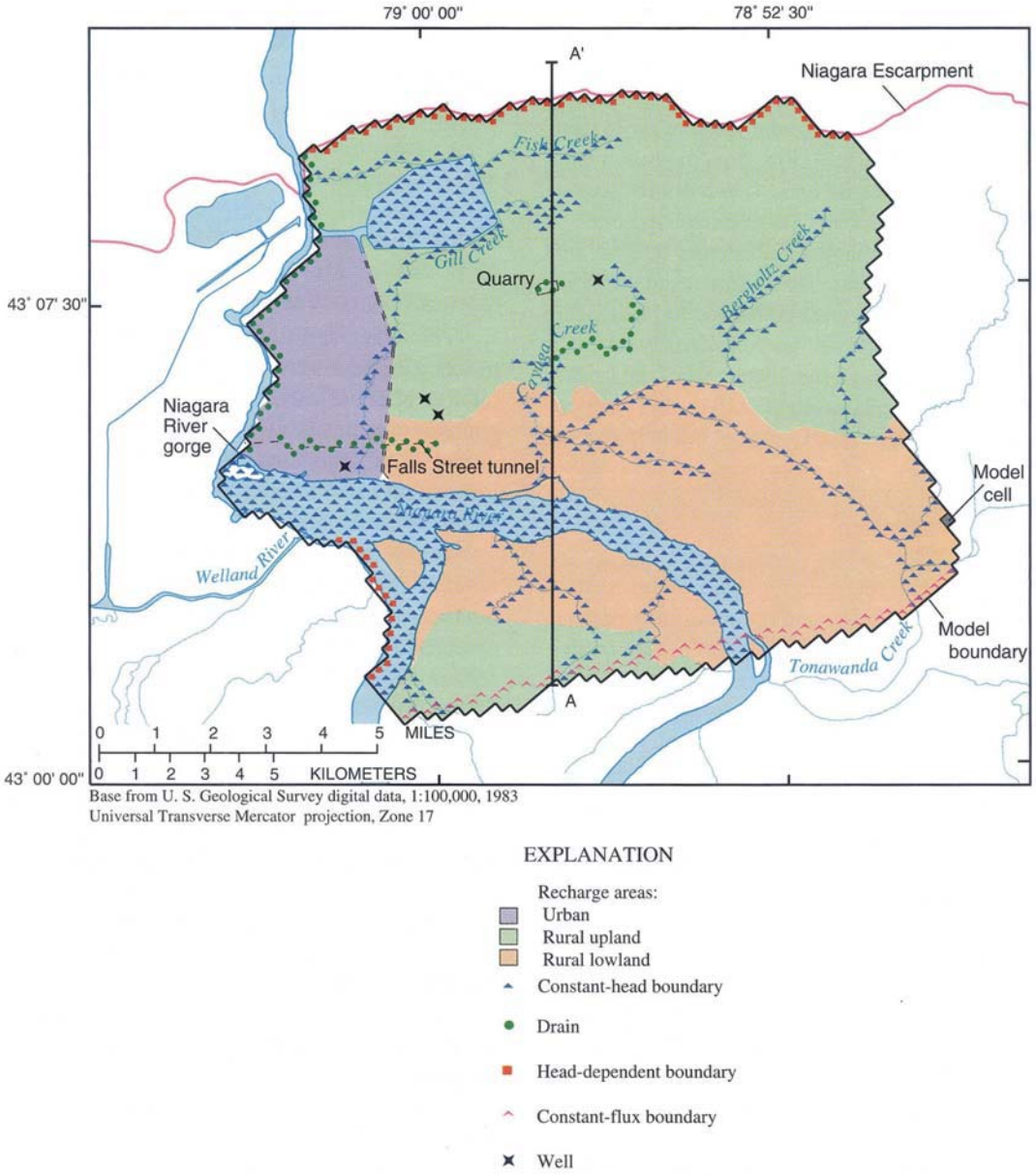
FIGURE 4.1.1-1

MODEL DOMAIN AND BOUNDARY CONDITIONS



Source: Yager 1996

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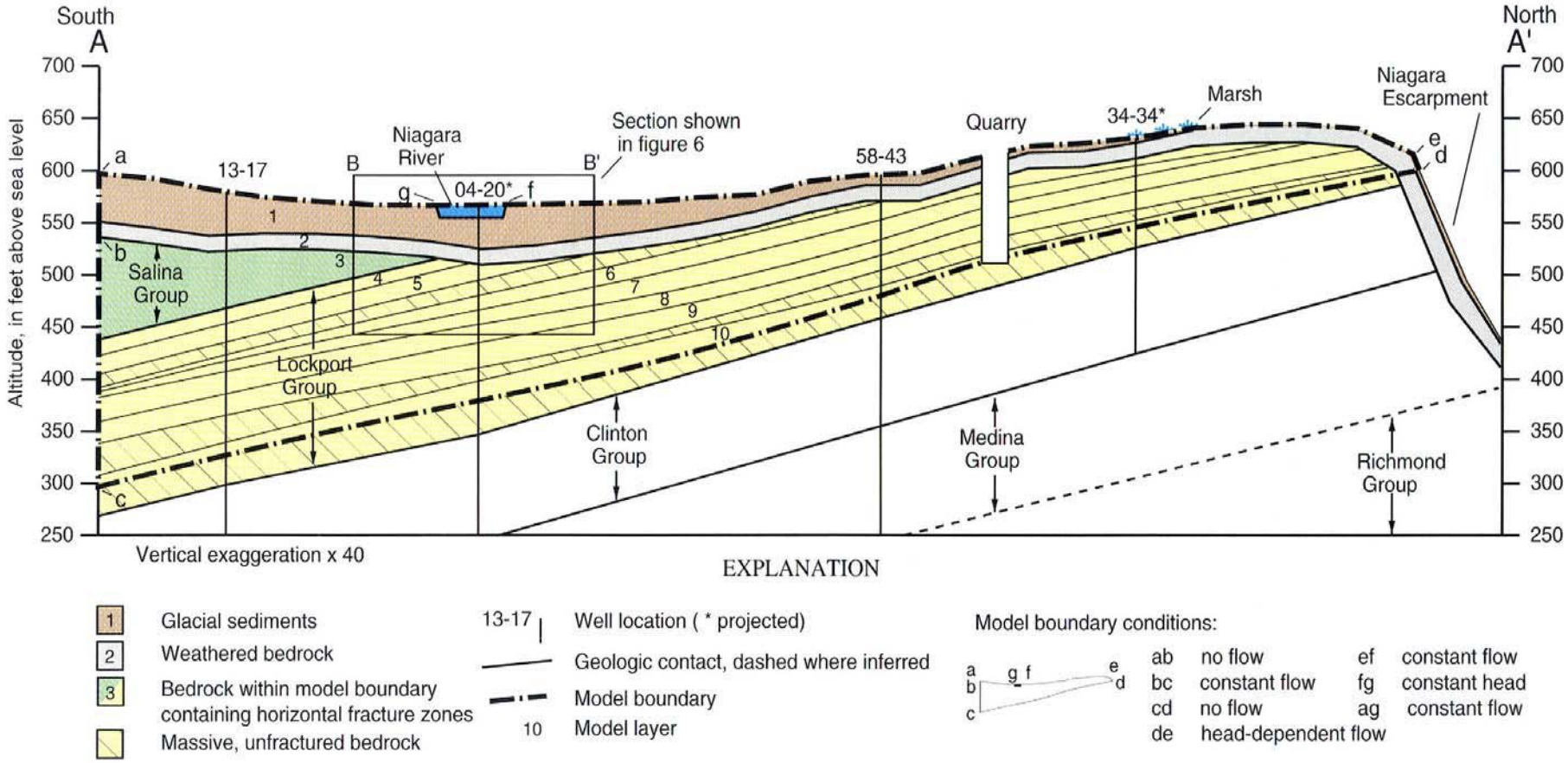
FIGURE 4.1.1-2

GENERALIZED SECTION SHOWING EXTENT OF MODEL LAYERS AND MODEL BOUNDARY CONDITIONS



Source: Yager 1996

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FIGURE 4.1.1-3

HYDRAULIC HEADS IN WEATHERED BEDROCK (MODEL LAYER 2), CALIBRATED USGS 1996 MODEL

[NIP – General Location Maps]

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FIGURE 4.1.1-4

HYDRAULIC HEADS IN GASPORT DOLOMITE (MODEL LAYER 10), CALIBRATED USGS 1996 MODEL

[NIP – General Location Maps]

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FIGURE 4.1.1-5

AREAS CONTRIBUTING TO DISCHARGE LOCATIONS IN WEATHERED BEDROCK (MODEL LAYER 2), CALIBRATED USGS 1996 MODEL

[NIP – General Location Maps]

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FIGURE 4.1.1-6

AREAS CONTRIBUTING TO DISCHARGE LOCATIONS IN GASPORT DOLOMITE (MODEL LAYER 10), CALIBRATED USGS 1996 MODEL

[NIP – General Location Maps]

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FIGURE 4.1.2-1

HYDRAULIC HEADS IN WEATHERED BEDROCK (MODEL LAYER 2), GMS MODEL

[NIP – General Location Maps]

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FIGURE 4.1.2-2

HYDRAULIC HEADS IN GASPORT DOLOMITE (MODEL LAYER 10), GMS MODEL

[NIP – General Location Maps]

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FIGURE 4.1.2-3

HYDRAULIC HEADS IN ERAMOSA DOLOMITE (MODEL LAYER 8), GMS MODEL

[NIP – General Location Maps]

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FIGURE 4.1.2-4

HYDRAULIC HEADS IN GOAT ISLAND DOLOMITE (MODEL LAYER 9), GMS MODEL

[NIP – General Location Maps]

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FIGURE 4.1.3-1

DOMAIN OF THE FOCUSED MODEL

[NIP – General Location Maps]

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FIGURE 4.1.4-1

HYDRAULIC HEADS IN WEATHERED BEDROCK (MODEL LAYER 2), FOCUSED MODEL

[NIP – General Location Maps]

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FIGURE 4.1.4-2

HYDRAULIC HEADS IN ERAMOSA DOLOMITE (MODEL LAYER 8), FOCUSED MODEL

[NIP – General Location Maps]

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FIGURE 4.1.4-3

HYDRAULIC HEADS IN GOAT ISLAND DOLOMITE (MODEL LAYER 9), FOCUSED MODEL

[NIP – General Location Maps]

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FIGURE 4.1.4-4

HYDRAULIC HEADS IN GASPORT DOLOMITE (MODEL LAYER 10), FOCUSED MODEL

[NIP – General Location Maps]

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FIGURE 4.2.1-1

PIEZOMETER AND SURFACE WATER SAMPLING LOCATIONS

[NIP – General Location Maps]

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FIGURE 4.2.3-1

SCHEMATIC DIAGRAM OF STRADDLE PACKER ASSEMBLY

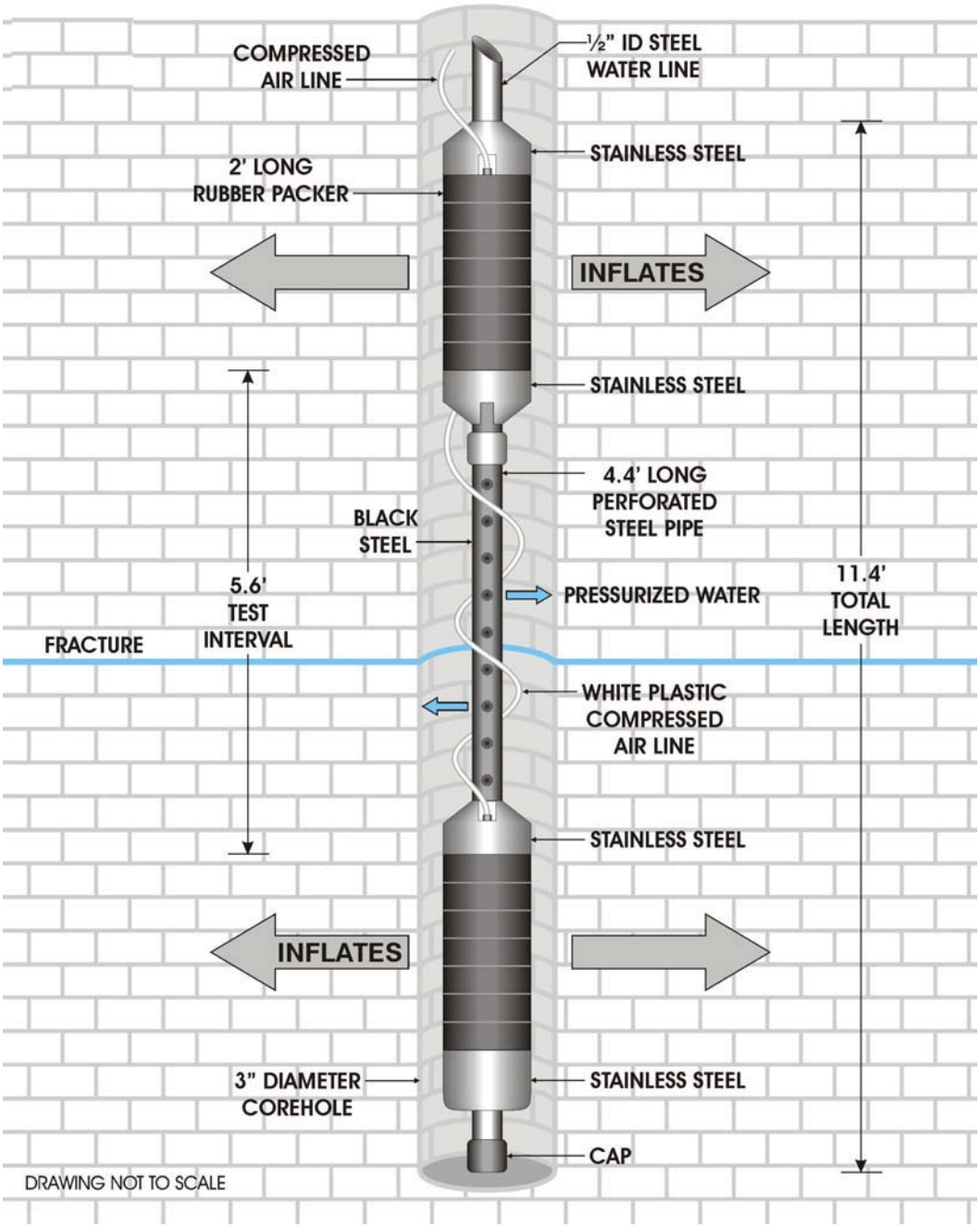

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FIGURE 4.2.4-1

TYPICAL NESTED PIEZOMETER CONSTRUCTION

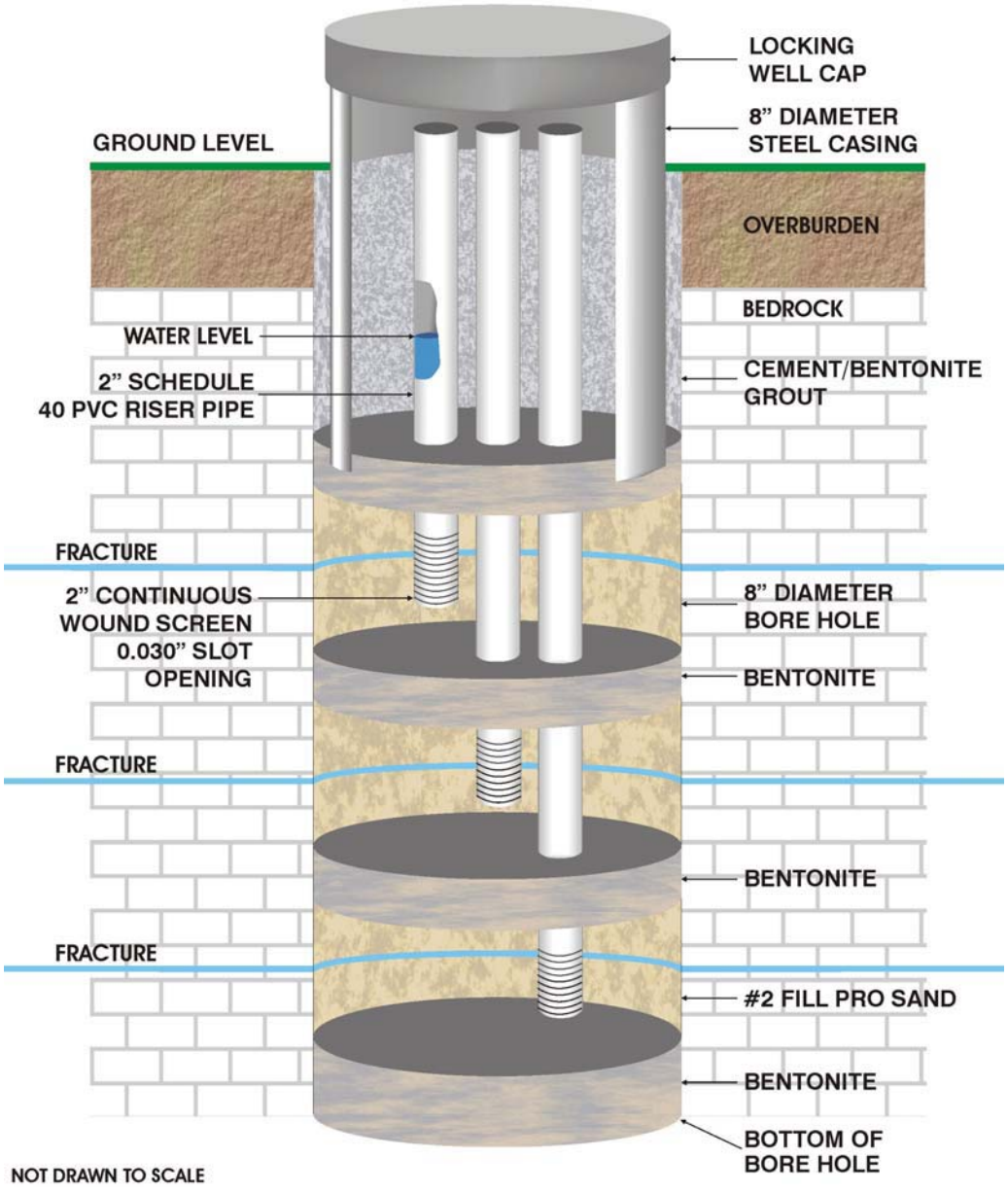

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FIGURE 4.3-1

CONDUIT MONITORING WELLS, STAFF GAUGES, PUMP STATIONS, AND PIEZOMETERS

[NIP – General Location Maps]

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FIGURE 4.3-2

RESERVOIR DIKE MONITORING WELLS

[NIP – General Location Maps]

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FIGURE 4.3.3-1

SCHEMATIC DIAGRAM OF ELECTRONIC DATALOGGER CONFIGURATION

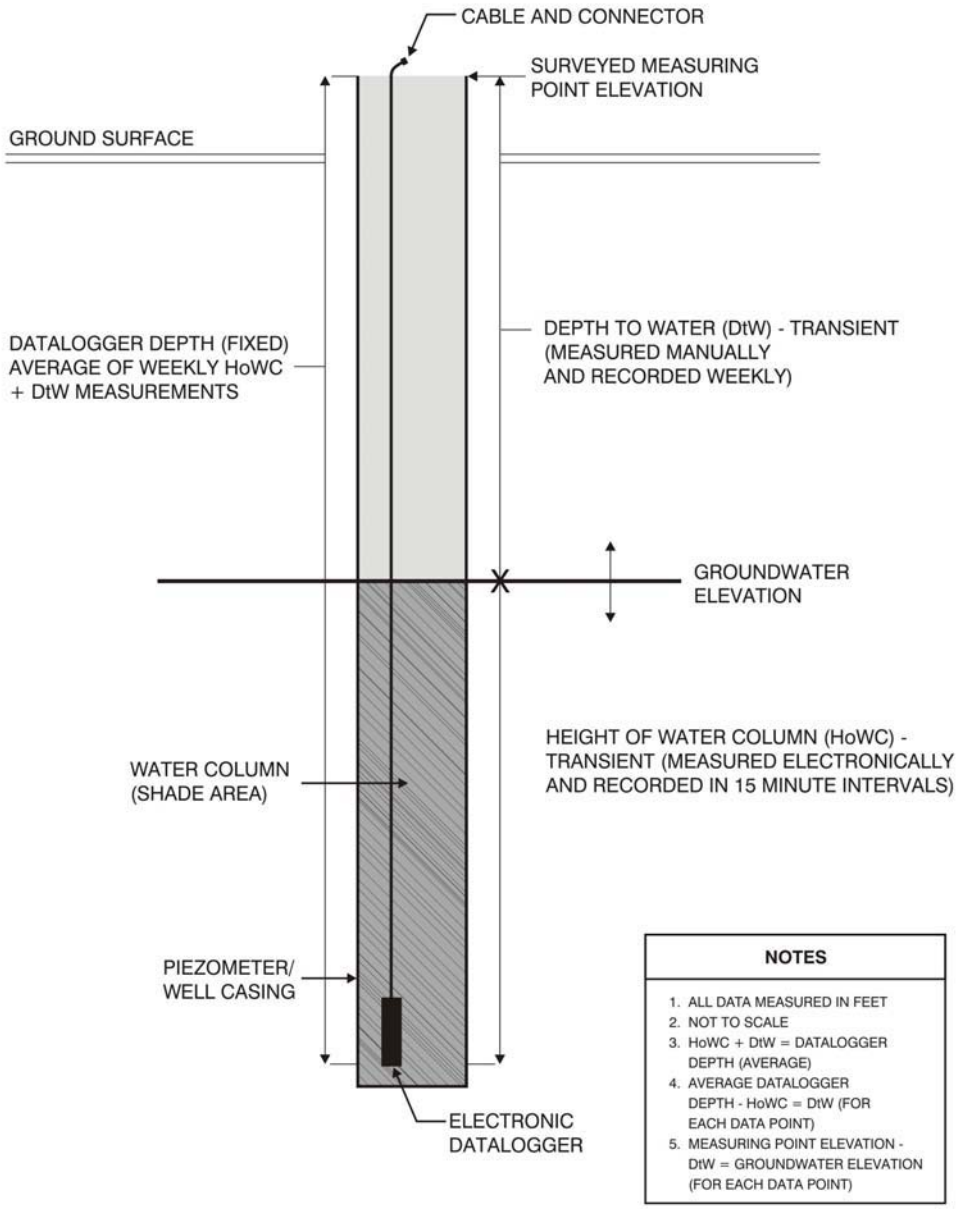

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FIGURE 4.3.5-1

LOCATION OF ESCARPMENT SEEP RECONNAISSANCE

[NIP – USGS Topographic Maps]

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FIGURE 4.3.5-2

AREA OF FISH CREEK RECONNAISSANCE

[NIP – USGS Topographic Maps]

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FIGURE 4.3.5-3

AREA OF GILL CREEK RECONNAISSANCE

[NIP – USGS Topographic Maps]

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FIGURE 4.4.1-1

FST/SSI SYSTEM LAYOUT

[NIP – General Location Maps]

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FIGURE 4.4.4-1

SSI INTERCEPTOR FLOW METER SETUP

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FIGURE 4.4.5-1

MEASURING WEIR FLOW METER SETUP

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5.0 RESULTS

5.1 Modeling Results

5.1.1 Objectives of the Modeling Effort

As mentioned in Section 4.1, the objective of the focused modeling effort was to investigate the groundwater flow regime within the vicinity of the Lewistion Reservoir, and the objective of the regional modeling effort was to investigate the groundwater flow regime in the area surrounding the NYPA conduits.

5.1.2 Application of the Focused Model: Groundwater Flow Regime in the Reservoir Vicinity

The focused model was applied to investigate the flow regime in the area east of the Lewiston Reservoir.

The Lewiston Reservoir was constructed by creating a berm and filling the space enclosed by the berm with water from the Niagara River. Elevation of the water surface in the reservoir varies in response to the operation of the Project. It is, therefore, generally higher than the natural potentiometric surface in the surrounding aquifer and has a potential of being a major source of water for the Lockport aquifer. Based on the groundwater flow model described previously, the magnitude of the flow from the reservoir into the bedrock is on the order of 1,000 gpm.

The water from the reservoir is thought to infiltrate downward into the fractured bedrock immediately below (model Layer 2). From there, it flows both horizontally and vertically between the different water-bearing zones. A grout curtain has been constructed around the reservoir in the upper bedrock. The grout curtain cannot, however, eliminate this flow, but only reduce its magnitude.

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The groundwater model simulates the interaction of the reservoir infiltration with the natural flow regime within the Lockport aquifer. The model can be therefore used to determine to what extent natural flow is affected by the reservoir. Particle-tracking was employed into the model to accomplish this task.

Using the model, simulated particles were introduced into the flow field at the top of Layer 2 (fractured bedrock) beneath the Lewiston Reservoir. These particles reside directly in the path of water infiltrating from the reservoir into the aquifer. Tracking particle movement is therefore equivalent to visualizing the movement of water originating in the reservoir. The particles were followed to their discharge points. Particle paths were used to delineate the section of the Lockport aquifer receiving reservoir water.

The groundwater flow model developed by USGS represents long-term average, steady-state conditions. The conditions are set by the magnitude of stresses applied to the system—recharge, pumping, stream stages and water level in the reservoir. In applying the focused model, all stresses were maintained at their long-term average levels. The exception was the Lewiston Reservoir.

Water level in the reservoir fluctuates on a daily and weekly basis. The amplitude of fluctuation over the course of a week is approximately 38 feet. In order to estimate the upper and lower bound of the reservoir influence, reservoir levels from the entire range of possible values were imposed on the long-term average aquifer conditions. Three simulations were performed: low reservoir level of El. 620 feet, average reservoir level of El. 640 feet and high reservoir level of El. 660 feet. This is a very conservative approach. Reservoir levels never remain at extreme stages for long periods (less than 15% of the time), a condition that would be required to establish equilibrium with the surrounding aquifer. The envelope of reservoir influence on local flow patterns obtained as a result of this modeling effort were therefore exaggerated.

Each of the three simulations was performed in two stages. First, a given elevation of water surface in the reservoir was entered into the regional model. Once the solution of the regional hydraulic heads was obtained, the heads were contoured onto the focused model domain. In this manner, specified

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heads at the southern and southwestern boundaries of the focused model were allowed to vary with change in the reservoir stage. Following this, the focused model was activated, generating the flow field in the study area. Particles were inserted at the reservoir bottom and were tracked to their discharge locations. Particle paths were used to delineate the area of reservoir influence.

An example of the visual output is presented in Figure 5.1.2-1. The envelope of the influence area based on all three simulations is shown in Figure 5.1.2-2. Under average long-term conditions, water from the reservoir migrates only about 1,500 feet to the east of the reservoir. Regional flow from the northeast, as well as flow infiltrating into the aquifer within the wetland at the head of Gill Creek, east of the reservoir, create a hydraulic barrier, preventing further migration of the reservoir water. The influence of reservoir level on the outcome is negligible. This phenomenon is expressed as a groundwater divide east of the reservoir.

Figures 5.1.2-3 through 5.1.2-6 show hydraulic heads in four model layers occurring within the study area. These are, from top to bottom: weathered bedrock (model layer 2), Eramosa dolomite (model layer 8), Goat Island dolomite (model layer 9), and Gasport dolomite (model layer 10). Within the weathered bedrock, Eramosa dolomite, and Goat Island dolomite, water infiltrating the aquifer from the Lewiston Reservoir initially flows to the east. The infiltrating water encounters regional westward flow from the area of the Tuscarora Lands. A groundwater divide forms approximately 1,500 feet east of the reservoir, with the infiltrating water either discharging into local streams or being redirected to the north or south. In the deepest modeled stratum (Gasport dolomite), the influence of the reservoir is negligible. The regional westward flow direction is preserved throughout the study area.

5.1.3 Application of the Regional Model: Groundwater Flow Regime in the Conduit Vicinity

The drainage system constructed around the Power Authority conduits constitutes a significant factor in shaping of the flow patterns in the study area. Following the conduits, the drainage system cuts through the entire thickness of the Lockport Dolomite along the northern part of the conduits. However, because the aquifer strata dip to the south, three lowest layers are located below the southern section of

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the conduits and are not in direct contact with the conduit drainage system. These layers are the Eramosa dolomite, Goat Island dolomite, and Gasport dolomite.

Modeled hydraulic heads in the Eramosa dolomite, Goat Island dolomite, and Gasport dolomite are shown in Figures 5.1.3-1 through 5.1.3-3.

In the northern portion of the conduit alignment, where the conduits intersect the entire aquifer, the conduit drainage system serves as a major sink. Groundwater discharges into the system both from the east (Tuscarora Lands and Lewiston Reservoir) and from the west (City of Niagara Falls). In the southern section the significance of the conduit drainage as a sink appears to decrease. In the vicinity of the FST and farther south towards the Niagara River, groundwater flows away from the conduits on the west side. It appears that the flow in the deep portion of the Lockport aquifer in that area is dominated by the industrial extraction wells, located approximately 4,000 feet west of the conduits. Based on local flow directions, it also appears that some flow may pass underneath the conduits from east to west, in the direction roughly parallel to the Niagara River.

5.2 Results of Drilling Program/Hydrogeology

Continuous rock core samples were taken at 17 locations across the study area shown in Figure 4.2.1-1. Detailed rock core descriptions were recorded and compared to published descriptions of the stratigraphy of the Niagara region. Individual rock strata were correlated among piezometer locations. The geologic cross-sections constructed from the rock core descriptions show the stratigraphy and geological structure across the study area. The geologic cross-sections are presented in Figures 5.2-1 through 5.2-4. Boring logs from the piezometers are included in Appendix B.

Fractures observed in the rock core samples were compared to regional fractures identified in published reports. Equivalent fracture intervals were traced between piezometer clusters. Packer testing conducted at 10 selected piezometers was also employed to assist in identifying permeable water-bearing

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zones in the bedrock. Piezometer screens were subsequently installed to straddle the regional water-bearing horizons based on the rock core analysis and packer test data (see Section 4.2.4-1).

5.2.1 General Stratigraphy

The Niagara region is underlain by sedimentary rocks 1,980-3,000 feet thick (Tesmer, 1981). The upper 290 feet of these rocks are exposed in the Niagara gorge. The rocks exposed in the gorge are Ordovician (oldest) to Silurian (youngest) in age, deposited 415-430 million years ago. The piezometers installed during this investigation monitor a section of the Silurian rock consisting of dolomite, limestone and shales from the Clinton and Lockport Groups. A group is a stratigraphic term for an assemblage of related layers of rock. A group is subdivided into formations that are identifiable by distinctive lithologic (rock type) characteristics and stratigraphic (same-time) sequence. Formations are mappable at the surface and traceable in the subsurface. A formation normally consists of a geographic name (e.g., Goat Island) followed by the dominant rock type (e.g. dolomite). Formations are typically named for the geographic location of the type section, or the outcropping section deemed to be representative of the stratigraphic unit, where the strata were originally described. Formations can be subdivided into members. A member may be formally defined and named. It combines a geographic name (e.g., Pekin) and the word 'member'. A member is higher in stratigraphic nomenclature rank than a bed.

5.2.1.1 Detailed Stratigraphy

This report follows the stratigraphic nomenclature for the Clinton and Lockport Groups recently revised by USGS (Brett et al. 1995). A generalized stratigraphic column for the Clinton and Lockport Group rocks is shown in Figure 2.1.3-3.

As defined in the USGS report, the Clinton Group is divided into eight formations. The two uppermost Clinton formations (Rochester shale and overlying DeCew dolomite) were penetrated to varying degrees by piezometers installed during the groundwater flow study.

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The Lockport Group is divided into four formations listed from bottom to top (i.e., oldest to youngest): the Gasport Formation (dolomite), the Goat Island Formation (dolomite), the Eramosa Formation (dolomite), and the Guelph Formation (dolomite).

The Gasport Formation consists of two members: the Gothic Hill Member (lower) and the Pekin Member (upper).

The Goat Island Formation contains three members: Niagara Falls Member (lower), the Ancaster Member, and the Vinemount Member (upper).

The Eramosa Formation is not formally divided into members, but is instead broken into six major units termed A through F.

The Guelph Formation, encountered at only two piezometer locations (GW03-016 and –017, in the southern part of the investigation area) is not formally divided into members.

5.2.1.2 Lithology

The rock cores were described in detail on individual boring logs included in Appendix B. Features noted while describing the cores included rock type, color, grain-size, degree of weathering, presence of fossils, mineralization (calcite, dolomite, gypsum, galena, pyrite, and sphalerite), visible porosity (pits, voids, and small openings called vugs), and features like vertical and horizontal fractures.

Rock type, color, grain-size variations, bedding thickness, and degree of fracturing were noted in different formations. In addition, lateral variations in lithology were noted within the same formation.

The rocks encountered during the drilling program were primarily dolomite (Guelph, Eramosa, Goat Island, Gasport, and DeCew Formations). The dolomite was sometimes shaly (containing clay), and

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in this case was referred to as argillaceous dolomite. The Rochester Formation was described as a calcareous or dolomitic shale.

A general lithologic description for the Clinton and Lockport Group strata is provided below.

5.2.1.2.1 Clinton Group

Rochester Formation

Dark gray, or gray brown, medium hard to hard, very fine to fine, argillaceous dolomite grading to shale. It contains a few pyrite-filled vugs.

DeCew Formation

Medium to dark gray or dark gray brown, occasionally olive green, very fine to fine, hard argillaceous dolomite with shaly or carbonaceous partings (about ¼-inch thick). It contains a few shaly nodules, rip-up clasts, and jagged pressure solution features called stylolites.

5.2.1.2.2 Lockport Group

Gasport Formation

Gothic Hill Member: gray grading to brown, sometimes mottled, fine to medium, sometimes coarse-grained, dolomite. Becomes argillaceous in thin dark gray or black shaly beds. These beds are often wavy. The Gothic Hill is mostly thick-bedded. It contains some fragments of crinoid fossils. It has small vugs filled with calcite and a few very thin carbonaceous partings and a few stylolites.

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Pekin Member: light to dark gray, brown or gray brown, fine or very fine-grained dolomite. It contains a few thin coarse-grained beds and thin argillaceous zones but is mostly thick-bedded. The Pekin contains some vugs filled with gypsum and calcite, a few carbonaceous partings, and a few stylolites.

Goat Island Formation

Niagara Falls Member: Color varies from light brown to dark gray brown, fine-grained dolomite. It has some thin black argillaceous beds, and vugs filled with gypsum, calcite, and sphalerite (or rarely pyrite). Crinoid fossil fragments were occasionally seen.

Ancaster Member: Mostly brown but can be brown gray, fine to medium grained dolomite with numerous irregular shaped light brown or light gray chert nodules. It has discontinuous wavy argillaceous bands, some coral or crinoid fragments, some gypsum- or sphalerite-filled vugs.

Vinemount Member: Dark brown or dark gray, mostly fine or some times very fine, dolomite. The Vinemount has dark gray or black argillaceous wavy thin beds. Some very thin gypsum bands were noted along bedding planes, as well as small vugs filled with calcite, dolomite, sphalerite, or pyrite.

Eramosa Formation

Eramosa A: Mostly medium gray, sometimes gray brown, very fine to fine, occasionally medium-grained dolomite. It has small to large vugs filled with various minerals but some are not filled. Some porosity is pinpoint size. It has a few stylolites, and some very thin, dark gray argillaceous beds.

Eramosa B: Dark brown or gray brown, mostly fine dolomite with mostly horizontal but some very wavy beds. It has a few thin argillaceous beds or carbonaceous partings. Vugs may be mineral-filled or open.

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Eramosa C: Dark brown to medium gray brown, mostly fine but has very fine to medium grains. It contains a few black carbonaceous partings, and stylolites. Cross-bedding was noted in the rock core at one piezometer location and a small mound-like reef-related bioherm was noted in the rock core from another piezometer location. It has a few mineralized vugs.

Eramosa D: Dark brown or gray, sometimes light or medium brown, fine dolomite with numerous vugs. High-angle carbonaceous partings were observed in one piezometer.

Eramosa E: Dark brown fine to medium-grained dolomite.

Eramosa F: Dark brown fine to medium dolomite with some gypsum or sphalerite-filled vugs. Contains a few stylolites.

Guelph Formation

Medium gray or dark brown, fine to medium dolomite with some vugs and some gypsum along bedding planes.

5.2.2 Structural Geology

The geological cross-sections (Figures 5.2-1, 5.2-3, and 5.2-4) show that rock layers in the investigation area are inclined (dipping) to the south, at a low angle, dropping about 30 feet over the course of a mile. This shallowly dipping structure is termed a homocline. The homocline has been slightly deformed and is not uniformly dipping.

The rock layers from piezometer location GW03-011 north to GW03-003 dip at a steeper angle than rock layers south of GW03-011. At GW03-003 the direction of dip changes to the north (Figure 5.2-4). This piezometer was located near the crest of a small fold called an anticline.

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5.2.2.1 Fractures

Fractures in the Lockport Group consist of vertical planar cracks (often called joints) or horizontal bedding plane separations. Fractures can be observed in bedrock exposed in the Niagara gorge, at several outcrops on the Niagara escarpment, and in the LaFarge Redland quarry. A smaller number of vertical fractures was encountered in rock cores in the boreholes drilled in the 2003 groundwater study. Numerous horizontal and vertical breaks were seen in the rock cores, particularly in the weathered upper 10-20 feet of bedrock.

Horizontal fractures where dolomite or gypsum deposits have been dissolved along bedding planes can transmit significant amounts of water. Individual bedding plane fractures have been traced up to 4 miles (Johnston 1964). Kappel and Tepper (1992) noted fractures being developed near lithologic contacts of members and formations that are planes of weakness in the Lockport. Kappel and Tepper (1992) attributed the origin of the fracture zones as an unloading phenomenon where fractures developed after the weight of overlying rock was removed by erosion, and when Pleistocene-age glacial ice sheets melted. A result of this unloading phenomenon, called isostatic rebound, was observed in the northern hemisphere after glaciers retreated from the area. Glacial lake shorelines in Canada were mapped as tilted to the south (Holmes 1965), indicating that the crust had slowly risen after the enormous weight of the glacial ice sheet was removed.

Johnston (1964) identified seven significant bedding plane fractures in the Niagara region. Some of the horizontal fracture zones in massive (3- to 6-feet thick or more) rock zones are isolated from other bedding plane fractures. Piezometers in these isolated fracture zones have abruptly different static water elevations than upper or lower fractures. Other fracture zones are interconnected by open vertical fractures. Fracture zones may consist of multiple individual horizontal fractures in a relatively thin vertical section.

Packer test results and rock core samples were used to correlate significant horizontal fracture zones between boreholes across the study area. Nine horizontal bedding plane water-bearing fracture

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zones in the Lockport Group and upper Clinton were identified from the results of the drilling program. The nine zones correspond to six zones identified by Johnston (1964), two zones identified by Yager (1996), and an upper weathered bedrock zone.

Four extensive bedding plane fractures were found within the Eramosa Formation. A significant bedding plane fracture separates the Eramosa from the underlying Goat Island Formation. One regional bedding plane fracture was identified within the Goat Island dolomite. A significant bedding plane fracture was found at the boundary of the Goat Island and underlying Gasport dolomite. A single regional fracture was found at the contact between the Gasport and underlying DeCew Formation. Figure 5.2.2-1 shows the relationship between the model layers, stratigraphy, and piezometer screens.

A well-connected network of vertical fractures linking horizontal fractures occurs in the upper 10 -25 feet of the bedrock (Yager and Kappel 1987). Leakage between the horizontal fractures zones has been noted at industrial waste sites in Niagara Falls where dense contaminants have migrated down through vertical fractures to lower zones in the bedrock (Yager and Kappel 1987).

5.2.3 Packer Test Results

Packer testing background and methods was described in Section 4.2.3. One hundred seventy nine tests were conducted on ten piezometer boreholes during June and July 2003. Packer test results are included in Appendix J.

Before the packer testing began it was thought that the lower formations tested (i.e., DeCew and Rochester formations) would be impermeable and that little or no water could be injected into these zones. It was also thought that testing would show several thin permeable zones where regional horizontal fractures are separated by thicker impermeable unfractured rock. It was anticipated that the upper weathered zone, where numerous fractures were identified in the rock cores, would require large volumes of water during testing.

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Testing at several piezometer locations showed that the lower impermeable zone often extended much higher than anticipated into rock layers above the DeCew Formation. Packer testing in other piezometer locations of the equivalent rock layers above the DeCew revealed permeable zones containing horizontal fractures. It was concluded from the packer test data that some of the horizontal water-bearing fractures have variable water-transmitting ability where permeable areas are separated laterally by relatively impermeable sections.

Packer testing also showed that, at some piezometer locations, permeable rock sections were much thicker than anticipated. Six piezometer locations (GW03-010, -011, -013, -015, -016 and -017) packer tested in the southern portion of the study area showed about 60% of the test zones to be permeable (greater than 0.5 gpm injected). The most permeable zones tested took from 10 to 16 gpm of injected water. Four of the piezometer locations (GW03-013, -015, -016, and -017) with higher permeability zones were drilled close to the conduit. Blasting during conduit construction may have fractured surrounding rock some distance from the conduit excavation. As a result, these piezometers may have been installed in more permeable fractured rock than the surrounding, intact rock farther from the conduit.

In comparison, piezometer locations in the northern portion of the study area (GW03-001, -003, -005, and -007) showed only a few permeable zones compared to six piezometer locations tested to the south. In the northern area about 70% of the tests were conducted in low-permeability zones, defined as rock sections into which less than 0.5 gpm of water was injected. Piezometers at these locations were constructed in sections of the Gasport, DeCew and Rochester Formations that had few horizontal fractures.

5.2.4 Water-Bearing Zones

Nine regional water-bearing horizontal fracture zones were identified and targeted as intervals to be monitored by piezometers for this investigation. These zones include six water-bearing zones identified by Johnston (1964) and two upper zones identified by Yager (1996). The fracture horizons also

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include an upper weathered interval within the top 10 to 15 feet of the bedrock. Most of the water-bearing zones are continuous across the length of the study area except where they have been eroded and are missing in the area's northern portion. The Lockport Group is also thinner as a result of erosion in this area. The wells installed in this area are shallower than those to the south, and are screened in only a few fracture zones. A map showing eroded layers of the Lockport Group strata, extending from the southern end of the Lewiston Reservoir, north to the escarpment is presented in Figure 5.2.4-1. Glacial sediments cover this eroded portion of the Lockport Group. This configuration is referred to as a bedrock subcrop or a subsurface outcrop.

Regional horizontal water-bearing fractures are represented by groundwater model layers established in the original 1996 USGS groundwater flow model (Yager 1996). The model layers are shown in Figure 2.1.3-6, which is a generalized cross-section depicting the relationship between the groundwater model layers, stratigraphy, and the groundwater monitoring wells installed as part of this investigation.

A brief discussion of correlations between each model layer and the water-bearing zones identified as part of this investigation is presented below:

- Layer 2 – represents the upper weathered bedrock water-bearing zone. It is present throughout the modeled area, and is independent of stratigraphy. This zone ranges in depth over the entire investigation area from approximately 15 to 30 feet bgs.
- Layer 6 – represents the water-bearing zone identified at the stratigraphic contact between Units E and D of the Eramosa dolomite. This zone is only present at well location GW03-017 at a depth of approximately 48 feet bgs.
- Layer 7 – represents the water-bearing zone identified at the stratigraphic contact between Units D and C of the Eramosa dolomite. This zone is only present at well location GW03-017 at a depth of approximately 60 feet bgs.

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reservoir, this zone ranges in depth from approximately 25 to 130 feet bgs, while along the conduits this zone ranges in depth from approximately 130 to 160 feet bgs.

Fracture zones were identified during the groundwater study by examining rock cores and describing their lithology and natural fracturing (i.e., fracturing not caused by drilling). Some fractures identified in the rock cores were correlated to regional water-bearing fractures identified by Johnston (1964) and Yager (1996). These regional fracture zones occur at the contact between several members in the Eramosa and Goat Island Formations. Where regional fracture zones could not be identified in the rock cores, lithology descriptions and packer test data were used to select piezometer screen depths. Lithologic characteristics were used to correlate Lockport Group formations and member rock units across the study area. Piezometers were installed at the stratigraphic contacts where regional fracture zones had been identified by Johnston (1964) and Yager (1996) but were not discernible in the rock cores. Permeable zones identified in packer tests were used to select some piezometer screen intervals. These zones were often located close to stratigraphic contacts where regional fracture zones had been previously identified by Johnston (1964) and Yager (1996). The depth where drilling fluid losses occurred was generally used to select piezometer screen intervals in the upper weathered bedrock zone (Layer 2), where fracturing is most extensive.

During construction of the conduit, Johnston (1964) noted that individual fractures could be traced laterally for distances of one to four miles. He also observed that a water-bearing zone consisted of either a single opening or of several open bedding planes. The water-bearing zones were seen to occur primarily in thin-bedded intervals (about 1/4 to 4 inches thick), which are overlain by thick, massive beds. Where water-bearing zones occur within thick-bedded rock they are isolated within a single fracture.

Johnston also noted places along a prominent water-bearing zone where no seepage was taking place. He concluded these areas act as supporting zones for the open, productive portion of the fracture zone. Variations in piezometer yield were noted during groundwater sampling. Sampling personnel purged several piezometers that yielded limited quantities of water. Most of these piezometers were screened in the lowest fracture zone, where the Gasport dolomite and underlying DeCew are in contact.

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- Layer 8 – represents two water-bearing zones identified at the stratigraphic contacts between Units C and B, and Units B and A of the Eramosa dolomite. For the purposes of discussing groundwater analytical results, this model layer has been divided into model layers 8A (upper screened interval at the Eramosa C/Eramosa B contact) and 8B (lower screened interval at the Eramosa B/Eramosa A contact). Along the conduits, Layer 8A ranges in depth from approximately 45 to 80 feet bgs, and Layer 8B ranges in depth from approximately 60 to 90 feet bgs.
- Layer 9 – represents two water-bearing zones identified at the stratigraphic contacts between the Eramosa dolomite and the Goat Island dolomite, and between the Vinemount Member and the Ancaster Member of the Goat Island dolomite. For purposes of discussing groundwater analytical results, this model layer has been divided into model layers 9A (upper screened interval at the Eramosa/Goat Island contact) and 9B (lower screened interval at the Vinemount/Ancaster contact). Near the reservoir Layer 9A ranges in depth from approximately 23 to 65 feet bgs, and Layer 9B ranges in depth from approximately 32 to 85 feet bgs. Along the conduits, these layers range in depth from approximately 70 to 100 feet bgs (Layer 9A), and 85 to 120 feet bgs (Layer 9B), respectively.
- Layer 10 – represents a group of water-bearing zones identified at or near the stratigraphic contact between the Goat Island dolomite and the Gasport dolomite. Layer 10 is the deepest layer included in the groundwater flow model. Near the reservoir, this zone ranges in depth from approximately 45 to 100 feet bgs. Along the conduits, this zone ranges in depth from approximately 100 to 135 feet bgs.
- Gasport/DeCew Contact – this water-bearing zone, which was identified below the deepest groundwater flow model layer, represents a water-bearing zone at the stratigraphic contact between the Gasport dolomite of the Lockport Group and the DeCew dolomite of the Clinton Group. Near the

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The static water levels in these wells are easily drawn down during purging and the wells slowly recharge. Johnston (1964) noted that this fracture zone is open locally. Several other low-yield piezometers were screened in the middle of the Lockport. These piezometers were located between higher yielding piezometers. The lateral variations in permeability and piezometer yield within the same fracture interval were observed during pump tests in the Lockport at the Necco Park Landfill (DuPont et al. 2002).

Groundwater in the Lockport Group is under artesian, semi-artesian and unconfined conditions (Johnston 1964). Artesian flow was seen temporarily at GW03-005 after coring was completed.

5.2.5 Groundwater

Groundwater samples were collected from 84 of 91 piezometers at 17 nested piezometer locations during three quarterly sampling events, one conducted from September 24 to October 14, 2003, the second conducted from December 2 to 18, 2003, and the third conducted from February 24 to March 10, 2004.

Groundwater samples were collected from the following piezometers.

Borehole A	Borehole B	Borehole C
GW03-001A- P1, P2		
GW03-002A- P1, P2		
GW03-003A- P1, P2		
GW03-004A- P1, P2		
GW03-005A- P1, P2		
GW03-006A- P1, P5	GW03-006B-P2, P4	
GW03-007A- P1, P2, P3	GW03-007B-P4, P5	
GW03-008A- P1, P2, P3	GW03-008B-P4, P5, P6	
GW03-009A- P1, P2, P3	GW03-009B-P4, P5, P6	
GW03-010A- P1, P2, P3	GW03-010B-P4, P5, P6	GW03-010C-P7
GW03-011A-P1, P2, P3	GW03-011B-P4, P5	GW03-011C- P7, P8
GW03-012A- P1, P2, P3	GW03-012B-P4, P5, P6	GW03-012C- P7
GW03-013A- P1, P2, P3	GW03-13B-P4, P5, P6	GW03-013C- P7
GW03-014A- P1, P2, P3	GW03-014B-P4, P5, P6	GW03-014C- P7

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GW03-015A- P1, P2, P3	GW03-015B-P4, P5, P6	GW03-015C- P7
GW03-016A- P1, P2, P3	GW03-016B-P4, P5, P6	GW03-016C- P7, P8
GW03-017A- P1, P2, P3	GW03-017B-P4, P5, P6	GW03-017C- P7, P8, P9

As mentioned in Section 4.5.2-1, during the October event, four piezometers (GW03-002- P2, GW03-012- P4, GW03-012- P7, and GW03-017- P3) could not be sampled because of low water volume. During the December event four piezometers (GW03-001- P2, GW03-008- P6, GW03-013- P6, and GW03-015- P3) could not be sampled, also because of low water volume. Three other piezometers (GW03-006- P3, GW03-011-P5, and GW03-012-P1) could not be sampled in either event because of low water volume.

5.2.6 Natural Gases

Natural gases (e.g., methane and hydrogen sulfide) were encountered while drilling several boreholes across the study area (Table 5.2.6-1). Hydrogen sulfide (H_2S) gas was noticeable at the wellhead by its characteristic odor (rotten eggs). Well site geologists were also equipped with a hand-held photoionizing device (PID) that can detect concentrations of explosive gases (like methane), oxygen, carbon monoxide, and H_2S. High H_2S PID readings caused well site geologists to halt air hammer reaming at GW03-011 out of safety concerns, and the boring was completed using mud rotary drilling methods.

A significant methane accumulation was encountered while coring GW03-016, driving borehole water several feet above ground surface while retrieving a core barrel from the Rochester Formation at 164.7 feet. Drilling was halted temporarily. Temporary fencing was staked around the borehole location and labeled with caution signs. Methane from the borehole was allowed to vent overnight. By the following day, methane concentration at the ground surface had dropped to safe levels.

Low levels of methane that had not been noticed during drilling operations were reported during groundwater sampling. Methane was noted by groundwater samplers at several locations as bubbles rising to the surface water, or as gas that accumulated under the piezometer cap. Sampling personnel also

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noted "sulfur" or H_2S odors from piezometers where such an odor had not been noticed during drilling. H_2S was often mixed with varying concentrations of methane. Gray or black-tinted water was also noted by the sampling team as associated with sulfur or H_2S zones.

Well site geologists and groundwater samplers noted methane, H_2S, and gray- or black-tinted water at 12 drilling locations. The gases were noted in piezometers monitoring different stratigraphic zones and were not limited to a single zone. The gas-bearing zones span a thickness of over 130 feet. An H_2S odor was noticed at a relatively shallow depth (28-33 feet) in GW03-006. Methane and sulfur odors were also noticed as deep as 164 feet in GW03-016.

The significant accumulation of methane in the piezometer monitoring the Rochester Formation may indicate that the formation is a petroleum source rock. That is, the shale may have contained organic material that was heated sufficiently over a period of geologic time to generate methane gas. The methane accumulation encountered by the GW03-016 piezometer was probably limited in extent and volume because of the low porosity and permeability of the Rochester shale.

Most of the methane and H_2S encountered in the piezometers in the Lockport Group is probably the result of biological processes active in the subsurface. Methane can be formed by bacterial degradation of organic-rich material (Hunt 1979). H_2S can be formed by the reduction of sulfates in minerals like gypsum found in the Lockport Group to sulfides by bacteria (Levorsen 1967).

5.3 Water Level Monitoring Results

5.3.1 New Wells

Groundwater elevation measurements were recorded from 91 newly installed bedrock piezometers at 17 locations (GW03-001 through GW03-0017) throughout the investigation area and from two overburden piezometers at one location (GW03-018) in the wetland at the head of Gill Creek within

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the Tuscarora Nation (see Figure 4.2.1-1). Groundwater levels were measured using both manual and electronic methods.

Plots of both manual and continuous electronic elevation data versus time are presented in Figures 1 through 18 in Appendix K. Elevation averages for all piezometers arranged by measurement method (datalogger or manual) and by season (tourist and non-tourist) and with combined averages are provided in Table 5.3.1-1.

Manual water level measurements were made on September 26, 2003 and November 17/18, 2003. They represent conditions for tourist and non-tourist season, respectively. Figures 19 through 22 in Appendix K are geologic cross-sections showing water elevations for September 26 (tourist season). Figures 23 through 26 in Appendix K are geologic cross-sections showing water elevations for the November 17/18 (non-tourist season). Additionally, plan view plots of September 26, 2003 and November 17/18, 2003 manual water level data are presented for selected water-bearing zones (Appendix K, Figures 27 through 32)

5.3.2 Existing Wells

Groundwater elevation data were recorded from previously installed monitoring wells located within the project area (OW-139 and OW-650D) using both manual and electronic methods (see Figure 4.3-1). Plots of recorded elevation data are presented in Figures 5.3.2-1 and 5.3.2-2. Data for these two locations was only collected till December 8, 2003.

5.3.3 Pump Stations

Plots of the electronic water elevation data recorded within Pump Stations A and B are presented on Figures 5.3.3-1 and 5.3.3-2, respectively. Manual water level data are not included in the plots since only a single calibration measurement was taken at the time of initial installation.

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5.3.4 NYPA Permanent Gauges

Surface water elevation data were recorded electronically from three locations (Intakes, Forebay and Reservoir) on an hourly basis. Plots of the data are presented in Figure 5.3.4-1. The average, maximum, and minimum water elevations for each of these three gauges are presented in Table 5.3.4-1. Manual water level measurements were not recorded for these locations.

5.3.5 NYPA Reservoir Dike Monitoring Wells

Groundwater elevation data from selected Lewiston Reservoir dike monitoring wells (see Figure 4.3-2) are plotted on Figures 1 through 25 in Appendix L.

5.3.6 Field Reconnaissance Observations

Observations made during field reconnaissance of the Niagara Escarpment and Fish and Gill Creeks are presented below.

5.3.6.1 Escarpment Seeps

Along the short section (see Figure 4.3.5-1), three small seeps were observed with estimated individual flow volumes ranging between 2 and 5 gpm (Figure 5.3.6-1). All three seeps were located along the same elevation, presumably along the same geologic contact between the Lockport and Clinton Groups (Figure 5.3.6-2) and were spaced by 100 to 150 feet.

Along the long section (see Figure 4.3.5-1), only one moderately sized seep was observed at the base of the Niagara Falls member of the Goat Island Formation. The flow was approximately 25 gpm and at one time had been collected and stored in a cistern and pump house structure (Figure 5.3.6-3). No other seeps were observed to be draining from above the railroad right-of-way.

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5.3.6.2 Fish and Gill Creeks

At the time of the reconnaissance, there was no free flowing water in either creek immediately east of the reservoir (i.e., at Garlow Road). However, substantial and measurable flow was observed further down stream in both creeks, approximately 1¼ miles (6,500 feet) due west of Garlow Road. Both creeks are adjacent to the reservoir dike at these locations.

At the time of project construction, the course of both creeks was permanently rerouted around the eastern edge of the reservoir. The location of the altered flow path along the toe of the dike, excavated into rock in some places, possibly created significant hydraulic connection between the bedrock and the creeks (e.g. Gill Creek now lies within a deep gully, up to 10-feet deep, excavated into bedrock along the south east corner of the reservoir [Figure 5.3.6-4]).

Results of the Fish Creek and Gill Creek flow measurements are provided in Tables 5.3.6-1 through 5.3.6-3. Flow profiles are presented in Figure 5.3.6-5. Since no quantitative measurements were recorded for the escarpment reconnaissance, no results are reported.

5.4 Falls Street Tunnel

As described in Section 4.4, in order to evaluate the potential relationship between the NYPA conduits and the FST, URS investigated groundwater infiltration into the FST in two stages: (1) reconnaissance, and (2) measurement and recording of infiltration flow rates. The FST study area is bounded by Drop Shaft 14B at its upstream end, and Drop Shaft 12 at its downstream end.

5.4.1 Tunnel Reconnaissance Observations

Results of FST reconnaissance observations are presented in the following sections.

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5.4.1.1 Drop Shaft 14A

Drop Shaft 14A is an approximately 25-foot deep brick manhole, about 2 feet in diameter. The FST at Drop Shaft 14A is cut directly into rock. During the tunnel reconnaissance, approximately 2 feet of sludge was observed at the bottom of the tunnel, with approximately one foot of water on top of the sludge. Water appeared stagnant. No groundwater infiltration through the tunnel walls was observed (Figures 5.4.1-1 and 5.4.1-2). A 24-inch diameter pipe entering the FST was observed on the south side of the tunnel (Figure 5.4.1-3). The pipe was carrying no flow.

5.4.1.2 Drop Shaft 12

Drop Shaft 12 is an approximately 25-foot deep brick manhole, about 2 feet in diameter. The tunnel at this location is cut directly in rock. A measuring weir is located approximately 20 feet upstream of the manhole (Figure 5.4.1-4). The weir is easily accessible. Immediately downstream of the weir, the channel bottom drops by approximately 2.5 feet before returning to its original elevation. This low part of the channel bottom downstream of the weir was seen to contain several sandbags.

Approximately 2 inches of flowing water was observed in the FST at the base of the manhole. The water was fairly clear. The water depth on the upstream side of the weir was 10.25 inches. Depth at the weir crest was approximately one inch, as measured at three locations along the crest (both ends and the middle). The width of the weir crest was measured at 60 inches. The drop on the downstream side of the weir is approximately one foot. Conditions at the weir are shown in Figures 5.4.1-5 and 5.4.1-6.

No groundwater infiltration was observed from the tunnel walls.

5.4.1.3 Drop Shaft 13A and the East Bypass Gate Structure

Drop Shaft 13A is an approximately 25-foot deep concrete or brick manhole. The entrance is 22 inches in diameter. The manhole widens significantly towards the bottom. The FST at Drop Shaft 13A is cut directly into rock.

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A 3-foot high diversion dam is located immediately upstream of the manhole. The freeboard on the upstream side of the dam was measured at 7.5 inches. See Figure 5.4.1-7.

A significant accumulation of sludge was observed on the inside corner of the junction between the FST and the East Bypass Pipe. Significant groundwater infiltration in the form of large seeps was visible in the tunnel, predominantly from the ceiling (Figures 5.4.1-8 and 5.4.1-9). Velocity of water entering the East Bypass pipe was relatively high. The gate of the East Bypass Gate Structure, located on the 84-inch concrete pipe just downstream of the junction with the FST was partially closed, blocking direct access to the remainder of the pipe (Figure 5.4.1-10).

To access the pipe downstream of the gate, it was necessary to enter from the gate structure manhole. The entrance to the structure is an approximately 2-foot diameter manhole. Immediately below this point, however, the structure widens to a vault. Approximately 10 inches of water was reported in the 84-inch diameter tile pipe, flowing at a velocity of approximately 1.5 feet per second over approximately 14 inches of sludge (Figure 5.4.1-11). The sludge was mostly soft. No groundwater infiltration was observed within the pipe.

5.4.1.4 Drop Shaft 13

Drop Shaft 13 is an approximately 25-foot deep brick manhole, 2 feet in diameter at the entrance and widening towards the bottom. A stoplog structure is found downstream of the manhole, from the junction with the West Bypass Pipe. Water was flowing from west to east over the stoplog structure at crest depth of 4.5 inches. The sludge thickness and water levels in the tunnel and the West Bypass Pipe were similar to those observed at Drop Shaft 13A. Infiltration was observed through the tunnel walls. The gate of the West Bypass Gate Structure was open, permitting access to the 84-inch bypass pipe (Figure 5.4.1-12).

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Water depth and sludge thickness in the 84-inch tile bypass pipe were measured at distances of 5 feet and 30 feet downstream of the gate. Approximately 7 to 9 inches of water was flowing over 14 to 17 inches of sludge. No groundwater infiltration was observed through the pipe walls (Figure 5.4.1-13).

5.4.2 Development of Flow Diagram Based on Reconnaissance Observations

Since the FST and SSI are part of a network of combined storm/sanitary sewers, the flow regime within these structures is affected by runoff generated by precipitation, easily obscuring groundwater infiltration rates. In order to aid in the understanding of the response of the sewer network to precipitation, and as described in Section 4.4, a rain gauge was installed on the roof of the Pump Station A, located in the area between the conduits, the FST and the SSI. Rainfall data were utilized to define the wet weather periods and to correlate them with flow rates and flow directions obtained during the flow monitoring program. These wet-weather flows were then excluded from the analysis of groundwater infiltration. Data from the rain gauge are presented on Figure 5.4.2-1

Results of the reconnaissance were used to create a flow diagram of the dry-weather flow conditions in the section of the FST that was the subject of this investigation. The resultant flow diagram is shown in Figure 5.4.2-2. The upstream dry weather inflow into the study area is eliminated by the diversion dam and the connection to the SSI at Drop Shaft 14B. Groundwater infiltration entering through the FST walls between Drop Shafts 14B and 13A is directed into the SSI by the diversion dam at Drop Shaft 13A, flowing entirely within the East Bypass Pipe. The groundwater infiltration occurring between Drop Shafts 13A and 12 is split between flow into the SSI via the West Bypass Pipe and flow over the weir located at Drop Shaft 12.

Groundwater infiltration appears to form the bulk of the dry-weather flow within the FST study area. The only other input was observed at a 2-foot diameter pipe entering the FST at Drop Shaft 14. As described in Section 5.4.3, however, the magnitude of this flow was seen to be negligible compared to groundwater infiltration.

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Based on information gathered during the reconnaissance, three locations were selected for flow monitoring: (1) the measuring weir at drop Shaft 12, (2) the West Bypass Pipe, and (3) the east Bypass Pipe. The locations are shown in Figure 5.4.2-2. Flow metering methodology is described in Section 4.4 and Appendix H. The sum of dry-weather flows at these three points provides an estimate of the groundwater infiltration rates into the FST in the vicinity of the NYPA conduits.

5.4.3 Flow Observations

As indicated by the stagnant water observed during the reconnaissance in Drop Shaft 14A, the upstream dry weather inflow into the monitored section of the FST is being cut off by the diversion dam and a connection to the SSI, located at Drop Shaft 14B. Throughout the flow monitoring study, visual observations were made at Drop Shaft 14A, located immediately downstream of 14B. The conclusion of the reconnaissance was verified, that is, that (in dry weather) no flow is occurring at Drop Shaft 14A.

The only source of dry-weather inflow into the monitored section of the FST identified during the reconnaissance was a 2-foot diameter pipe emptying into Drop Shaft 14. This inflow is a tributary to the East Bypass Pipe. Throughout the monitoring study, six measurements of this flow were made with the aid of a bucket and stopwatch. Each time, flow was measured at approximately 10 gpm (see Appendix H). This value is negligible compared to the flow rates of several thousand gpm measured at the East Bypass Pipe. For this reason the flow from the 2-foot diameter pipe at Drop Shaft 14 will not be considered further.

5.4.4 Measurement of Flow Rates

The flow monitoring program was undertaken in order to estimate groundwater infiltration rates into the FST in the vicinity of the NYPA conduits and to determine whether the operation of the Niagara Power Projects impacts those rates. As described in Section 1.1, the Project is operated in two modes: a tourist season mode and a non-tourist season mode. The two operating modes differ with respect to the flow rate diverted from the Niagara River through the NYPA conduits. The change from the tourist to

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non-tourist season takes place on October 31. Flow meters were operating in the FST from October 20 to November 25, 2003. The flow monitoring program therefore covered periods corresponding to both operating regimes.

Detailed analysis of the data is presented in Appendix H. This section presents a summary of findings and a discussion of results. Groundwater infiltration into the FST between Drop Shafts 14B and 12 is summarized on Table 5.4.4-1.

5.4.4.1 Drop Shaft 12 and West Bypass

During dry weather, flow generated by groundwater infiltrating into the FST between Drop Shafts 13A and 12 is distributed between the Drop Shaft 12 weir and the West Bypass Pipe. The portion spilling over the weir continues downstream within the FST. The remaining part flows into the SSI via the West Bypass Pipe. See Figure 5.4.2-2.

The SSI forms the downstream control for the flow within the West Bypass Pipe. A sufficient increase of the flow depth within the SSI will change the flow direction in the West Bypass Pipe. If this occurs, water from the SSI will flow from the SSI into the FST section between Drop Shafts 13A and 12 and spill over the weir. This phenomenon is illustrated on Figure 5.4.4-1. Negative flow velocities in the West Bypass indicate flow from the SSI into the FST.

Initially, the reversals appeared to occur independently of precipitation. The cause of the reversals was traced to the operating regime of the WWTP's main pump station, which controls the downstream level in the SSI. The water level at the pump station was relatively high. This allowed for the flow depth in the SSI within the study area to rise significantly in response to the diurnal fluctuation patterns of sewage generation. In response to these observations, URS asked the City of Niagara Falls to lower the downstream control level at the pump station. Once this was done, the resulting operating regime lowered the flow depths in the SSI to the point where the diurnal depth fluctuations remained

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below the elevation of the monitoring point, effectively eliminating the problem of dry-weather flow reversals.

Beginning on October 25, the problem of dry-weather flow reversals was eliminated. Following that date, reversals correspond only to high-intensity rainfall events. Note that periods of missing or erratic velocity data occur following large precipitation events (November 2 and November 20). This is due to the accumulation of sediment at the monitoring location.

During reversal periods, flow over the Drop Shaft 12 weir consists of the groundwater infiltration and flow entering the FST from the SSI via the bypass pipe. As shown in Figure 5.4.4-2, the combined flow over the weir is significantly higher than the typical dry-weather flow, consisting only of groundwater infiltration. To estimate groundwater infiltration, dry-weather flows had to be separated from wet-weather events. The graph showing only dry-weather flows over the weir appears in Figure 5.4.4-3.

Dry-weather flow over the Drop Shaft 12 weir is relatively constant. The average values for the tourist and non-tourist seasons were estimated to be 250 and 240 gpm, respectively. The flows display a slight diurnal fluctuation pattern, with the amplitude remaining most of the time at approximately +/-20% around the mean.

The average values of 250 and 240 gpm are too close for determining whether the change in the operating regime of the Project from tourist to non-tourist season affects the results.

Flow rates measured at the West Bypass location are presented in Figure 5.4.4-4. Flow reversals are shown as negative flow rates. Periods of missing or erratic data occur following the large precipitation event on November 2. This is due to the accumulation of sediment at the monitoring location. Likewise, sediment accumulation after the November 20 event obstructed the centerline sensor, making flow estimates during the subsequent period based only on the remaining single sensor. These data were not considered to be equally reliable as data obtained when both sensors were operating.

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Finally, as described previously, flow reversals prior to the change in the operating regime of the WWTP's main pump stationon October 25 represent diurnal fluctuation patterns in the SSI, and not wet-weather events.

Figure 5.4.4-5 shows dry-weather flows only, following the removal of the reversal periods and periods of missing or unreliable data. Similarly to the Drop Shaft 12 weir, flows through the West Bypass display a relatively constant average magnitude and a similar weak diurnal fluctuation pattern, limited most of the time to approximately +/-25% around the mean.

While flows at Drop Shaft 12 were estimated using a relatively accurate measuring weir approach, flows at the West Bypass were obtained by integrating information from two depth and velocity sensors placed in an approximately 6-foot wide flow channel. Flow balance calculations and velocity profiling performed at the West Bypass monitoring location to assess the accuracy of the flow instrumentation revealed that the flow rates as measured are overestimated, possibly as a result of an asymmetrical velocity distribution. Details are presented in Appendix H. As discussed in Appendix H, a correction factor of 0.75 was calculated. Based on that, the actual average flow measured at the West Bypass is 1,250 gpm for the tourist season and 1,130 gpm for the non-tourist season (Table 5.4.4-1). The difference between the two estimates is not sufficient to recognize any influence of the change in the operating regime of the Project on groundwater infiltration.

5.4.4.2 East Bypass

Dry-weather flow in the FST generated by groundwater infiltrating between Drop Shafts 14B and 13A is directed into the SSI via the East Bypass Pipe (Figure 5.4.2-2). During wet-weather periods, flow reversals similar to those described for the West Bypass may occur. However, such reversals in the East Bypass are much less frequent, as shown in Figure 5.4.4-6. This is because the East Bypass is located farther upstream than the West Bypass and the pipe inverts are at higher elevations. The only reversal recorded during the monitoring period was associated with a precipitation event on November 2, 2003, of approximately 1.3 inches.

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A plot of East Bypass flows containing only dry-weather data is presented in Figure 5.4.4-7. A significant difference may be observed between the flow patterns during the tourist and non-tourist seasons. During the tourist season, regular diurnal fluctuations of approximately +/-35% occur around the mean of 3,580 gpm. During the non-tourist season, diurnal fluctuations appear to be superimposed on an approximately weekly pattern of variation. The mean of 2,740 gpm is significantly lower than during the tourist season. Because of the superimposed dual fluctuation pattern the total amplitude is relatively high—approximately +/-60% around the mean.

Flow rates at the East Bypass location were obtained by means of an identical setup as that described for the West Bypass, that is, two depth/velocity sensors were placed in an approximately 6-foot wide flow channel. However, unlike at the West Bypass, velocity profiling conducted at the East Bypass location indicated a symmetrical velocity distribution and a high level of measurement accuracy. As a result, the use of a correction factor was not required. See Appendix H.

5.5 Water Sampling Results

To assess general water quality and the potential for Project operations to influence groundwater, both surface water and groundwater samples were collected within and adjacent to the conduits, forebay, and reservoir. Surface water was sampled in October and November 2003. Groundwater was sampled in September/October 2003, December 2003, and February/March 2004. This section presents the analytical results of these sampling efforts.

Groundwater sample analytical results were validated in accordance with USEPA Region II data validation guidelines. Data Usability Summary Reports have been prepared following guidelines provided in NYSDEC Division of Environmental Remediation *Guidance for the Development of Data Usability Summary Reports*, dated June 1999. Data Usability Summary Reports and complete analytical results for surface water and groundwater samples, including validation qualifiers, are presented in Appendix M.

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5.5.1 Surface Water

The results of each sampling event are summarized in Appendix M (Section M8, Table 1) and Figures 5.5.1-1 through 5.5.1-4, and are further described in the sections below.

5.5.1.1 General Water Quality

General water quality parameters analyzed for the three sampling events included hardness, TDS, TOC and TSS. Major ionic species analyzed for included calcium, magnesium, potassium, sodium, alkalinity (total), chloride, and sulfate. Results of analysis for general water quality parameters and major ions are summarized in Figures 5.5.1-1, 5.5.1-2,and Appendix M (Section M8, Table 1).

Hardness values were consistent in the river-sourced locations, ranging from 111 mg/L (SW03-008, March 2004) to 211 mg/L (SW03-011, October 2003). The local-sourced surface water locations ranged in concentration from 111 mg/L (SW03-002, March 2004) to 830 mg/L (SW03-004, October 2003).

TDS concentrations were consistent for the river-sourced water, ranging from 138 mg/L in SW03-010 (October 2003) to 233 mg/L in SW03-010 (March 2004). TDS concentrations in the local-sourced locations were higher, ranging from 143 mg/L in SW03-002 (March 2004) to 546 mg/L in SW03-005 (October 2004).

TOC, which measures the amount of carbon-containing particles suspended in the water column, is a general indicator of water quality. Organic carbon, through the action of decomposing microorganisms, is converted to carbon dioxide gas, with oxygen consumed in the process. The larger the carbon or organic content, the greater the activity of microorganisms, and the more oxygen is consumed. This can contribute to the depletion of oxygen supplies in the water column. TOC concentrations were low (less than 25 mg/L) for all sample locations in the study area. TOC concentrations in the river-sourced water locations ranged from 1.2 mg/L in SW03-006 (October 2003) to 2.4 mg/L in SW03-010

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(October 2003). The local-sourced surface water locations showed slightly higher concentrations, ranging from 1.4 mg/L in SW03-001 (October 2003) to 23.1 mg/L in SW03-004 (November 2003).

TSS concentrations were much lower than the TDS results for almost every sample collected. With the exception of SW03-004, the remaining sampling locations contained concentrations ranging from non detect to 61.0 mg/L in SW03-009 (November 2003). TSS concentrations in SW03-004 varied from 457 mg/L in October 2003 to 5 mg/L in March 2004.

Major ions detected in surface water included calcium, magnesium, potassium, sodium, alkalinity, chloride, and sulfate (Figure 5.5.1-2). For the river-sourced samples, calcium concentrations were consistent, ranging from 30,300 ug/L in SW03-009 (October 2003) to 43,500 ug/L in SW03-010 (March 2004). Calcium concentrations in the local-sourced surface water sample locations were higher, ranging from 29,200 ug/L in SW03-003 (March 2004) to 107,000 ug/L in SW03-004 (October 2003).

Magnesium was detected in all 11 sampled locations. For the river-sourced samples, magnesium concentrations were consistent ranging from 7,670 ug/L in SW03-009 (October 2003) to 9,690 ug/L in SW03-010 (November 2003). Magnesium concentrations in the remaining sample locations were higher, ranging from 10,000 ug/L in SW03-002 (March 2004) to 32,200 ug/L in SW03-005 (November 2003).

Potassium was also detected in all 11 sampled locations. For the river-sourced samples, potassium concentrations were consistent ranging from 1,470 ug/L in SW03-009 (October 2003) to 3,010 ug/L in SW03-010 (March 2004). Potassium concentrations in the local-sourced surface water sample locations were slightly higher, generally ranging from 2,050 ug/L in SW03-003 (March 2004) to 11,800 ug/L in SW03-004 (November 2003).

Sodium was detected in all 11 sampled locations. For the river-sourced samples, sodium concentrations ranged from 9,600 ug/L in SW03-008 (November 2003) to 26,900 ug/L in SW03-010 (March 20043). Sodium concentrations in the local-sourced sampling locations were higher, generally ranging from 2,510 ug/L in SW03-004 (October 2003) to 56,600 ug/L in SW03-005 (October 2003).

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Total alkalinity from the river-sourced water sample locations were generally consistent, ranging from 59.9 milligrams per liter (mg/L) in SW03-010 (October 2003) to 101 mg/L in SW03-006 (November 2003), SW03-010 (November 2003), and SW03-011 (October 2003). The local-sourced locations showed generally higher alkalinities, ranging from 71.5 mg/L (SW03-002, March 2004) to 218 mg/L (SW03-004 (October 2003) and SW03-005, November 2003).

Chloride concentrations were consistent in the river-sourced water samples, ranging from 16.6 mg/L (SW03-007, October 2003) to 50.3 mg/L (SW03-010, March 2004). With the exception of SW03-004, chloride concentrations in the local-sourced surface water locations were generally higher, ranging from 16 mg/L (SW03-003, March 2004) to 83.6 mg/L (SW03-005, October 2003).

Sulfate analysis indicated that low concentrations (less than 250 mg/L) were present at all sample locations. Sulfate concentrations for the river-sourced water were generally consistent between each sample and ranged from 24.0 mg/L in SW03-008 (October 2003) to 36.5 mg/L in SW03-010 (November 2003 and March 2004). The remaining sample locations were more variable, with sulfate concentrations ranging from 14.3 mg/L in SW03-004 (March 2004) to 201 mg/L in SW03-004 (October 2003.)

5.5.1.2 Chemical Contaminants

Complete laboratory analytical results, including the practical quantitation limits, are given in Appendix M. A summary of detected target analytes for this investigation is provided in Section M8, Table 2 of this Appendix. Of the SVOC and VOC compounds analyzed for in this study only two VOCs were detected and no SVOCs were detected (Figure 5.5.1-3). Acetone was detected in surface water sample SW03-001 (October 2003) at a 2.4 micrograms per liter (ug/L). Acetone was detected in 5 other samples, however, these results were rejected in laboratory validation. Carbon disulfide was detected in SW03-001 (October 2003) at 1.1 ug/L. Carbon disulfide was not detected in any of the remaining 18 samples. With regard to pesticides and PCBs analysis, only one compound was detected: Delta BHC, in SW03-006 (November 2003) at 0.04 ug/L and in SW03-011 (November 2003) at 0.043 ug/L.

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Lead, a heavy metal, was detected in only one of the 10 sampled locations. Surface water sample SW03-004 contained lead at concentrations of 24.4 ug/L and 16.8 ug/l in the October and November 2003 sampling events, respectively (Figure 5.5.1-3). Lead was not detected at this location in March 2004.

Monomethyl mercury present in natural waters is principally produced by bacteria from inorganic mercury that is naturally present and from mercury that is added from pollutant sources (Rudd et al. 2003). Monomethyl mercury is formed within the low oxygen/low sulfide redox transition zone where water shifts from oxygenated conditions to deoxygenated conditions due to physical impediments to the movement of oxygen and/or biological activity (Tetra Tech 2005). Monomethyl mercury was detected in four of the six samples collected from the river-sourced water samples. Detections ranged from 0.074 nanograms per liter (ng/L) in SW03-011 (October 2003) to 0.140 ng/L (SW03-008, November 2003). Monomethyl mercury detections in local-sourced surface water samples ranged in concentration from 0.085 ng/L (SW03-001, October 2003) to 1.590 ng/L (SW03-004, November 2003).

5.5.1.3 Bacteriological

All samples were submitted for heterotrophic plate count (HPC), total coliform, and fecal coliform count (Figure 5.5.1-4). HPC is used to estimate the number of live bacteria present in the water. HPC does not indicate what types of bacteria are present but rather, is used as an indicator parameter for general water quality. HPC concentrations were variable between samples but generally were lower in the river-sourced water locations. For the river-sourced locations, HPC concentrations ranged from 21 colony-forming units per milliliter (CFU/ML) in SW03-008 (March 2004) to 2,500 CFU/ML in SW03-010 (November 2003). For the local-sourced surface water sample locations HPC concentrations ranged 590 CFU/ML in SW03-004 (March 2004) to 110,000 CFU/ML in SW03-004 (November 2003).

Coliform bacteria consist of several general forms of bacteria. Coliform bacteria are normally non-pathogenic (Driscoll 1986). Their presence suggests conditions are conducive for the growth of pathogenic bacteria. The presence of coliform bacteria also indicates fecal contamination may be present.

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Total coliform was detected in all sampled locations. For river-sourced locations, detected total coliform concentrations ranged from 40 colonies per 100 milliliters (C/100 ML) in SW03-008 (November 2003) to 14,000 C/100 ML in SW03-009 (October 2003), with none detected in the November 2003 sample. Total coliform detected in the local-sourced surface water locations varied greatly, ranging from 120 C/100 ML in SW03-005 (October 2003) and SW03-004 (March 2004) to 94,000 C/100 ML in SW03-004 (November 2003).

Fecal coliform concentrations for all surface water locations were much lower than the total coliform concentrations and ranged from non-detect in numerous locations to 100 C/100 ML in SW03-004 (November 2003), SW03-011 (November 2003), and SW03-005 (March 2004).

5.5.2 Groundwater

This section presents the results of groundwater analytical testing for the September/October, December 2003, and March 2004 groundwater sampling events. For the purposes of discussing groundwater analytical results, the regional water-bearing zones targeted by this investigation have been grouped by groundwater model layers. Results of the general water quality parameters (hardness, TDS, TOC, and TSS) are presented in Figures 5.5.2-1 through 5.5.2-9. Concentrations of major ions (calcium, magnesium, potassium, sodium, alkalinity (total), chloride, and sulfate) are summarized in Figures 5.5.2-10 through 5.5.2-18. Concentrations of detected target analytes are presented in Figures 5.5.2-19 through 5.5.2-27.

5.5.2.1 General Water Quality

Groundwater samples collected during this investigation were analyzed for general water quality indicator parameters, including hardness, TDS, TOC, and TSS. Groundwater samples were also analyzed for bacterial and microbial parameters, including HPC and total coliform. The general water quality parameters detected in each of nine fracture zones and model layers are shown in Figures 5.5.2-1 through 5.5.2-9. Major ionic species including calcium, magnesium, potassium, sodium, alkalinity (total),

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chloride, and sulfate (as SO_4) are presented in Figures 5.5.2-10 through 5.5.2-18. The presence of four metals (calcium, magnesium, potassium, and sodium) is indicative groundwater mineralization.

A summary of analytical results for major ions and general water quality parameters is provided in Appendix M (Section M8, Table 2).

The concentration ranges for the major ions and general water quality parameters are summarized on Table 5.5.2-1. The data show a wide range of concentrations, with the most mineralized waters generally found in the lower two fracture zones.

5.5.2.2 Chemical Contaminants

For complete groundwater sample laboratory analytical results, including the practical quantitation limits, please refer to Appendix M. A summary of detected target analytes for this investigation is provided in Section M8, Table 3 of this Appendix.

Analytical results are presented in Figures 5.5.2-19 through 5.5.2-27. The figures illustrate where VOCs, SVOCs, metals, PCBs, and pesticides were detected in each of nine groundwater model layers. A total of 30 VOCs, 11 SVOCs, 5 pesticides, 1 PCB, and 3 heavy metals were detected in the samples.

Chlorinated VOCs such as 1,1,2-trichloroethane, 1,2-dichloroethane, 1,2-dichloroethene (cis), 1,2-dichloroethene (trans), chlorobenzene, chloroform, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride were detected in multiple fracture zones in several piezometers located along the east side of the conduits (GW03-017, -016, and -015). The highest concentration of total chlorinated VOCs was detected in piezometer GW03-015B-P5 (at 1,084 ug/L, December 2003). See Appendix M (Section M8, Table 3).

Fuel-related compounds like benzene, toluene, ethylbenzene and xylenes (BTEX) contamination were detected in three piezometers located along the conduits. The highest BTEX concentrations in this

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area were detected in the Gasport/DeCew water-bearing zone in GW03-016, GW03-014, and GW03-012. BTEX contamination was also detected in several piezometers around the Lewiston Reservoir. The highest levels of BTEX in this area were also detected in the Gasport/DeCew water-bearing zone in piezometers GW03-009A-P3, GW03-007A-P3, and GW03-005A-P2. A gasoline additive, methyl-tertiary-butyl-ether (MTBE) was also detected in four upper water-bearing zones at well location GW03-009. Cyclohexane and methylcyclohexane, also fuel related VOCs, were detected in GW03-005, GW03-007, and GW03–009 (12 to 110 ug/L) east of the Lewiston Reservoir, and in GW03-016 (14-86 ug/L) along the conduits in the Gasport/DeCew water-bearing zone.

SVOCs most frequently detected in the groundwater samples included naphthalene, bis (2-ethylhexyl) phthalate, and several phenolic compounds (phenol, 2-chlorophenol, 2-methylphenol, 4-methylphenol, and 2,4-dimethylphenol). These compounds were found to be most prevalent in fractures monitored at the Gasport/DeCew water–bearing zone.

Pesticides were detected infrequently and at low concentrations in the groundwater samples. The compounds alpha-, beta-, delta-, and gamma-BHC (lindane) and 4,4-DDT were detected in piezometers at GW03-014, GW03-015, GW03-016, and GW03-017 along the conduits. The PCB Aroclor 1242 was detected in a single sample from piezometer GW03-015A-P1 at 0.44 ug/L (October 2003).

Heavy metals detected in some groundwater samples included arsenic, lead, and cadmium. Maximum concentrations were detected at GW03-007A-P3 (arsenic at 75.9 ug/L), GW03-008B-P6 (lead at 78.9 ug/L), and GW03-010C-P7 (cadmium at 4.8 ug/L).

For groundwater samples, monomethyl mercury was only analyzed for in well locations GW03-001 through GW03-009 around the reservoir. Monomethyl mercury was detected during at least one sampling event in 8 of 32 piezometers analyzed (GW03-001A-P1, GW03-004A-P1, GW03-006A-P1, GW03-007B-P5, GW03-003A-P2, GW03-004A-P2, GW03-005A-P2, and GW03-009A-P3). Monomethyl mercury concentrations detected in groundwater ranged from 0.062 ng/L (GW03-007B-P5) to 1.37 ng/L (GW03-005A-P2).

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5.5.2.3 Bacteriological Parameters

Groundwater samples were analyzed for the presence of microorganisms, with special attention to coliform bacteria. Differentiating and identifying specific types of pathogenic bacteria is a difficult and laborious effort. For this reason, bacteria remain undifferentiated in these analyses.

HPC greater than 1,000 colony forming units per milliliter (CFU/ml) were detected in 22 piezometers. Relatively high readings were often found in the deepest fracture zones. The high HPC may be due to iron- or sulfate-reducing bacteria or to aerobic bacteria breaking down organic contaminants.

Coliform bacteria were detected in 30 piezometers in various fracture zones. The coliform count ranged from 20 to 460 colonies per 100 ml. Coliform bacteria were detected in both sampling rounds in only eight piezometers. These piezometers are GW03-007A-P1, GW03-014B-P6 and GW03-014C-P7, GW03-015A-P1 and GW03-015C-P7, GW03-016B-P6 and GW03-016C-P7, and GW03-017B-P5. Piezometers with relatively high coliform levels (>200 colonies/100ml) were located in areas where the City of Niagara Falls supplies drinking water to users.

E. coli was found in 16 piezometers reporting coliform bacteria in the December 2003 and February-March 2004 sampling events. *E. coli* was found in both sampling rounds in only five piezometers, including GW03-005A-P2, GW03-010B-P6, GW03-010C-P7, GW03-016-P4 and GW03-016C-P7.

Select samples were analyzed for fecal coliform based on a result of greater than 200 colonies/100ml total coliform for the previous sampling event. A total of five groundwater samples (GW03-005A-P2, GW03-014C-P7, GW03-015A-P1, GW03-015B-P6, and GW03-017C-P7) were analyzed for fecal coliform. Fecal coliform was not detected in any of the five groundwater samples analyzed as part of this investigation.

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5.6 GW03-015 Chloride Monitoring Results

5.6.1 Groundwater Elevations

Groundwater elevation measurements were recorded from location GW03-015 from March 25 through April 6, 2004. This includes data from one week prior to the switchover from non-tourist to tourist and one week afterward. Groundwater levels were measured using manual and electronic methods.

Results of the investigation are discussed by water-bearing zone in the following sections. Plots of electronic groundwater elevation data verses time are presented in Appendix N.

5.6.2 GW03-015-P1 Results

Piezometer P1 is screened within water-bearing zone 8A (Figure 5.2.2-1). This piezometer is within the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. In addition, electronic groundwater elevations are plotted for comparison on each figure.

5.6.3 GW03-015-P2 Results

Piezometer P2 is screened within water-bearing zone 10 (Figure 5.2.2-1). This piezometer is located below the CDS. Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

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5.6.4 GW03-015-P3 Results

Piezometer P3 is screened within the Gasport/DeCew water Bearing Zone (Figure 5.2.2-1). This piezometer is located below the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

5.6.5 GW03-015-P4 Results

Piezometer P4 is screened within water-bearing zone 8B. This piezometer is also within the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

After several days of data collection, it was determined that the chloride probe on the P5 troll was defective. Due to relatively low-recorded chloride levels in P4, this probe was removed and inserted into P5's troll. During this switch over, no data was collected at P4 on March 29-30, 2004.

5.6.6 GW03-015-P5 Results

Piezometer P5 is screened within water-bearing zone 9A. This piezometer is also within the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

As noted in Section 5.6.5, due to a defective probe, no chloride data was collected in P5 from March 25 through March 29.

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5.6.7 GW03-015-P6 Results

Piezometer P6 is screened within water-bearing zone 9B. This piezometer is also located near the base of the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

5.6.8 GW03-015-P7 Results

Piezometer P7 is screened within water-bearing zone 2. This piezometer is also located within the CDS (see Figure 5.2-1). Ion probe electronic data for chloride, conductivity, pH, ORP, DO, barometric pressure, and temperature are presented in Appendix N. Electronic groundwater elevations are also plotted for comparison on each figure.

5.6.9 Tourist/Non-Tourist Water Quality Results

A limited groundwater sampling event was conducted on April 12 and 13, 2004 following the switch over from non-tourist season to tourist season on April 1. During this event, groundwater samples were collected from location GW03-015 only.

Groundwater sample analytical results were validated in accordance with USEPA Region II data validation guidelines. Data Usability Summary Reports have been prepared following guidelines provided in NYSDEC Division of Environmental Remediation Guidance for the Development of Data Usability Summary Reports, dated June 1999. Data Usability Summary Reports and complete analytical results for groundwater samples, including validation qualifiers, are presented in Appendix M. A discussion of the results is presented below.

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5.6.9.1 General Water Quality Parameters

Groundwater samples collected from GW03-015 (piezometers P1, P2, and P4 through P7) were analyzed for general water quality indicator parameters, including hardness, TDS, TOC, TSS, and major ions (calcium, magnesium, potassium, sodium, alkalinity (bicarbonate and total), chloride, sulfate (as SO4),) indicative of groundwater mineralization. Groundwater samples were also analyzed for bacterial and microbial parameters, including HPC and total coliform. A summary table of the March and April 2004 sampling events is presented in Appendix M (Section M8, Table 4).

Due to an insufficient volume of water, the groundwater sample from piezometer P3 was only analyzed for TOC.

The analytical results for this sampling event (tourist-season) were compared to results from March 2004 (non-tourist season). The results indicated:

- Generally, alkalinity concentrations decreased from the March to the April 2004 sampling events with the exception of P6, which increased slightly from 98.8 mg/L to 101 mg/L.
- Chloride concentrations increased in P1, P2 and P3. Concentrations decreased in P4, P5 and P6. The concentrations ranged from 79,000 mg/L (P6) to 51.4 mg/L (P1).
- Sulfate concentrations decreased in all piezometers except P2. Concentrations in P2 rose from 2,410 mg/L to 2,810 mg/L.
- Similarly, total dissolved solids concentrations rose only in P2 from 48,700 mg/l to 58,900 mg/L.
- Calcium and sodium concentrations rose in P2 and P7. Additionally, magnesium concentrations rose in P2 and P4.

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5.6.9.2 Chemical Contaminants

A summary table of detected analytes for March and April 2004 is presented in Appendix M (Section M8, Table 5). A review of the data indicates the following,

- For piezometer P7 (water-bearing zone 2): Of the nine compounds detected in March (VOCs and Pesticides) only six VOCs were detected in April 04. The concentrations were slightly higher (notably vinyl chloride concentrations increased to 460 ug/L). Additionally, one SVOC (4-chloroaniline) was detected for the first time.
- For piezometer P1 (water-bearing zone 8A): A total of eight VOCs were detected. Four of these compounds were not detected during previous events and include 1,2-dichloroethene (trans), benzene, chlorobenzene, and chloroform. Vinyl chloride concentrations increased from non-detect (October/December 03), 4.5 ug/L (March 04) to 150 ug/L. PCBs remained as non-detect.
- For piezometer P4 (water-bearing zone 8B): Tetrachloroethene was the only VOC (previously non-detect) reported at a concentration of 0.45 ug/L. One PCB (Aroclor 1248), which was not detected in this piezometer during any of the three previous sampling events, was detected at a concentration of 0.28 ug/L.
- For piezometer P5 (water-bearing zone 9A): Similar to March and December results, a total of 18 VOCs were detected. Some concentrations increased while others decreased (see Figure 5.5.2-12). Notably, the concentration of vinyl chloride increased from 30 ug/L to 460 ug/L. However, this concentration is lower than December's results (720 ug/L). Methylene chloride and tetrachloroethene were two additional VOCs present that had not been previously detected. Their concentrations were 6.4 ug/L

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and 0.84 ug/L, respectively. Two pesticides detected in March (delta-BHC and Endrin) were non-detect in April.

- For piezometer P6 (water-bearing zone 9B): A total of three VOCs were detected. The compounds 1,2-dichloroethene(cis and trans) were detected for the first time in April. Pesticide gamma-BHC (Lindane) went from 0.038 ug/L to non-detect.
- For piezometer P2 (water-bearing zone 10): A total of four VOCs were detected in April. Two compounds (cyclohexane and ethylbenzene) were detected for the first time at low concentrations (1.0 ug/L and 0.35 ug/L, respectively). In addition to the three SVOCs previously detected, one compound (2-methylnapthalene) was detected for the first time at a concentration of 2 ug/L.
- For piezometer P3 (the Gasport/DeCew contact): A total of five VOCs were detected. Compared to March, three compounds (acetone, benzene and toluene) decreased to non-detect in April. Carbon disulfide was detected for the first time at a concentration of 0.55 ug/L.

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TABLE 5.2.6-1

WATER QUALITY OBSERVATIONS DURING DRILLING AND SAMPLING

Well Location	Well/Interval	Depth (feet BGS)	Stratigraphic Horizon	Comment
GW03-001				no gas or odors noted
GW03-002				no gas or odors noted
GW03-003				no gas or odors noted
GW03-004				no gas or odors noted
GW03-005	P2	54-59	Gothic Hill/ DeCew	methane and artesian water flowing from well on July 3, 2003
GW03-006	P5	28-33	Vinemount/Ancaster	sulfur odor noted during sampling
GW03-007	P3	78-81	DeCew	H2S noted during sampling, methane built up under well cap
GW03-008	P2	71-81	Pekin	'gas' noted in water during sampling
GW03-009	P5	38-43	Eramosa 'A'	light gray water color noted during sampling
GW03-010	P4	40-50	Eramosa 'B'	sulfur odor noted during sampling
GW03-010	P5	57-62	Eramosa 'A'	'gas' noted in water during sampling
GW03-011	P1	64-74	Vinemount	H2S at ground surface during drilling, also while sampling
GW03-011	P2	98-108	Pekin	H2S at ground surface during drilling, also while sampling
GW03-012	P3	119-129	Gothic Hill/ DeCew	decayed or fish-like odor noted during sampling
GW03-013	P3	121-131	DeCew	'dark water' noted during sampling
GW03-014	P1	68-73	Eramosa 'C'	H2S and dark water noted during sampling
GW03-014	P3	137-147	DeCew	H2S noted during sampling
GW03-014	P5	76-86	Vinemount	'high' amounts of gas noted in sample
GW03-015	P2	108-118	Pekin	sulfur odor and gray water noted during sampling. Well cap under pressure
GW03-015	P3	137-147	Gothic Hill/ DeCew	well cap under pressure
GW03-015	P7	45-55	Eramosa 'C'	sulfur odor noted during sampling
GW03-016	P3	148-158	DeCew/ Rochester	methane at surface during coring. Samplers did not note gas in water samples
GW03-016	P3	148-158	DeCew/ Rochester	sulfur odor and black staining noted by samplers
GW03-016	P4	41-46	Eramosa 'D'	sulfur odor noted during sampling
GW03-017	P1	118-123	Ancaster	sulfur odor noted during sampling, methane noted. Gas build-up under well cap
GW03-017	P4	56-61	Eramosa 'C' and 'D'	sulfur odor noted during sampling
GW03-017	P8	47-52	Eramosa 'D' and 'E'	methane noted. Gas build-up under well cap

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TABLE 5.3.1-1

AVERAGE HEAD ELEVATION, GW03-001 THROUGH GW03-017

Location	Model Layer	Average Head						
		Tourist Season		Non-Tourist Season		All Seasons		All Seasons
		Datalogger	Manual	Datalogger	Manual	Datalogger	Manual	All Data
GW03-001A-P1	2	611.09	610.64	NA	611.96	611.09	611.30	611.23
GW03-001A-P2	DeCew	571.10[1]	590.10[1]	NA	608.51	571.10	599.30	589.90
GW03-002A-P1	2	611.39	610.77	NA	612.22	611.39	611.50	611.46
GW03-002A-P2	DeCew	576.48	579.75	NA	572.82	576.48	576.29	576.35
GW03-003A-P1	2	624.98	624.23	NA	625.71	624.98	624.97	624.97
GW03-003A-P2	DeCew	624.89	624.18	NA	625.48	624.89	624.83	624.85
GW03-004A-P1	2	613.12	615.61	NA	615.86	613.12	615.74	614.86
GW03-004A-P2	DeCew	611.43	610.56	NA	612.03	611.43	611.30	611.34
GW03-005A-P1	2	610.19	610.28	610.75	610.85	610.47	610.56	610.52
GW03-005A-P2	DeCew	571.75[1]	575.14[1]	NA	597.99	571.75	586.56	581.62
GW03-006A-P1	9A	617.01	615.95	NA	616.94	617.01	616.44	616.63
GW03-006B-P2	10	610.95	611.01	611.60	611.64	611.28	611.33	611.30
GW03-006B-P3	DeCew	NA	556.63	NA	556.11	NA	556.37	556.37
GW03-006B-P4	2	615.91	616.12	617.12	617.26	616.51	616.69	616.60
GW03-006A-P5	9B	611.97	610.28	NA	610.69	611.97	610.49	610.98
GW03-007A-P1	9A	616.67	615.53	NA	616.58	616.67	616.06	616.26
GW03-007A-P2	10	602.65	603.34	602.72	602.76	602.69	603.05	602.87
GW03-007A-P3	DeCew	NA	586.49	NA	594.60	NA	590.55	590.55
GW03-007B-P4	2	615.52	615.72	616.55	616.71	616.04	616.21	616.13
GW03-007B-P5	9B	607.25	603.55	NA	604.62	607.25	604.08	605.14

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TABLE 5.3.1-1 (CONT.)

AVERAGE HEAD ELEVATION, GW03-001 THROUGH GW03-017

Location	Model Layer	Average Head						
		Tourist Season		Non-Tourist Season		All Seasons		All Seasons
		Datalogger	Manual	Datalogger	Manual	Datalogger	Manual	All Data
GW03-008A-P1	8B	616.75	615.73	NA	616.64	616.75	616.18	616.37
GW03-008A-P2	10	602.20	603.09	602.48	602.53	602.34	602.81	602.58
GW03-008A-P3	DeCew	617.88	617.82	NA	617.49	617.88	617.66	617.73
GW03-008B-P4	2	615.00	615.41	616.07	616.10	615.53	615.75	615.64
GW03-008B-P5	9A	616.68	615.63	NA	616.57	616.68	616.10	616.29
GW03-008B-P6	9B	567.36	568.06	NA	567.00	567.36	567.53	567.47
GW03-009A-P1	9A	615.60	615.41	NA	616.22	615.60	615.81	615.74
GW03-009A-P2	10	601.63	602.70	602.67	602.62	602.15	602.66	602.41
GW03-009A-P3	DeCew	587.32	583.52	NA	559.21	587.32	571.36	576.68
GW03-009B-P4	2	617.80	617.97	618.83	618.76	618.31	618.36	618.34
GW03-009B-P5	8B	617.52	617.00	NA	618.22	617.52	617.61	617.58
GW03-009B-P6	9B	618.09	617.95	NA	618.71	618.09	618.33	618.25
GW03-010A-P1	9A	591.72	591.59	NA	591.55	591.72	591.57	591.62
GW03-010A-P2	10	601.61	602.44	602.63	602.65	602.12	602.54	602.33
GW03-010A-P3	DeCew	603.97	592.66[1]	NA	540.76[1]	603.97	566.71	579.13
GW03-010B-P4	8A	610.07	609.98	NA	610.27	610.07	610.12	610.10
GW03-010B-P5	8B	605.28	605.45	NA	606.57	605.28	606.01	605.77
GW03-010B-P6	9B	595.85	595.46	NA	595.81	595.85	595.63	595.71
GW03-010C-P7	2	609.80	609.98	610.78	610.26	610.29	610.12	610.20
GW03-011A-P1	9A	580.87	581.49	NA	582.97	580.87	582.23	581.78
GW03-011A-P2	10	591.70	592.84	590.10	590.18	590.90	591.51	591.20

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TABLE 5.3.1-1 (CONT.)

AVERAGE HEAD ELEVATION, GW03-001 THROUGH GW03-017

Location	Model Layer	Average Head						
		Tourist Season		Non-Tourist Season		All Seasons		All Seasons
		Datalogger	Manual	Datalogger	Manual	Datalogger	Manual	All Data
GW03-011A-P3	DeCew	591.20	591.26	NA	588.26	591.20	589.76	590.24
GW03-011B-P4	8A	603.29	603.43	NA	604.49	603.29	603.96	603.73
GW03-011B-P5	9B	531.01	530.86	NA	530.61	531.01	530.73	530.83
GW03-011C-P7	2	603.40	603.36	604.42	604.48	603.91	603.92	603.92
GW03-011C-P8	8B	600.64	600.99	NA	601.81	600.64	601.40	601.15
GW03-012A-P2	10	555.88	558.08	551.88	551.73	553.88	554.90	554.39
GW03-012A-P3	DeCew	551.62	552.11	NA	546.88	551.62	549.50	550.20
GW03-012B-P4	8A	NA	584.04	NA	584.89	NA	584.46	584.46
GW03-012B-P5	9A	NA	564.28	NA	564.40	NA	564.34	564.34
GW03-012B-P6	9B	555.76	557.89	NA	551.20	555.76	554.54	554.95
GW03-012C-P7	2	NA	597.85	NA	598.35	NA	598.10	598.10
GW03-013A-P1	8B	557.96	560.00	NA	558.21	557.96	559.10	558.72
GW03-013A-P2	10	555.97	558.21	551.84	551.52	553.91	554.87	554.39
GW03-013A-P3	DeCew	555.51	558.12	NA	551.40	555.51	554.76	555.01
GW03-013B-P4	8A	558.81	559.09	NA	558.30	558.81	558.70	558.73
GW03-013B-P5	9A	555.69	558.12	NA	551.45	555.69	554.78	555.09
GW03-013B-P6	9B	552.18	549.39	NA	519.08[1]	552.18	534.23	540.21
GW03-013C-P7	2	565.40	565.46	565.89	565.86	565.65	565.66	565.65
GW03-014A-P1	8B	552.42	553.20	NA	552.12[1]	552.42	552.66	552.58
GW03-014A-P2	10	NA	465.32	NA	465.85	NA	465.58	465.58
GW03-014A-P3	DeCew	547.45	547.21	547.11	547.02	547.28	547.11	547.20

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TABLE 5.3.1-1 (CONT.)

AVERAGE HEAD ELEVATION, GW03-001 THROUGH GW03-017

Location	Model Layer	Average Head						
		Tourist Season		Non-Tourist Season		All Seasons		All Seasons
		Datalogger	Manual	Datalogger	Manual	Datalogger	Manual	All Data
GW03-014B-P4	8A	557.50	557.89	NA	555.33	557.50	556.61	556.91
GW03-014B-P5	9A	556.95	558.95	NA	554.10	556.95	556.52	556.67
GW03-014B-P6	9B	556.97	558.98	NA	554.16	556.97	556.57	556.70
GW03-014C-P7	2	557.74	557.95	555.52	554.94	556.63	556.45	556.54
GW03-015A-P1	8A	557.86	559.60	NA	555.71	557.86	557.65	557.72
GW03-015A-P2	10	555.49	555.87	554.14	554.08	554.81	554.97	554.89
GW03-015A-P3	DeCew	NA	436.42	NA	438.07	NA	437.24	437.24
GW03-015B-P4	8B	558.30	560.04	NA	556.16	558.30	558.10	558.17
GW03-015B-P5	9A	557.82	559.44	NA	555.63	557.82	557.54	557.63
GW03-015B-P6	9B	557.71	559.55	NA	555.50	557.71	557.52	557.58
GW03-015C-P7	2	557.97	558.98	555.82	555.66	556.89	557.32	557.10
GW03-016A-P1	8A	NA	559.42	556.19	556.12	556.19	557.77	557.24
GW03-016A-P2	10	557.97	559.22	556.11	555.82	557.04	557.52	557.28
GW03-016A-P3	DeCew	NA	559.23	555.46	555.50	555.46	557.37	556.73
GW03-016B-P4	7	NA	558.61	555.55	555.37	555.55	556.99	556.51
GW03-016B-P5	8B	NA	558.92	555.85	555.78	555.85	557.35	556.85
GW03-016B-P6	9B	NA	559.61	556.01	555.89	556.01	557.75	557.17
GW03-016C-P7	2	557.16	558.21	555.44	555.19	556.30	556.70	556.50
GW03-016C-P8	9A	NA	559.54	556.14	556.02	556.14	557.78	557.24
GW03-017A-P1	9B	NA	559.94	557.00	557.09	557.00	558.51	558.01
GW03-017A-P2	10	NA	560.53	557.24	557.45	557.24	558.99	558.40

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TABLE 5.3.1-1 (CONT.)

AVERAGE HEAD ELEVATION, GW03-001 THROUGH GW03-017

Location	Model Layer	Average Head						
		Tourist Season		Non-Tourist Season		All Seasons		All Seasons
		Datalogger	Manual	Datalogger	Manual	Datalogger	Manual	All Data
GW03-017A-P3	DeCew	NA	NA	NA	429.12	NA	429.12	429.12
GW03-017B-P4	7	NA	560.78	557.86	557.92	557.86	559.35	558.85
GW03-017B-P5	8A	NA	560.62	557.44	557.76	557.44	559.19	558.61
GW03-017B-P6	9A	NA	560.51	557.41	557.53	557.41	559.02	558.48
GW03-017C-P7	2	NA	560.68	557.81	557.84	557.81	559.26	558.78
GW03-017C-P8	6	NA	560.77	557.95	557.99	557.95	559.38	558.90
GW03-017C-P9	8B	NA	559.70	557.58	557.41	557.58	558.56	558.23

[1]Water level not fully recovered from development or recent sampling event.

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TABLE 5.3.4-1

2003 WATER LEVELS– RESERVOIR, FOREBAY, AND NIAGARA RIVER INTAKES

Water Level	Reservoir	Forebay	Intakes
Tourist Season			
Average	643.37	555.05	563.22
Maximum	658.56	568.21	564.29
Minimum	620.73	539.17	561.83
Non-Tourist Season			
Average	649.00	552.38	562.81
Maximum	658.66	564.63	563.83
Minimum	623.12	537.18	561.90

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TABLE 5.3.6-1

CREEK RECONNAISANCE, FISH CREEK FLOW PROFILE B-B'

Location	Distance From Initial point (feet)	Width of Interval (feet)	Depth (feet)	Area (square feet)	Velocity at 60% of Depth (feet per second)	Flow Volume (cubic feet per second)	% of Total Flow
B	1.0	0.250	0.000	0.000	0.000	0.000	0.0%
	1.5	0.500	0.200	0.100	0.280	0.028	12.1%
	2.0	0.500	0.360	0.180	0.100	0.018	7.8%
	2.5	0.500	0.350	0.175	0.130	0.023	9.8%
	3.0	0.500	0.310	0.155	0.140	0.022	9.4%
	3.5	0.500	0.270	0.135	0.300	0.041	17.5%
	4.0	0.500	0.290	0.145	0.220	0.032	13.8%
	4.5	0.500	0.260	0.130	0.230	0.030	12.9%
	5.0	0.500	0.250	0.125	0.180	0.023	9.7%
	5.5	0.500	0.240	0.120	0.140	0.017	7.2%
	6.0	0.500	0.200	0.100	0.000	0.000	0.0%
B'	6.5	0.250	0.000	0.000	0.000	0.000	0.0%
					Flow Volume Total =	0.232	

104 gallons per minute 149,977 gallons per day 6,249 gallons per hour 20,049 cubic feet per day

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TABLE 5.3.6-2

CREEK RECONNAISANCE, GILL CREEK FLOW PROFILE A-A'

Location	Distance From Initial point (feet)	Width of Interval (feet)	Depth (feet)	Area (square feet)	Velocity at 60% of Depth (feet per second)	Flow Volume (cubic feet per second)	% of Total Flow
A	1.0	0.25	0.00	0.00	0.00	0.00	0.0%
	1.5	0.50	0.30	0.15	0.00	0.00	0.0%
	2.0	0.50	0.40	0.20	0.01	0.00	0.3%
	2.5	0.50	0.55	0.28	0.01	0.00	0.5%
	3.0	0.50	0.75	0.38	0.03	0.01	1.6%
	3.5	0.50	0.83	0.42	0.05	0.02	3.4%
	4.0	0.50	0.90	0.45	0.08	0.04	6.0%
	4.5	0.50	0.93	0.47	0.08	0.04	6.2%
	5.0	0.50	0.92	0.46	0.09	0.04	6.9%
	5.5	0.50	0.90	0.45	0.14	0.06	10.4%
	6.0	0.50	0.90	0.45	0.16	0.07	11.9%
	6.5	0.50	0.95	0.48	0.14	0.07	11.0%
	7.0	0.50	0.96	0.48	0.12	0.06	9.5%
	7.5	0.50	0.92	0.46	0.13	0.06	9.9%
	8.0	0.50	0.90	0.45	0.13	0.06	9.7%
	8.5	0.50	0.85	0.43	0.11	0.05	7.7%
	9.0	0.50	0.73	0.37	0.04	0.01	2.4%
	9.5	0.50	0.71	0.36	0.03	0.01	1.8%
	10	0.50	0.53	0.27	0.02	0.01	0.9%
	10.5	0.50	0.46	0.23	0.00	0.00	0.0%
	11	0.50	0.42	0.21	0.00	0.00	0.0%
	11.5	0.50	0.21	0.11	0.00	0.00	0.0%
	12	0.50	0.09	0.05	0.00	0.00	0.0%
A'	12.5	0.25	0.00	0.00	0.00	0.00	0.0%
					Flow Volume Total =	0.604	

271 gallons per minute
16,270 gallons per hour

390,487 gallons per day
52,200 cubic feet per day

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TABLE 5.3.6-3

CREEK RECONNAISANCE, GILL CREEK FLOW PROFILE B-B'

Location	Distance From Initial point (feet)	Width of Interval (feet)	Depth (feet)	Area (square feet)	Velocity at 60% of Depth (feet per second)	Flow Volume (cubic feet per second)	% of Total Flow
B	1.0	0.250	0.000	0.000	0.000	0.000	0.0%
	1.5	0.500	0.210	0.105	0.010	0.001	0.1%
	2.0	0.500	0.350	0.175	0.020	0.004	0.4%
	2.5	0.500	0.500	0.250	0.050	0.013	1.6%
	3.0	0.500	0.510	0.255	0.070	0.018	2.3%
	3.5	0.500	0.550	0.275	0.090	0.025	3.1%
	4.0	0.500	0.520	0.260	0.200	0.052	6.6%
	4.5	0.500	0.620	0.310	0.250	0.078	9.8%
	5.0	0.500	0.550	0.275	0.380	0.105	13.2%
	5.5	0.500	0.550	0.275	0.450	0.124	15.6%
	6.0	0.500	0.640	0.320	0.380	0.122	15.4%
	6.5	0.500	0.500	0.250	0.510	0.128	16.1%
	7.0	0.500	0.450	0.225	0.330	0.074	9.4%
	7.5	0.500	0.420	0.210	0.200	0.042	5.3%
	8.0	0.500	0.300	0.150	0.050	0.008	0.9%
	8.5	0.500	0.200	0.100	0.010	0.001	0.1%
B'	9	0.250	0.000	0.000	0.000	0.000	0.0%
					Flow Volume Total =	0.791	

355 gallons per minute
21,308 gallons per hour
511,397 gallons per day
68,364 cubic feet per day

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TABLE 5.4.4-1

GROUNDWATER INFILTRATION INTO THE FST BETWEEN DROP SHAFTS 14B AND 12

Location		Tourist Season	Non-tourist Season
East of conduits	At East Bypass	3,580 gpm	2,740 gpm
West of conduits	At West Bypass	1,250 gpm	1,130 gpm
	At Drop Shaft 12	250 gpm	240 gpm
	Subtotal West	1,500 gpm	1,370 gpm
Total GW infiltration		5,080 gpm	4,110 gpm

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TABLE 5.5.2-1

CONCENTRATION RANGES FOR MAJOR IONS AND GENERAL WATER QUALITY PARAMETERS, GROUNDWATER SAMPLES

Parameter	Min	Layer (piezometer)	Max	Layer (piezometer)
Calcium (ug/L)	41,900	2 (GW03-016C-P7)	30,100,000	Gasport/DeCew (GW03-014A-P3)
Magnesium (ug/L)	8,670	7 (GW03-017B-P4)	9,870,000	Gasport/DeCew (GW03-014A-P3)
Sodium (ug/L)	6,280	9A (GW03-007-P1)	38,100,000	Gasport/DeCew (GW03-014A-P3)
Alkalinity (total) (mg/L)	ND	9B (GW03-015B-P6)	543	8B (GW03-014A-P1)
Chloride (mg/L)	4.6	8B (GW03-011C-P8)	297,000	Gasport/DeCew (GW03-014A-P3)
Sulfate (mg/L)	39.7	2 (GW03-016C-P7)	14,400	10 (GW03-017A-P2)
Hardness (mg/L)	158	2 (GW03-016B-P7)	65,400	Gasport/DeCew (GW03-014A-P3)
Total dissolved solids (mg/L)	194	2 (GW03-016C-P7)	176,000	Gasport/DeCew (GW03-014A-P3)
Total organic carbon (mg/L)	ND	several layers and wells	19.7	9A (GW03-011A-P1)
Total suspended solids (mg/L)	ND	several layers and wells	2,820	Gasport/DeCew (GW03-005A-P2)

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FIGURE 5.1.2-1

MIGRATION OF WATER FROM LEWISTON RESERVOIR, LONG-TERM AVERAGE CONDITIONS, RESERVOIR AT 640 FEET

[NIP – General Location Maps]

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FIGURE 5.1.2-2

AREA OF INFLUENCE OF LEWISTON RESERVOIR, LONG-TERM AVERAGE CONDITIONS

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FIGURE 5.1.2-3

GMS FOCUSED MODEL HYDRAULIC HEADS, WEATHERED BEDROCK (MODEL LAYER 2), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.2-4

GMS FOCUSED MODEL HYDRAULIC HEADS, ERAMOSA DOLOMITE (MODEL LAYER 8), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.2-5

GMS FOCUSED MODEL HYDRAULIC HEADS, GOAT ISLAND DOLOMITE (MODEL LAYER 9), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.2-6

GMS FOCUSED MODEL HYDRAULIC HEADS, GASPORT DOLOMITE (MODEL LAYER 10), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.3-1

GMS REGIONAL MODEL HYDRAULIC HEADS, ERAMOSA DOLOMITE (MODEL LAYER 8), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.3-2

GMS REGIONAL MODEL HYDRAULIC HEADS, GOAT ISLAND DOLOMITE (MODEL LAYER 9), WITH GROUNDWATER FLOW DIRECTION

[NIP – General Location Maps]

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FIGURE 5.1.3-3

GMS REGIONAL MODEL HYDRAULIC HEADS, GASPORT DOLOMITE (MODEL LAYER 10), WITH GROUNDWATER FLOW DIRECTION

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FIGURE 5.2-1

GEOLOGIC CROSS-SECTION A-A'

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FIGURE 5.2-2

GEOLOGIC CROSS-SECTION B-B'

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FIGURE 5.2-3

GEOLOGIC CROSS-SECTION C-C'

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FIGURE 5.2-4

GEOLOGIC CROSS-SECTION D-D'

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FIGURE 5.2.2-1

STRATIGRAPHIC PROFILE WITH MODEL LAYERS

[NIP – General Location Maps]

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FIGURE 5.2.4-1

STRATIGRAPHIC CONTACT SUBCROP MAP

[NIP – General Location Maps]

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FIGURE 5.3.2-1

OW-139, DATALOGGER AND MANUAL GROUNDWATER ELEVATIONS, JULY-DECEMBER 2003

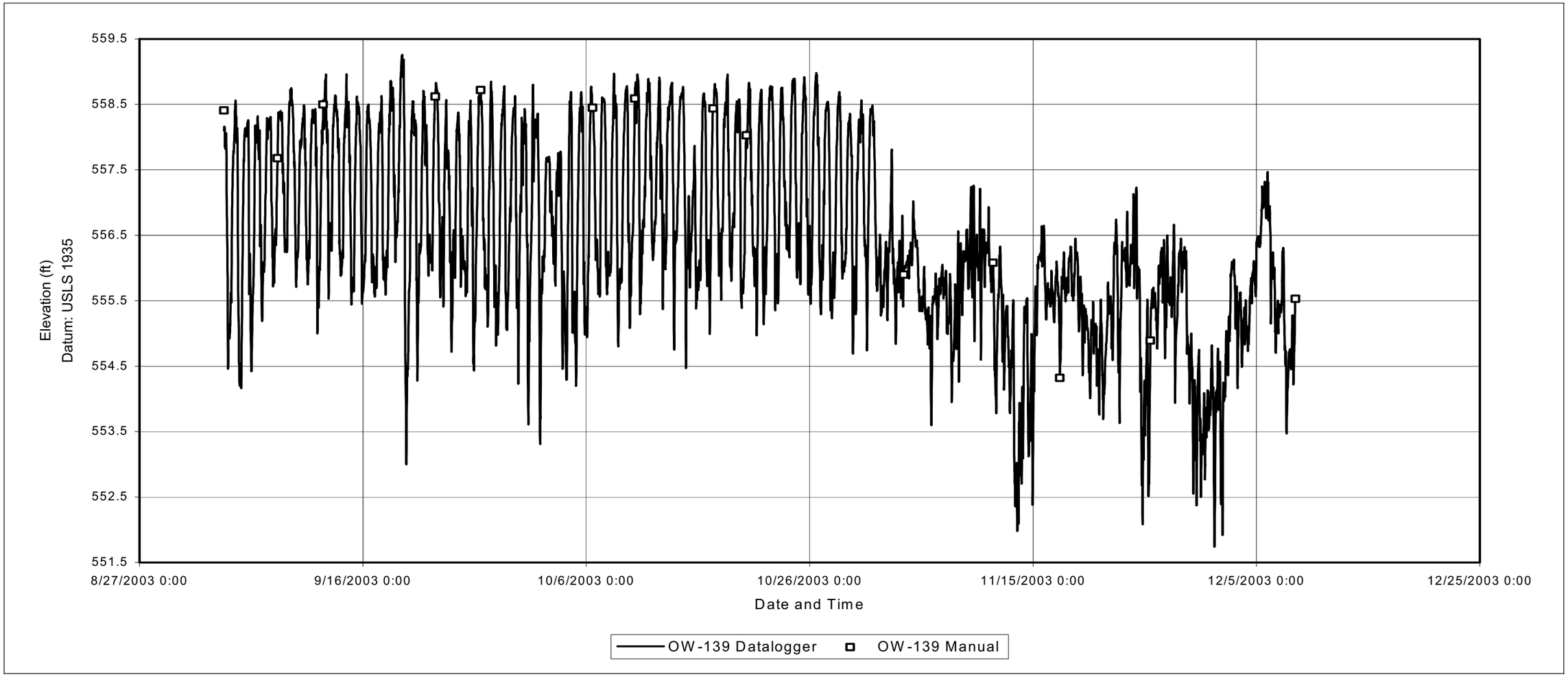

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FIGURE 5.3.2-2

OW-650D, DATALOGGER AND MANUAL GROUNDWATER ELEVATIONS, JULY-DECEMBER 2003

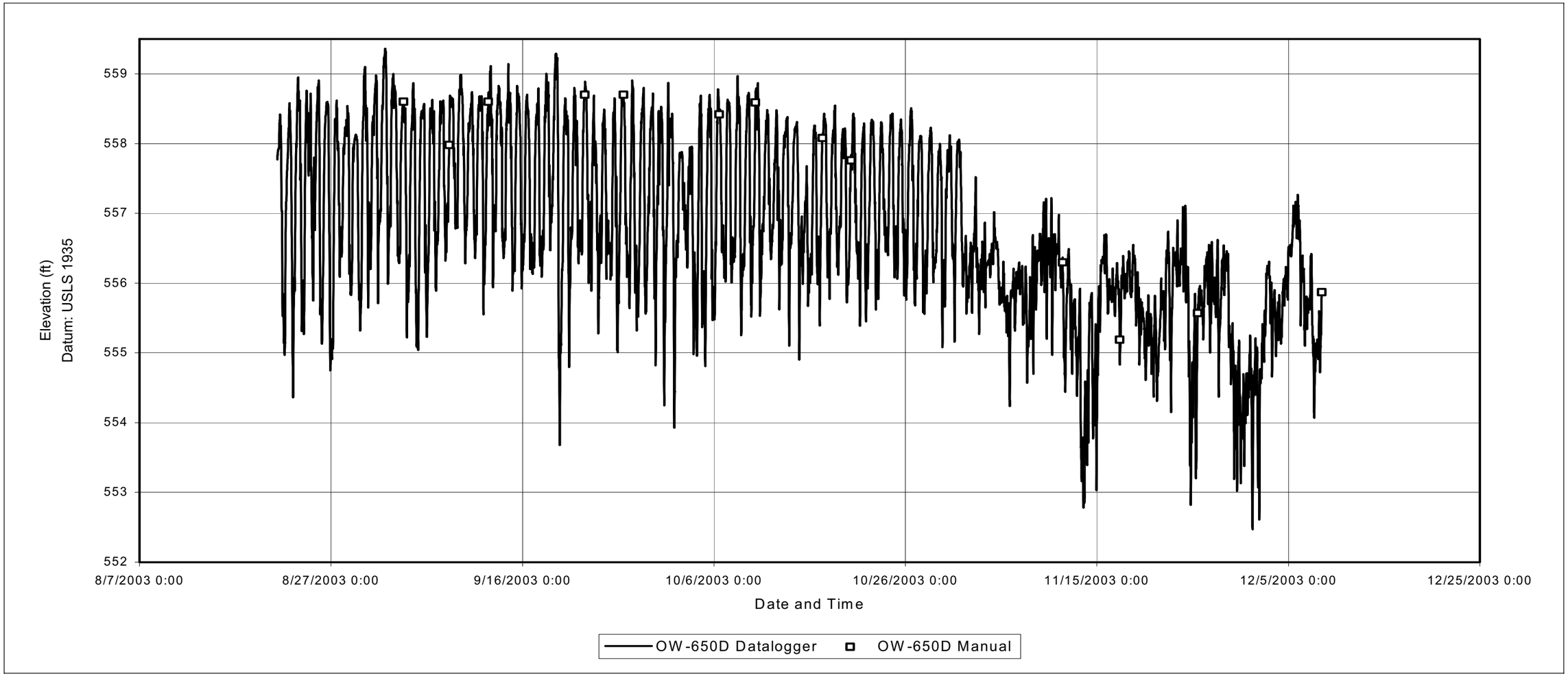

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FIGURE 5.3.3-1

PUMP STATION A (GW03-PSA) GROUNDWATER ELEVATIONS, AUGUST 2003-MAY 2004

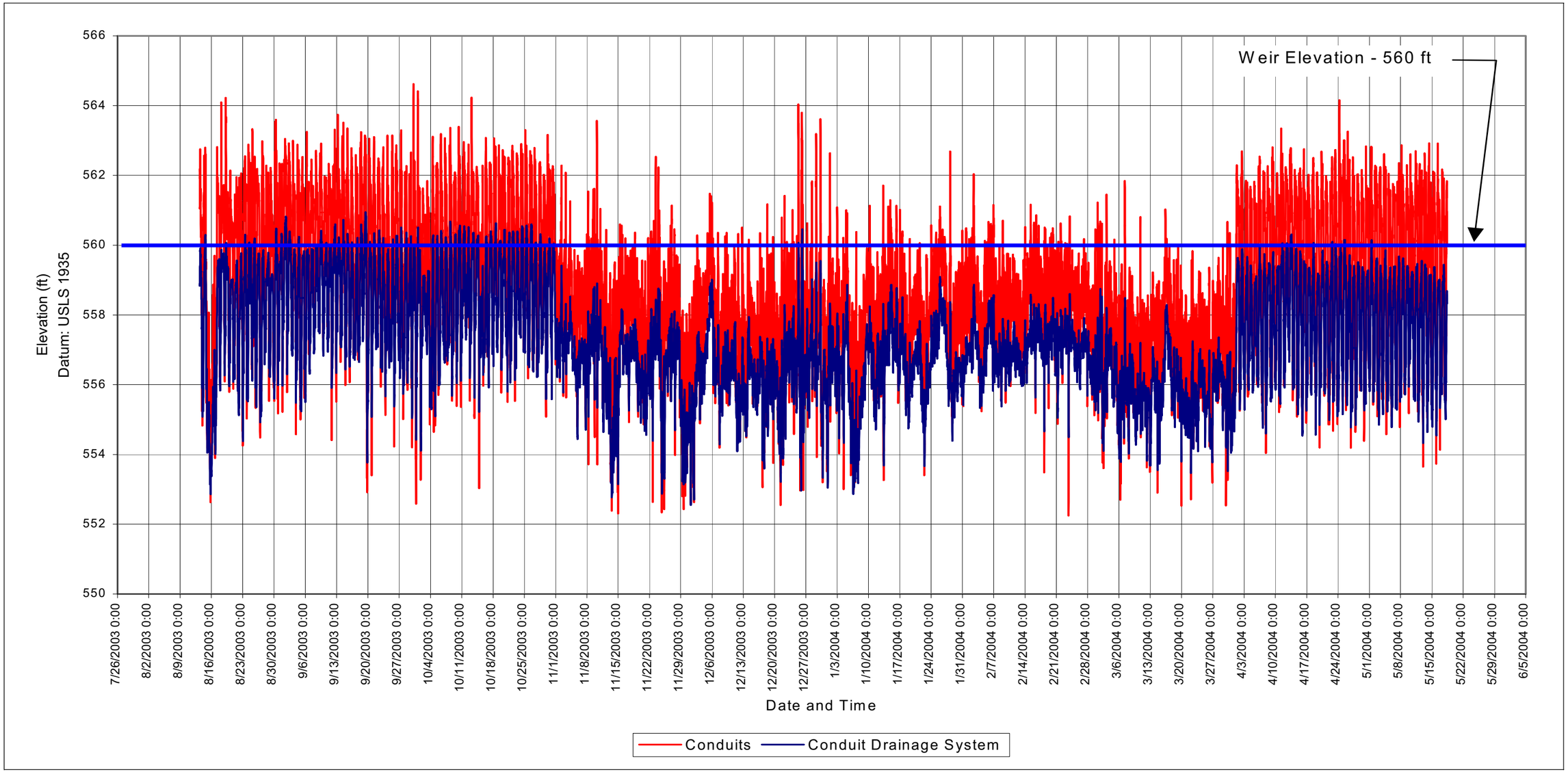

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FIGURE 5.3.3-2

PUMP STATION B (GW03-PSB) GROUNDWATER ELEVATIONS, AUGUST 2003-MAY 2004

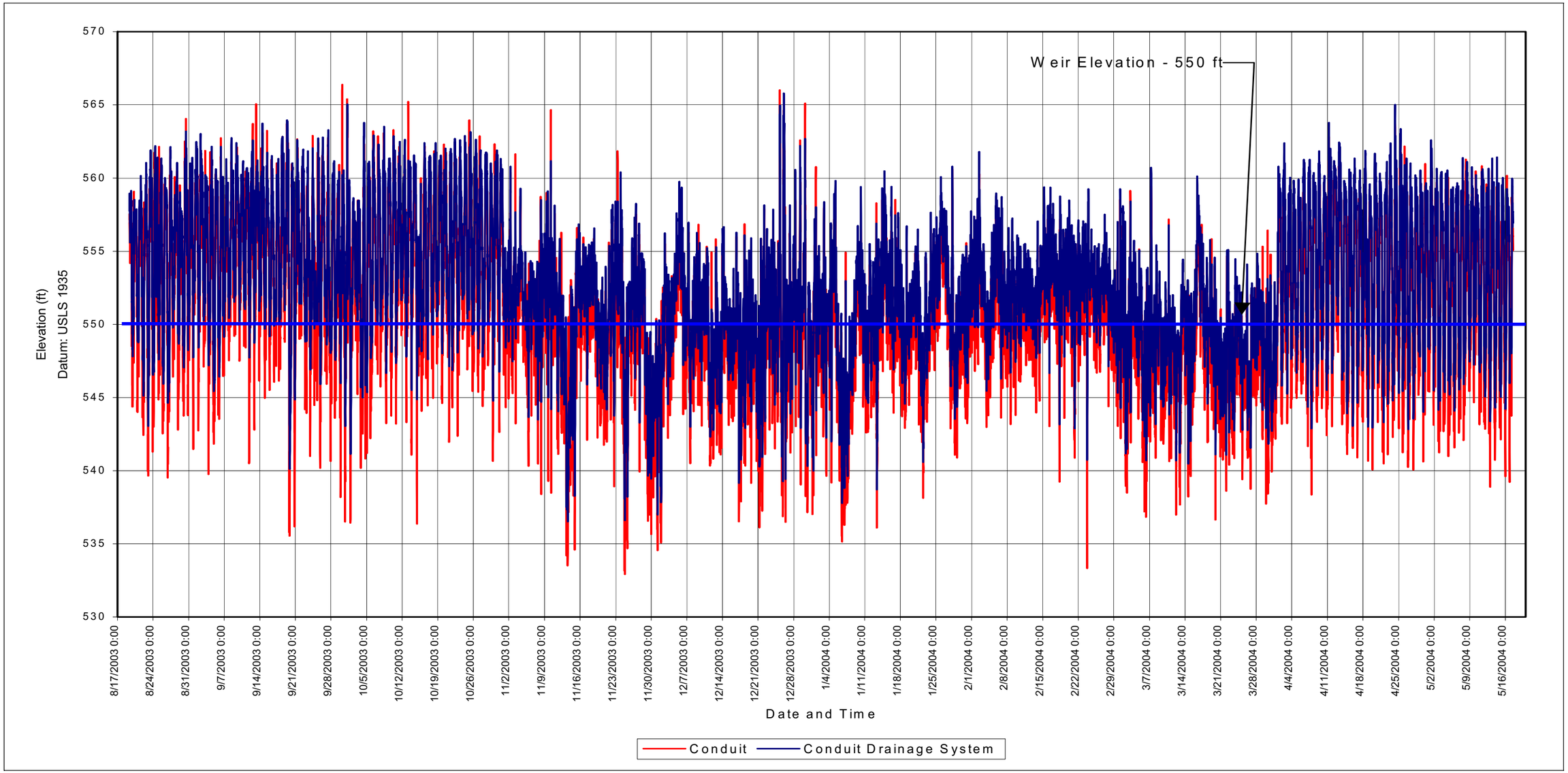

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FIGURE 5.3.4-1

GN-RESERVOIR, GN-RIVER_INT, GN-FOREBAY, DATALOGGER SURFACE WATER ELEVATIONS, JULY-DECEMBER 2003

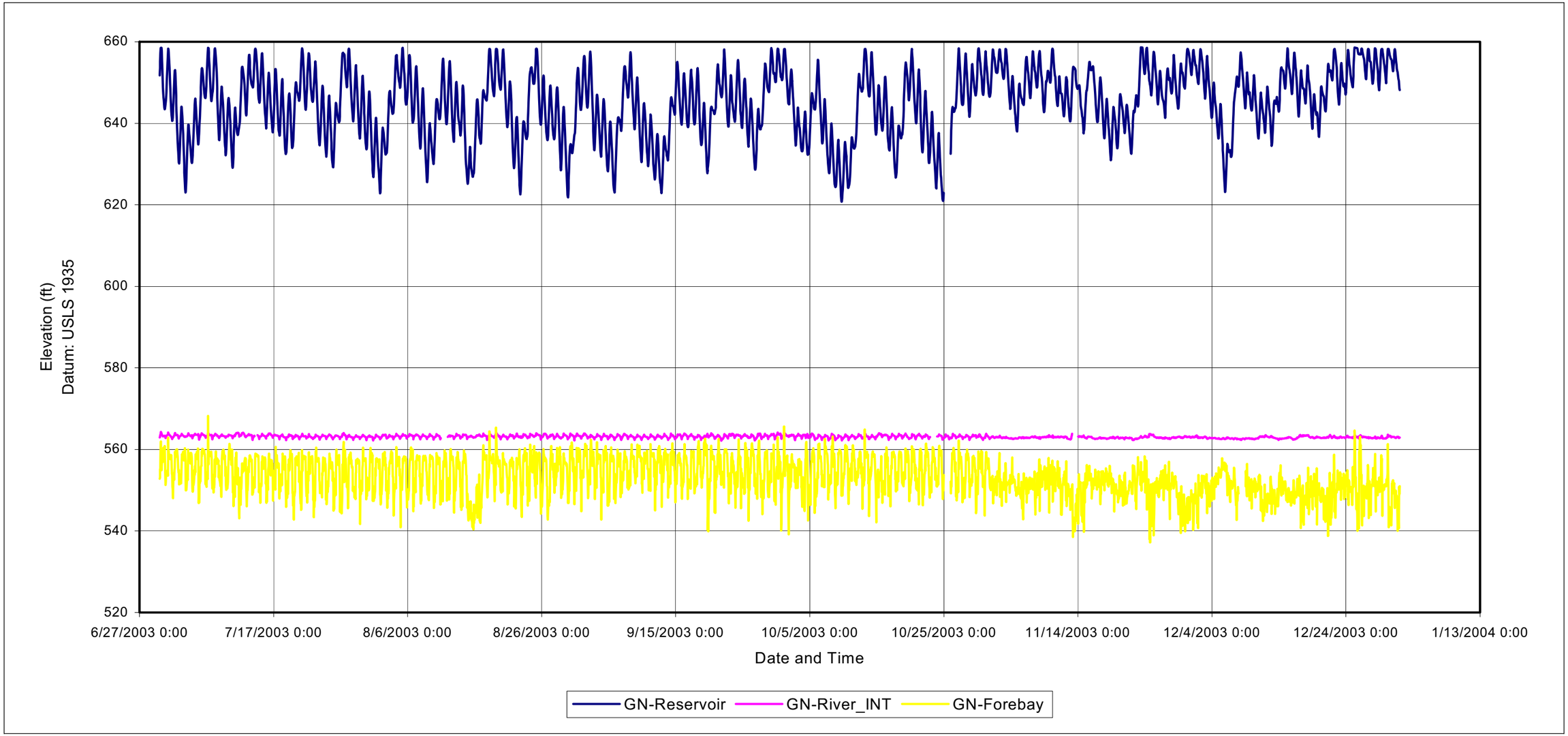

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FIGURE 5.3.6-1

ESCARPMENT RECONNAISSANCE, ONE OF THREE SMALL SEEPS ALONG SHORT SECTION

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FIGURE 5.3.6-2

LOCKPORT GROUP AND CLINTON GROUP INTERFACE, ESCARPMENT RECONNAISSANCE, SHORT SECTION

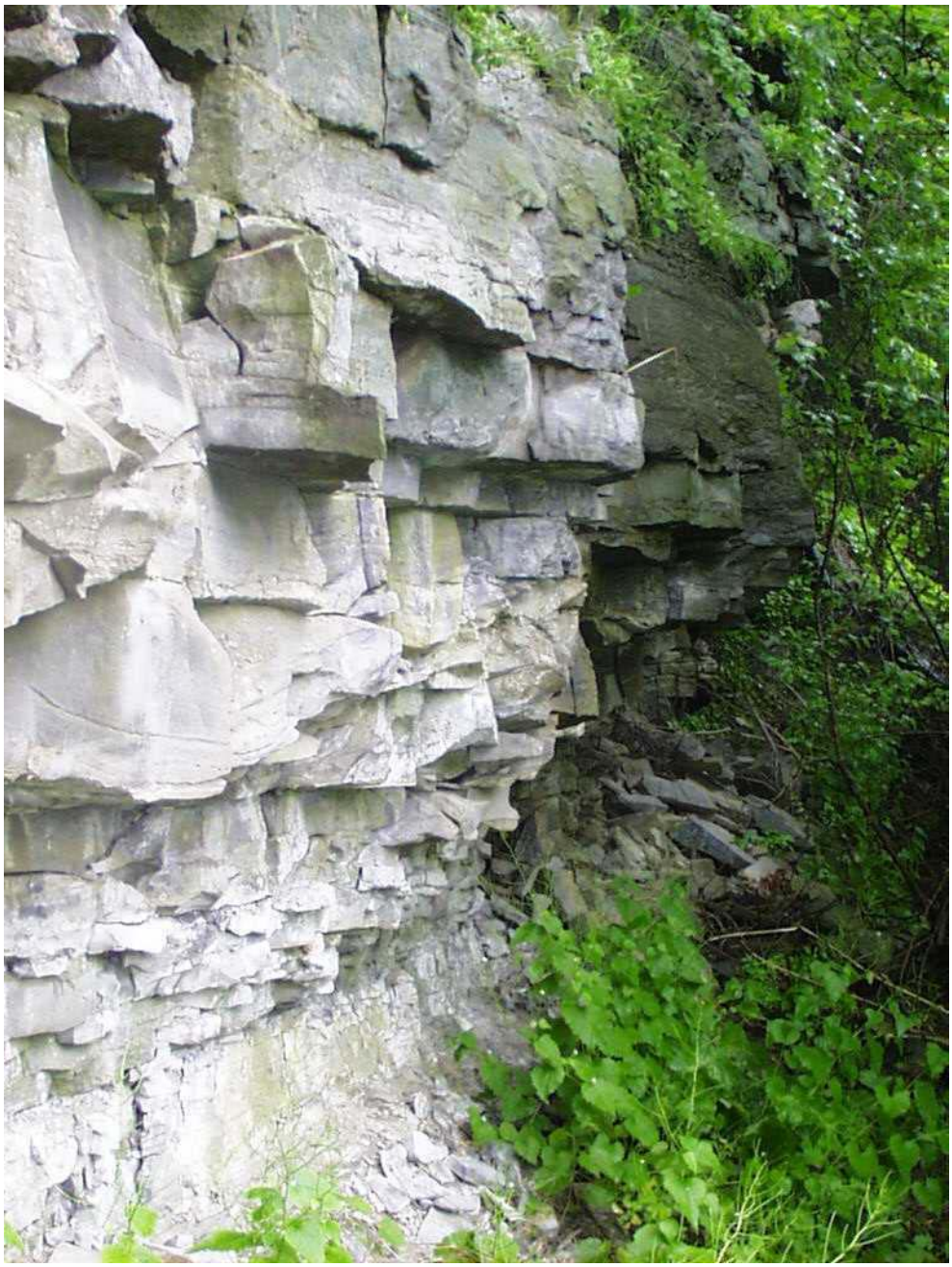

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FIGURE 5.3.6-3

ESCARPMENT RECONNAISSANCE, SEEP AT INACTIVE CISTERN, LONG SECTION

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FIGURE 5.3.6-4

GILL CREEK BEDROCK CUT ALONG SOUTH RESERVOIR DIKE, NEAR SOUTHEAST CORNER

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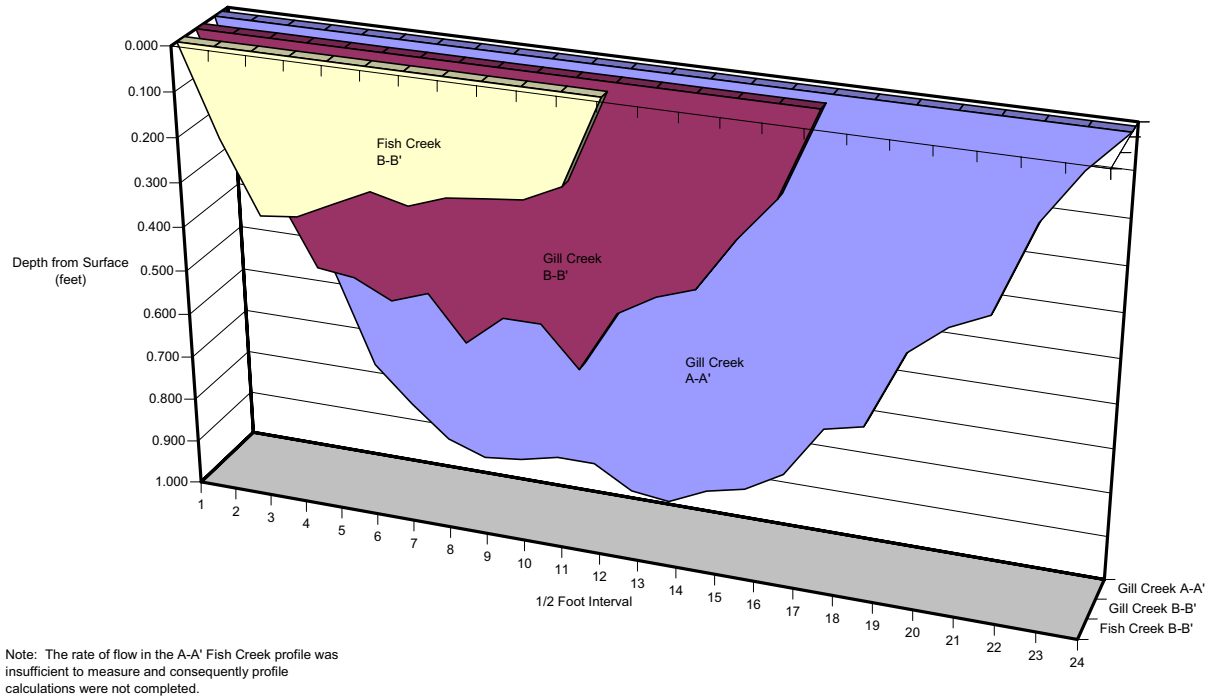
FIGURE 5.3.6-5

CREEK BOTTOM PROFILES, FISH AND GILL CREEKS, OCTOBER 2003



Note: The rate of flow in the A-A' Fish Creek profile was insufficient to measure and consequently profile calculations were not completed.

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FIGURE 5.4.1-1

FALLS STREET TUNNEL UPSTREAM OF DROP SHAFT 14A

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FIGURE 5.4.1-2

FALLS STREET TUNNEL DOWNSTREAM OF DROP SHAFT 14A

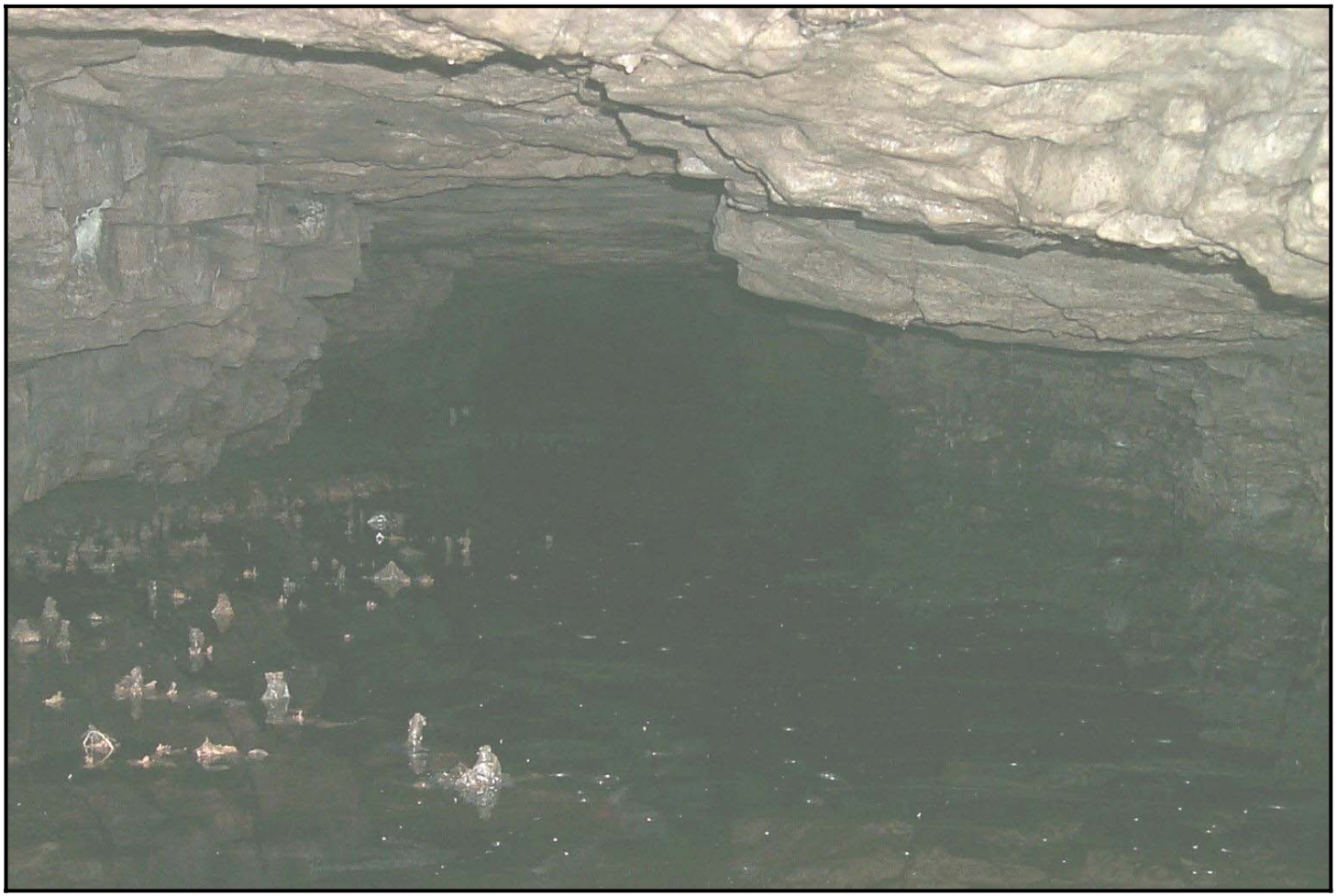

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FIGURE 5.4.1-3

PIPE AT DROP SHAFT 14A CONNECTING FALLS STREET TUNNEL AND SOUTH SIDE INTERCEPTOR

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FIGURE 5.4.1-4

DOWNSTREAM VIEW OF WEIR AT DROP SHAFT 12

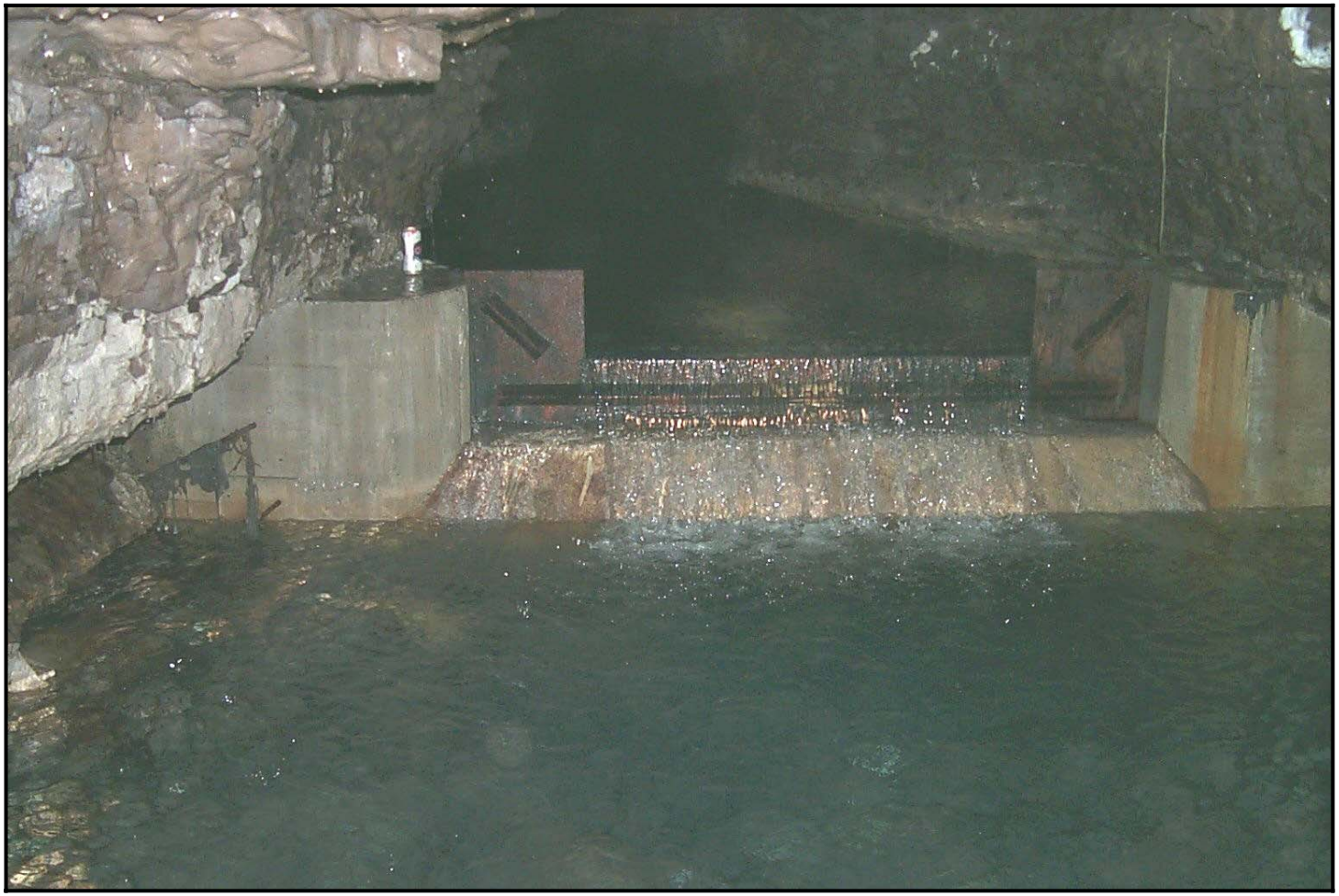

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FIGURE 5.4.1-5

CLOSE-UP OF WEIR AT DROP SHAFT 12 – END CONTRACTION

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FIGURE 5.4.1-6

CLOSE-UP OF WEIR AT DROP SHAFT 12 – FLOW DEPTH AND DROP

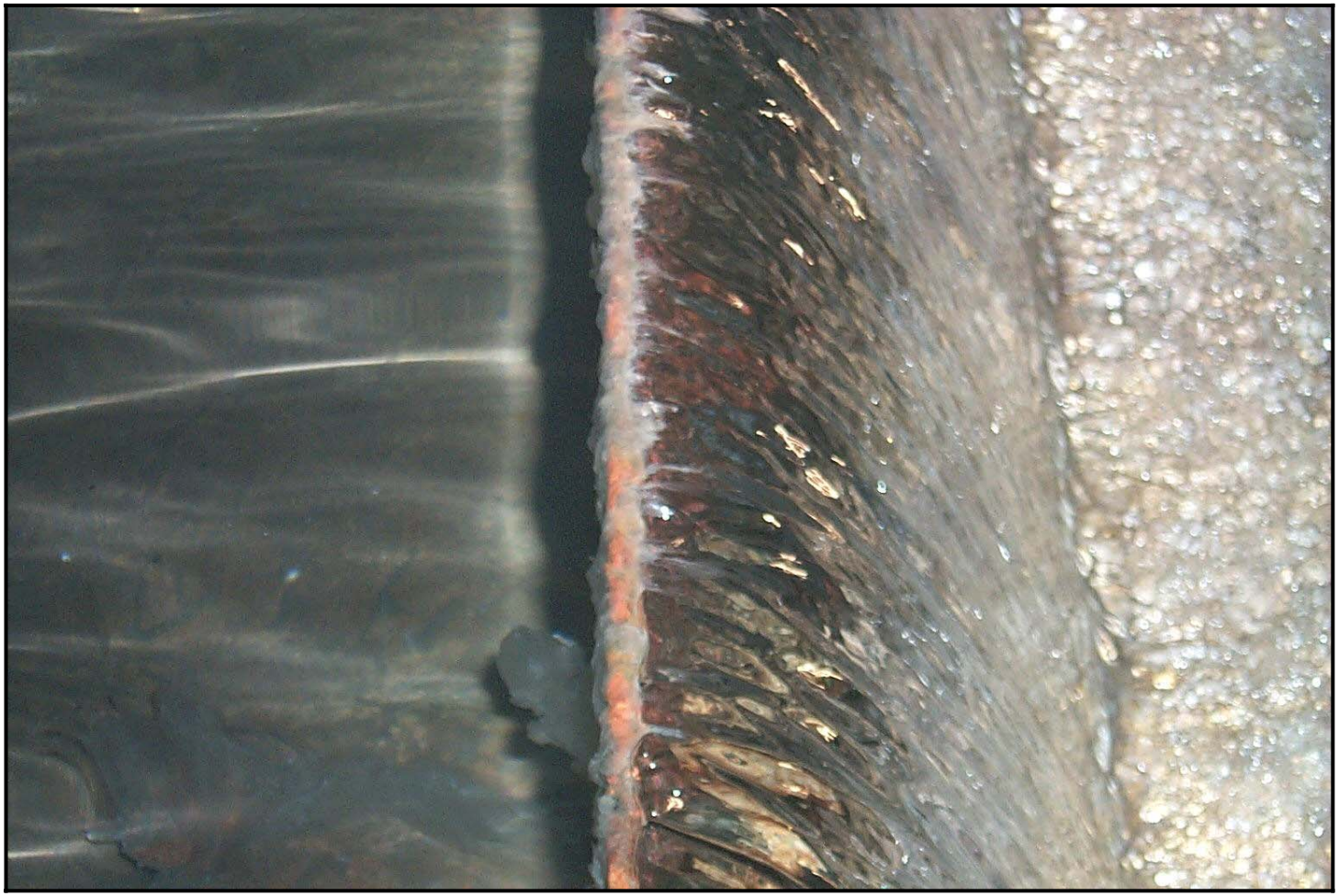

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FIGURE 5.4.1-7

DIVERSION DAM UPSTREAM OF DROP SHAFT 13A

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FIGURE 5.4.1-8

FALLS STREET TUNNEL UPSTREAM OF DROP SHAFT 13A

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FIGURE 5.4.1-9

FALLS STREET TUNNEL UPSTREAM OF EAST BYPASS GATE

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FIGURE 5.4.1-10

EAST BYPASS GATE STRUCTURE, NORTH SIDE

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FIGURE 5.4.1-11

MAINLINE TUNNEL LOOKING WEST FROM DS#13A

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FIGURE 5.4.1-12

WEST BYPASS GATE STRUCTURE

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FIGURE 5.4.1-13

WEST BYPASS PIPE

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FIGURE 5.4.2-1

PRECIPITATION MEASURED AT PUMP STATION A

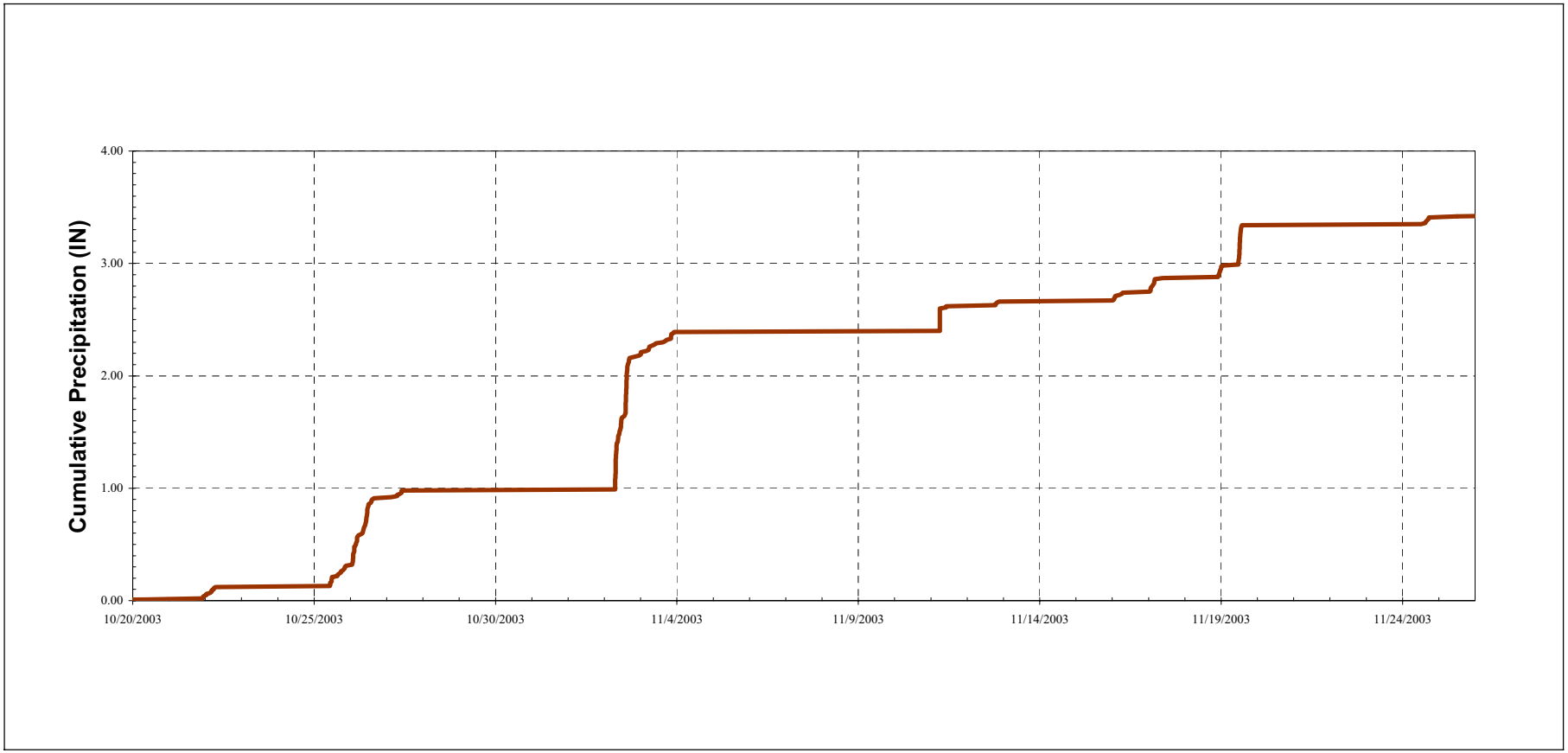

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FIGURE 5.4.2-2

DRY WEATHER FLOW PATTERN IN THE STUDY AREA

[NIP – General Location Maps]

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FIGURE 5.4.4-1

REVERSALS OF FLOW DIRECTION IN WEST BYPASS DURING WET WEATHER EVENTS

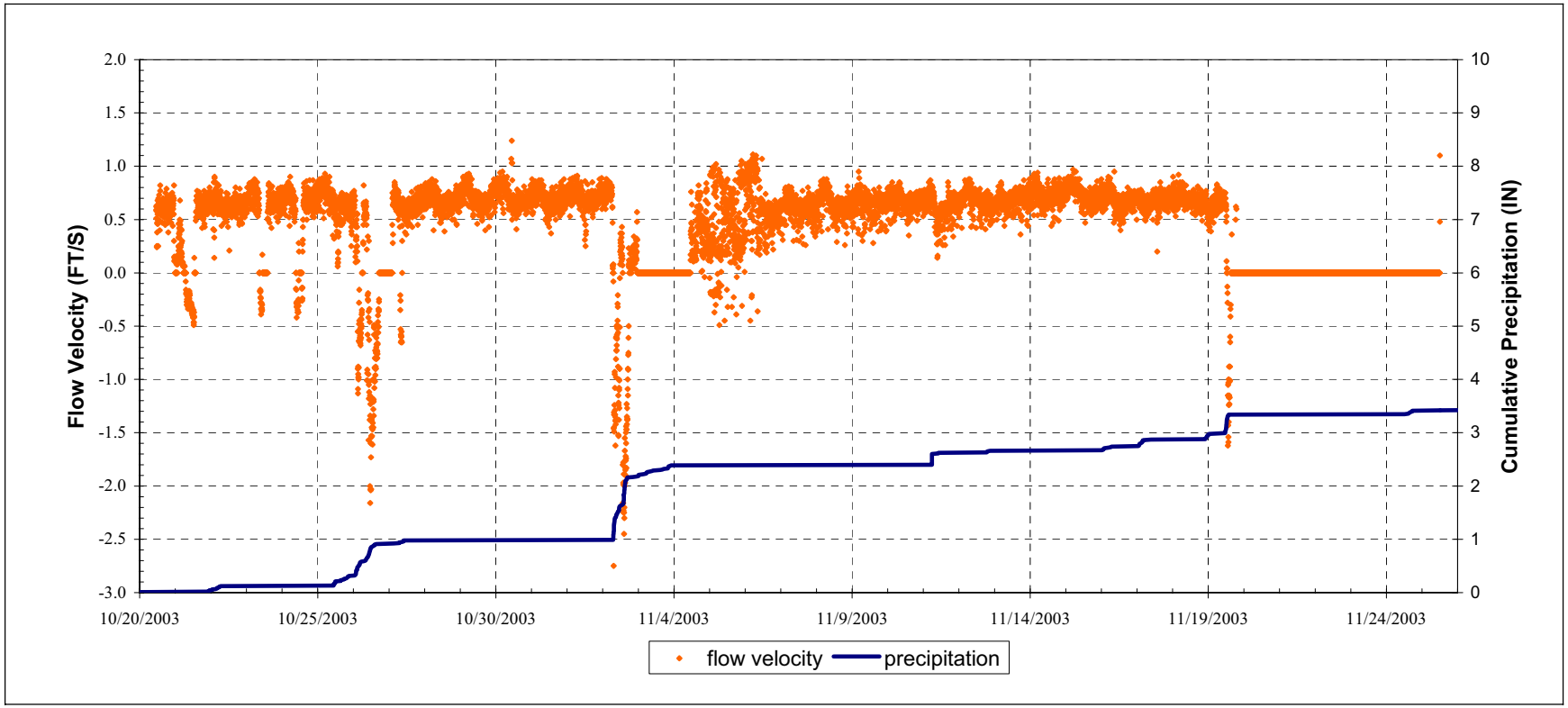

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FIGURE 5.4.4-2

FLOW RATES AT DROP SHAFT 12 WEIR

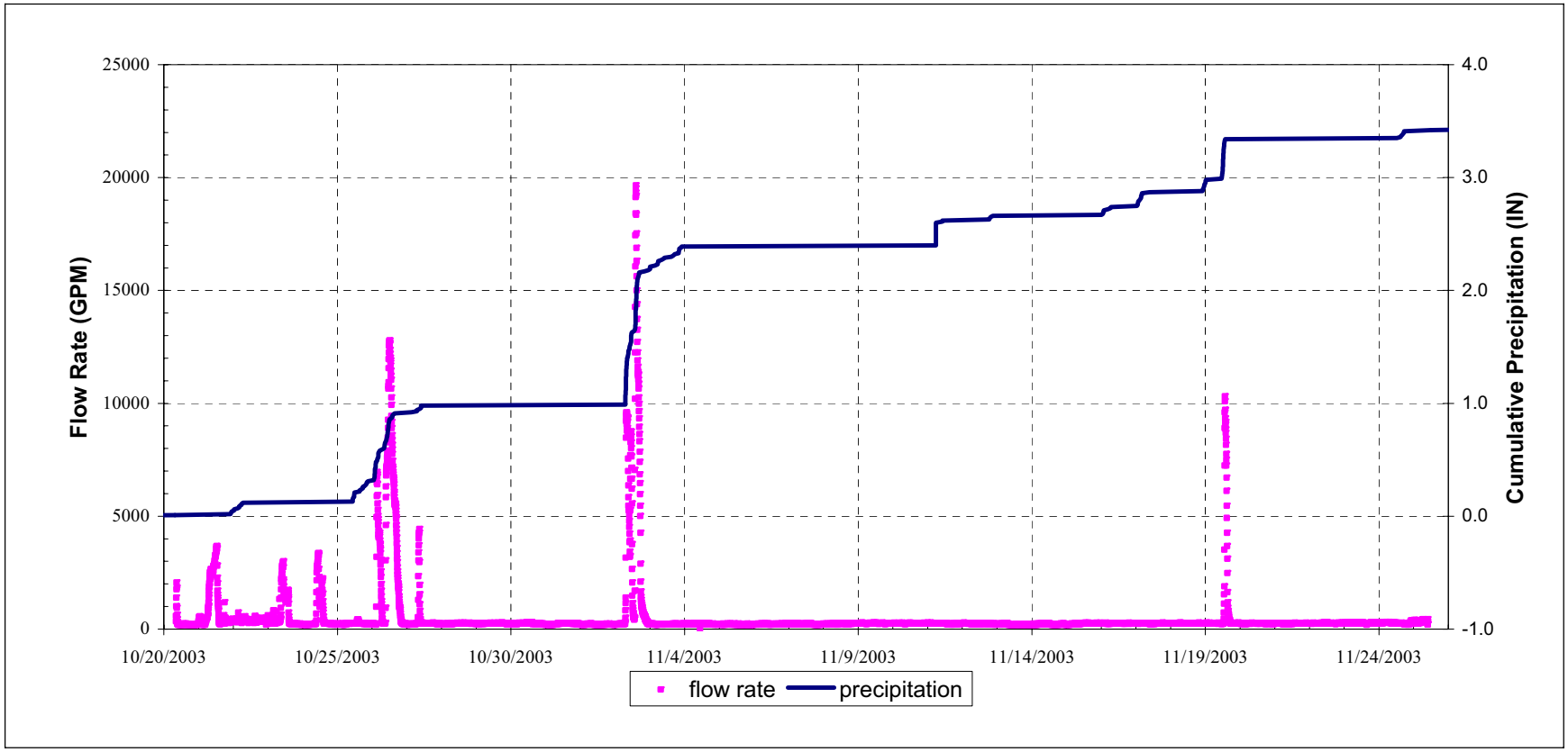

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FIGURE 5.4.4-3

DRY-WEATHER FLOW RATES AT DROP SHAFT 12 WEIR

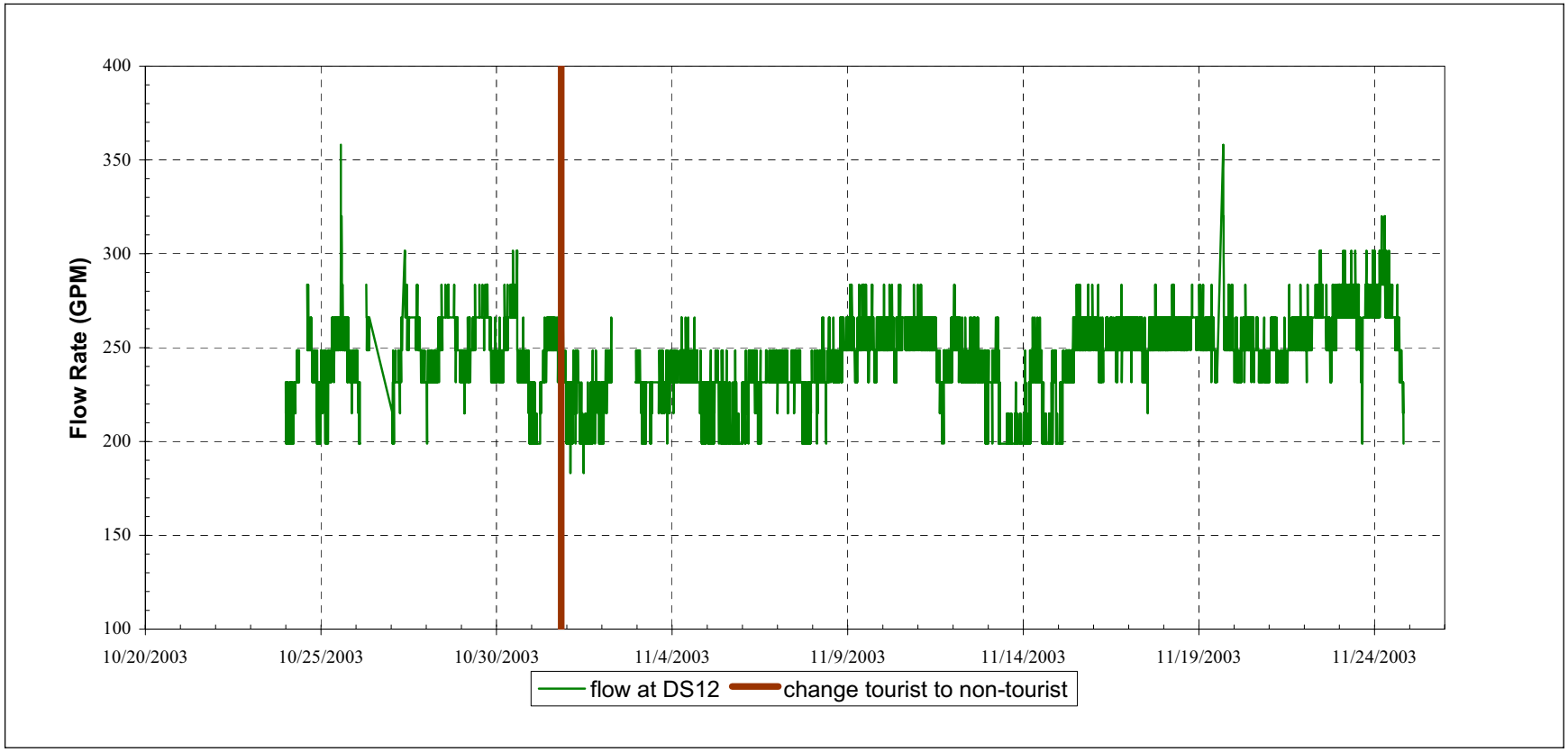

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FIGURE 5.4.4-4

FLOW RATES AT WEST BYPASS PIPE

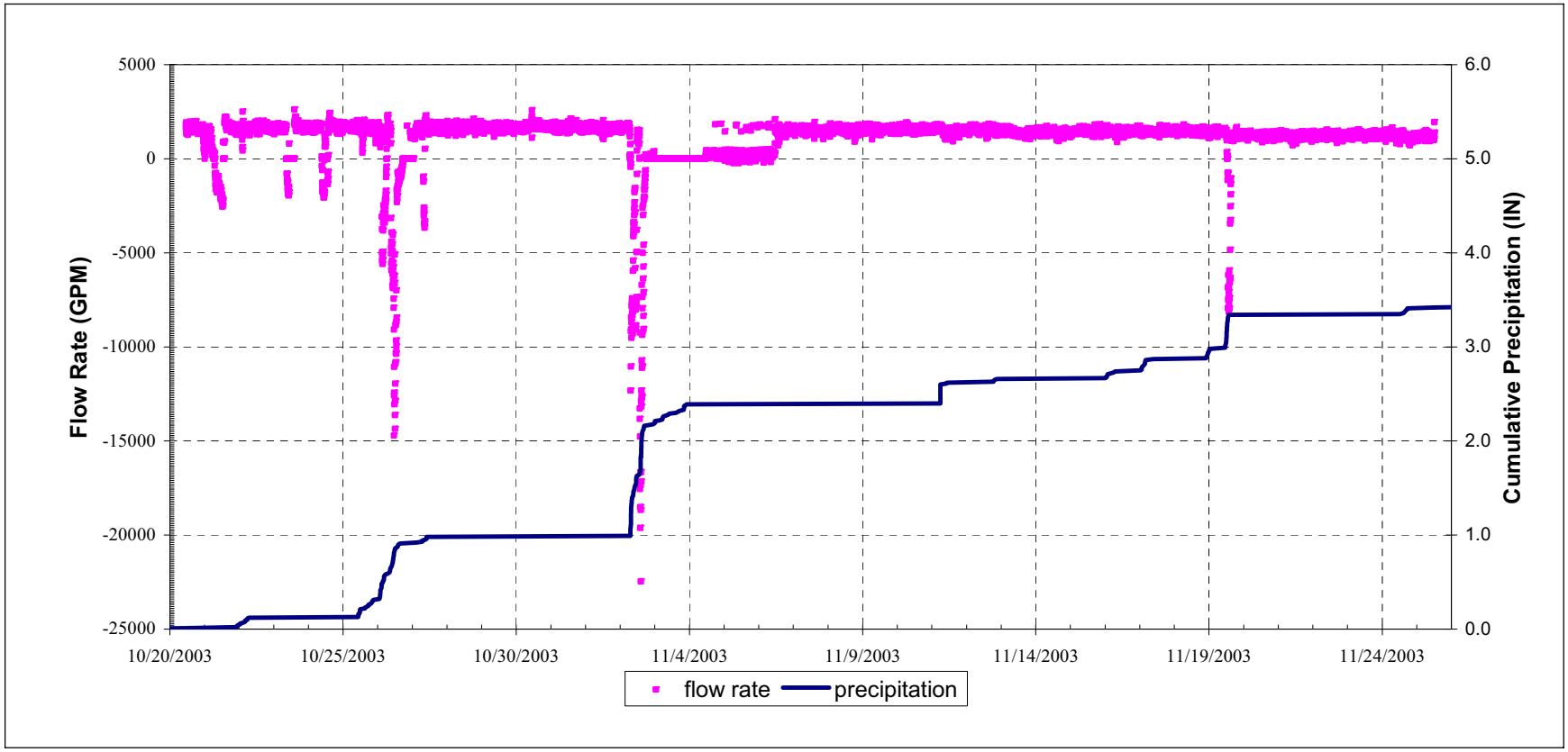

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FIGURE 5.4.4-5

DRY-WEATHER FLOW RATES AT WEST BYPASS PIPE

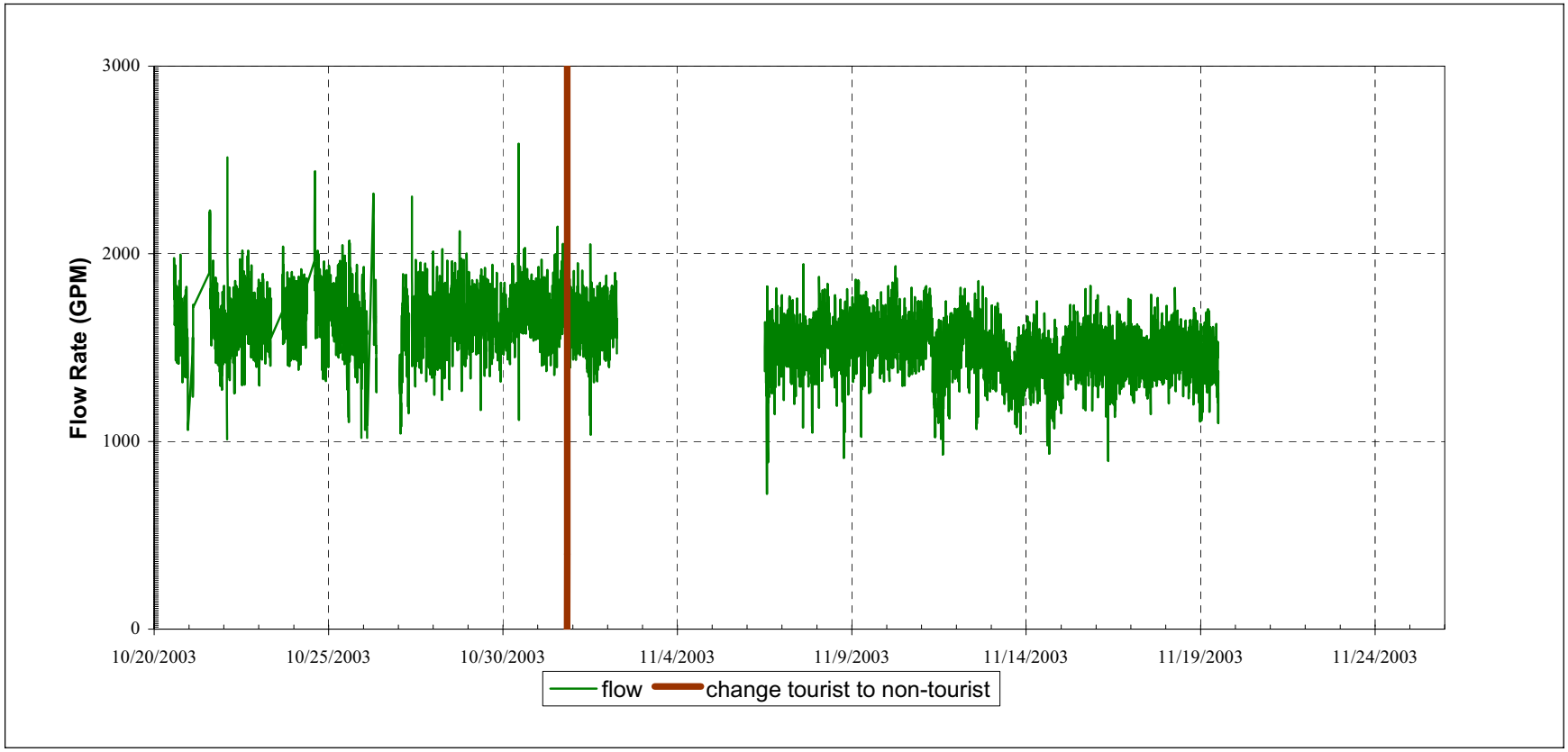

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FIGURE 5.4.4-6

FLOW RATES AT EAST BYPASS PIPE

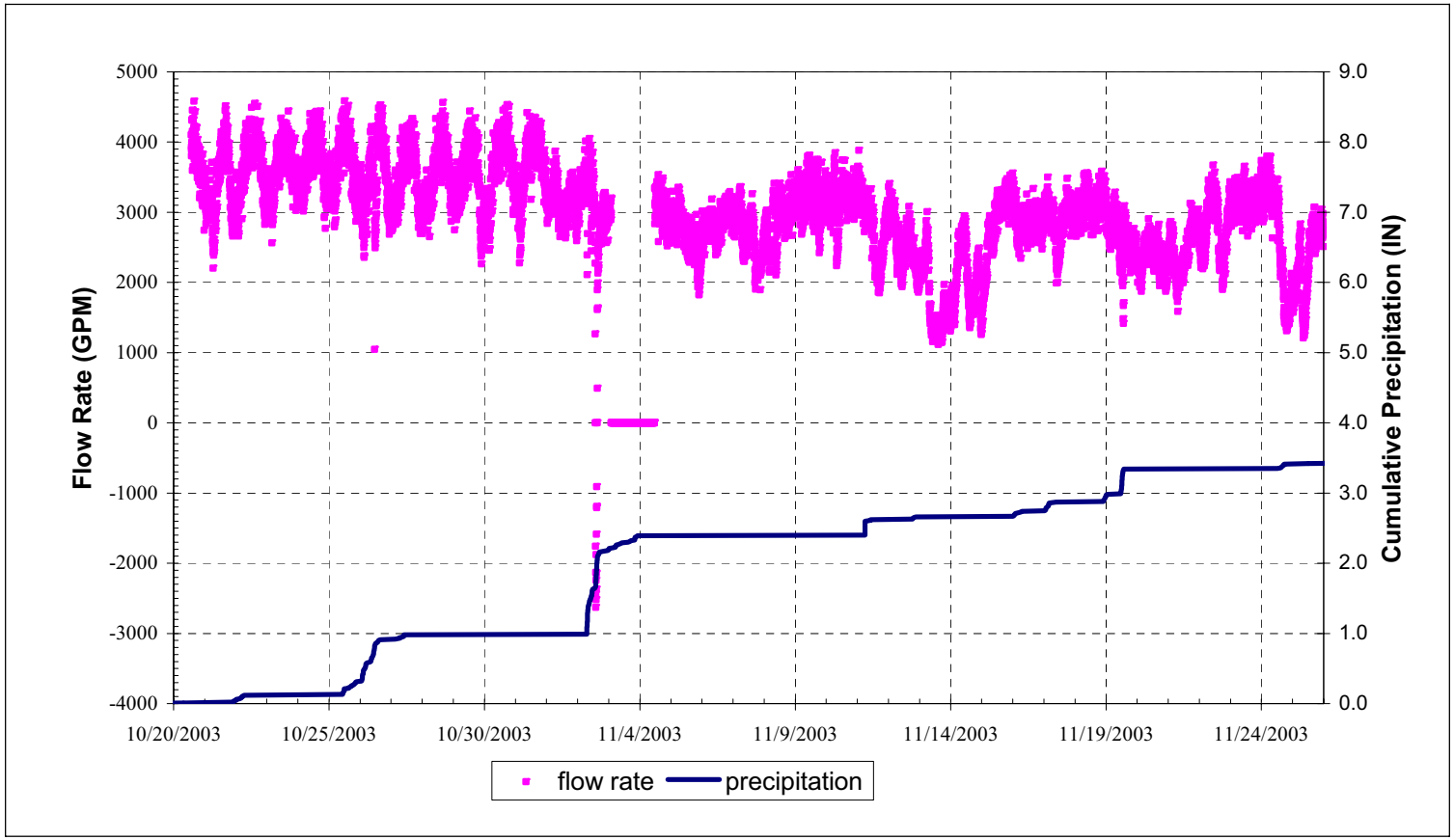

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FIGURE 5.4.4-7

DRY-WEATHER FLOW RATES AT EAST BYPASS PIPE

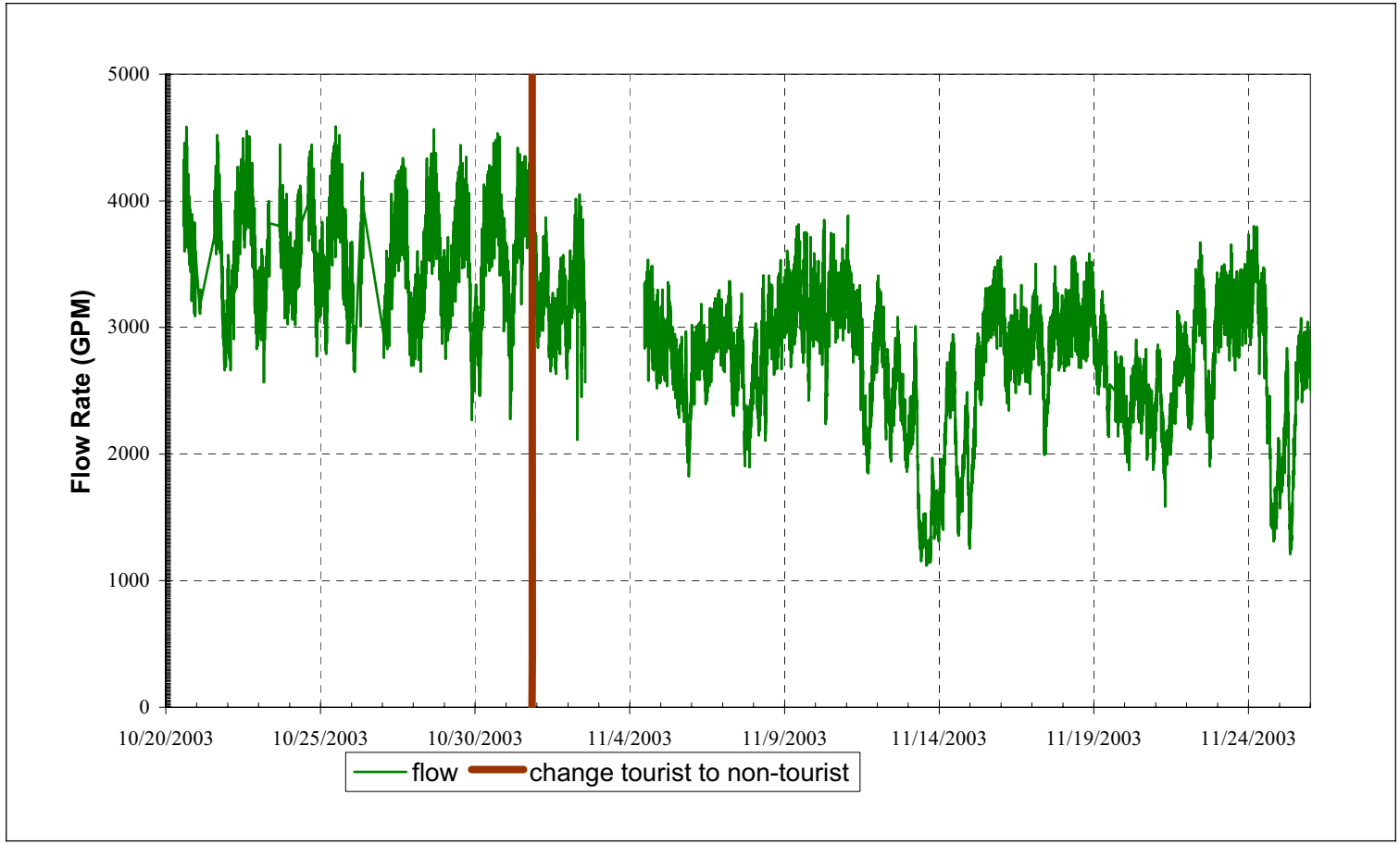

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FIGURE 5.5.1-1

SUMMARY OF SURFACE WATER SAMPLING RESULTS - GENERAL WATER QUALITY PARAMETERS

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FIGURE 5.5.1-2

SUMMARY OF SURFACE WATER SAMPLING RESULTS – MAJOR IONS

[NIP – General Location Maps]

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FIGURE 5.5.1-3

SUMMARY OF SURFACE WATER SAMPLING RESULTS – DETECTED TARGET ANALYTES

[NIP – General Location Maps]

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FIGURE 5.5.1-4

SUMMARY OF SURFACE WATER SAMPLING RESULTS - BACTERIOLOGICAL PARAMETERS

[NIP – General Location Maps]

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FIGURE 5.5.2-1

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 2

[NIP – General Location Maps]

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FIGURE 5.5.2-2

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 6

[NIP – General Location Maps]

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FIGURE 5.5.2-3

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 7

[NIP – General Location Maps]

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FIGURE 5.5.2-4

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 8A

[NIP – General Location Maps]

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FIGURE 5.5.2-5

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 8B

[NIP – General Location Maps]

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FIGURE 5.5.2-6

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 9A

[NIP – General Location Maps]

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FIGURE 5.5.2-7

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 9B

[NIP – General Location Maps]

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FIGURE 5.5.2-8

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, WATER-BEARING ZONE 10

[NIP – General Location Maps]

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FIGURE 5.5.2-9

SUMMARY OF GROUNDWATER SAMPLING RESULTS, GENERAL WATER QUALITY PARAMETERS, GASPORT/DECEW CONTACT WATER-BEARING ZONE

[NIP – General Location Maps]

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FIGURE 5.5.2-10

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 2

[NIP – General Location Maps]

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FIGURE 5.5.2-11

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 6

[NIP – General Location Maps]

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FIGURE 5.5.2-12

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 7

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FIGURE 5.5.2-13

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 8A

[NIP – General Location Maps]

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FIGURE 5.5.2-14

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 8B

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FIGURE 5.5.2-15

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 9A

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FIGURE 5.5.2-16

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 9B

[NIP – General Location Maps]

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FIGURE 5.5.2-17

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, WATER-BEARING ZONE 10

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FIGURE 5.5.2-18

SUMMARY OF GROUNDWATER SAMPLING RESULTS, MAJOR IONS, GASPORT/DECEW CONTACT WATER-BEARING ZONE

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FIGURE 5.5.2-19

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 2

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FIGURE 5.5.2-20

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 6

[NIP – General Location Maps]

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FIGURE 5.5.2-21

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 7

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FIGURE 5.5.2-22

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 8A

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FIGURE 5.5.2-23

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 8B

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FIGURE 5.5.2-24

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 9A

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FIGURE 5.5.2-25

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 9B

[NIP – General Location Maps]

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FIGURE 5.5.2-26

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, WATER-BEARING ZONE 10

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FIGURE 5.5.2-27

SUMMARY OF GROUNDWATER SAMPLING RESULTS, DETECTED TARGET ANALYTES, GASPORT/DECEW CONTACT WATER-BEARING ZONE

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6.0 DISCUSSION

The following sections provide a detailed discussion of the results of the field investigation with respect to NPP effects on (1) groundwater levels and flow patterns, (2) groundwater infiltration into the FST, and (3) groundwater and surface water quality.

6.1 Niagara Power Project Impacts on Groundwater Levels and Flow

Groundwater level fluctuations are a result of changes in the volume of water stored in an aquifer. As the volume of stored water increases and decreases over time, the water levels in a well tapping the aquifer will rise and fall. Changes in the volume of water stored reflect the interplay between the rate of discharge (generally constant) and the rate of recharge (dependent on multiple factors including evapotranspiration, surface permeability, and surface temperature). Recharge is greatest (1) where plant cover is scarce (i.e., where the role of plants in trapping and holding precipitation, or returning it to the air via evapotranspiration, is minimized); (2) when ground temperature is above freezing (i.e., when precipitation is not prevented by frost from infiltrating into the ground); and (3) when surface temperatures are moderate (making evaporation of precipitation less likely).

Additional factors influencing groundwater levels are changes in atmospheric, or barometric, pressure, and ocean tides. Fluctuations due to ocean tides are not observed in the Niagara Falls area. Fluctuations of groundwater level due to changes in barometric pressure were observed and can be a good indicator, when compared to fluctuations induced by other sources, of the relative influences. An illustrative example of a good (inverse) correlation between groundwater level fluctuations and barometric pressure is presented in Figure 6.1-1. As shown in the chart, groundwater level fluctuations of up to approximately 0.5 feet correlate closely with changes in barometric pressure of up to approximately 0.6 inches mercury (note: barometric pressure is plotted on an inverted scale). When groundwater levels respond to precipitation events (through recharge) they typically exhibit net changes greater than fluctuations induced by atmospheric pressure. An example of groundwater response to precipitation is presented in Figure 6.1-2. From this plot it may be concluded that for the fall of 2003 the underlying

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trend in groundwater levels, as indicated by water levels in well GW03-008A-P2, shifted from a decline (discharge dominant) to a rise (recharge dominant) on approximately October 26, 2003.

Groundwater levels in the vicinity of the NPP respond to both natural and manmade influences. Observed manmade influences result from NPP operations (filling and draining of the forebay and reservoir), and groundwater discharge to tunnels. Influences on groundwater levels, independent of NPP operations, were noted in a few observation wells and piezometers during the fall of 2003. Figure 6.1-3 shows observed drawdowns in selected wells and piezometers in apparent response to private residential or agricultural well withdrawals. The occurrences of apparent private well pumping were infrequent, of limited extent (both spatially and temporally), and are easily identified and differentiated from other influences.

Groundwater flow rate for a given aquifer medium (i.e., including both soil and rock) is proportional to the hydraulic gradient defined as the difference in elevation for two points within a given water-bearing zone divided by the horizontal distance between the points. The rate and direction of groundwater flow may be altered by natural changes in local and regional heads (e.g., precipitation/recharge and discharge) and differences in geology. The rate and direction of groundwater flow may also be modified by human activities. Such activities include (1) interception and diversion of runoff by pavement, buildings, and stormwater receptors (which tends to reduce infiltration); (2) construction of grout curtains, mines, subsurface conduits, and tunnels, (which alters geologic conditions); and (3) withdrawals from residential, municipal, and industrial pumping wells or construction of ponds and reservoirs (both of which tend to change hydraulic heads).

Alteration of groundwater flow patterns from natural conditions (i.e., conditions before construction of industrial wells and the NPP) to current conditions was qualitatively inferred and presented in Johnston 1964 (Figure 6.1-4). The conditions depicted in that report have not substantially changed, as is evident from later studies and reports (Miller and Kappel 1987, Yager 1996, DuPont et al. 1992, and URS et al. 2003). The natural flow patterns described in the report depict a northern groundwater divide, immediately south of the escarpment, with all groundwater flow south of the divide ultimately discharging directly into the lower Niagara River. The relatively small area of groundwater

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flow north of the divide is depicted as discharging by way of seeps directly from the escarpment. The conditions presented by Johnston show the greatest construction-related change in flow to be in the City of Niagara Falls west of the conduits and south of the forebay. Following NPP construction, flow in the eastern half of that area was observed to reverse from westward (discharging to the lower Niagara River) to eastward (discharging to the CDS and forebay). Alteration of flow patterns in the vicinity of the reservoir was due to a general increase in hydraulic head in that area (Figure 6.1-4).

As reported in Johnston 1964, a general overall long-term rise in the elevation of groundwater was observed after the October 1961 filling of the reservoir (Figure 6.1-5). The greatest rise in elevation observed by Johnston was 17 feet, but typical increases (observed near the perimeter of the reservoir) averaged approximately 5 feet. Similar elevated water levels continue to be observed (Table 5.3.1-1).

6.1.1 Lewiston Reservoir Effects

6.1.1.1 Lewiston Reservoir Water Level Fluctuations

The operational fluctuations of the Lewiston Reservoir follow a generally predictable pattern that involves three overlapping cycles. From longest to shortest they are (1) the tourist/non-tourist cycle, (2) the weekly cycle, and (3) the daily cycle. Typically, the weekly cycle exhibits the greatest range, followed by the daily, and the tourist/non-tourist cycles, respectively. The 2003 maximum water elevation observed in the reservoir (for all cycles) was El. 658.66 feet, and the minimum El. 620.73 feet, a difference of about 38 feet.

The tourist/non-tourist cycle reflects a twice-a-year change in Project operations (April and November). Typically, during the tourist season drawdown of the reservoir during the week is relatively great, and during the non-tourist season drawdown is less (Figure 6.1.1-1). The semiannual change in operational pattern results in a change in average weekly surface elevation in the reservoir of 5.3 feet (El. 643.4 feet during tourist season vs. El. 648.7 feet during non-tourist season).

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The weekly cycles exhibit a highly variable range of elevation differences, with a minimum observed difference in one week of 8.78 feet (January 6 to 12) and a maximum observed difference of 37.33 feet (October 20 to 26) in 2003 (Table 6.1.1-1).

The daily cycle exhibits a range of fluctuation similar to the weekly cycle, but to a lesser degree. A summary of the daily cycle statistics is presented in Table 6.1.1-2. Daily water level elevation differences for 2003 ranged between 4.4 and 24.2 feet.

6.1.1.2 Groundwater Levels

The relationship between cyclic fluctuations in the reservoir water level and corresponding groundwater level fluctuations observed in each well or "reservoir efficiency" can be calculated. The reservoir efficiency is a mathematical representation of the "connectedness" of a well and is calculated by dividing the net change in groundwater elevation measured at the well (for half of one complete cycle) by the corresponding net change in reservoir level. Reservoir efficiency values range between 0.0 and 1.0 (i.e. 0 to 100%) with 0 indicating no connection and 1.0 indicating complete connection.

Groundwater level fluctuations, reservoir level fluctuations, and calculated reservoir efficiencies for selected piezometers and wells are presented in Table 6.1.1-3. Reservoir efficiency values ranged from less than 0.05% (0.01 ft/18.68 ft) to 13.4% (2.51 ft/18.68 ft). Wells selected for inclusion in this table were selected based on evaluation of water level data collected from August 2003 through December 2003. Wells exhibiting cyclic water level fluctuations corresponding to reservoir fluctuations were included in the table. Generally, the reservoir efficiency values indicate limited reservoir influence on overburden and bedrock groundwater levels, relative to natural influences, with only five wells exhibiting efficiencies greater than 5%.

Both overburden wells and bedrock wells and piezometers exhibited a wide range of reservoir efficiencies. A plot of groundwater elevations in NYPA overburden well OW-189 (which exhibited the maximum observed reservoir efficiency of 13.4% [Table 6.1.1-3]), overburden well OW-193 (which

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exhibited relatively low reservoir efficiency at 1.4%), piezometer GW03-006B-P2 (the bedrock piezometer with the highest reservoir efficiency, at 3.6%) and the reservoir surface water elevations over time is presented in Figure 6.1.1-2. In the chart, data trend lines have been calculated and overlain on the water level data for each location. Natural seasonal groundwater fluctuations (i.e., natural recharge and discharge cycles) are represented by the trend lines plotted for all three wells. When compared with reservoir level data, these lines do not correlate with the trend observed for the reservoir for tourist and non-tourist operational cycles. The seasonal groundwater elevation for OW-193 (as depicted by the trend line) ranged between approximately El. 619.4 (March 15, 2003) and El. 612.5 feet (October 9, 2003), a difference of 6.9 feet. The plot illustrates that the magnitude of natural (seasonal) fluctuations exceeds the maximum reservoir induced fluctuations in all wells, as represented by the maximum reservoir efficiency for OW-189. Based on the congruence of the trend lines, it is reasonable to assume that the seasonal fluctuation of OW-189 and GW03-006B-P2 are similar in magnitude to OW-193 and greater than the maximum potential reservoir-induced fluctuation of 5.0 feet (as calculated by 13.4% reservoir efficiency x 37.3 feet [the product of the maximum observed reservoir efficiency and the maximum observed reservoir fluctuation for all cycles]).

Correlation of water-bearing zone with reservoir efficiency is generally limited to newly installed piezometers since the previously existing (OW and NW) wells were not specifically installed in differentiated water-bearing zones. Water-bearing zones have, however, been assigned some of the previously existing wells based on reported borehole depth (for "OW" designated wells) or placement of well screens (for "NW" designated wells) allowing for comparison of water levels with zones (Table 6.1.1-4). Calculated efficiencies of the reservoir area bedrock piezometers shown on Table 6.1.1-3 (GW03-001 through GW03-011) ranged between approximately 1.6% (GW03-006A-P1) and 3.6% (GW03-006B-P2) (Table 6.1.1-3), which fall within the range of existing reservoir bedrock well efficiencies of approximately 0.03% and 8.2%. Water level data were screened visually and efficiencies calculated for wells showing discernable responses to reservoir fluctuations are presented in this table. In very general terms the calculated efficiencies of wells and piezometers can be correlated with distance from the reservoir. Only piezometers and wells that are less than 290 feet from the reservoir exhibited efficiencies greater than 5% (Table 6.1.1-4). The hydrogeologic characteristics of specific water-bearing zones, however, likely play a role in determining the response exhibited with some piezometers

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independent of distance. Piezometers screened in the same zone exhibited similar efficiencies while at substantially different distances (e.g., GW03-006B-P2, GW03-011A-P2 and NW-05 and GW03-005A-P1 and GW03-006B-P4).

Conceptually, it would be expected that water-bearing zones would exhibit decreasing reservoir efficiency with increasing depth from ground surface (increasing vertical distance from the reservoir). However, the deeper bedrock zones (water-bearing zones 10, 9A and 9B) exhibited efficiencies similar to the upper zones (zones 8B and 2), due likely to the sub-cropping of the flow zones below the reservoir (Figure 5.2.4-1) and to the staggered design of the grout curtain around the reservoir, where the horizontal interval between boreholes drilled to the deeper zones was greater than the interval for upper zones.

6.1.1.3 Groundwater Flow

Results of the focused groundwater model of the Lewiston Reservoir (Section 5.1.2) show areas where groundwater flow is potentially influenced by infiltration of reservoir water (Figure 5.1.2-2). The extent of this zone of influence depends mainly on reservoir water levels and on seasonal variations in regional groundwater levels. The minimum and maximum extents of this influence (depicted in Figure 5.1.2-2) represent lowest and highest reservoir conditions, respectively, under long-term average groundwater level conditions. The conditions depicted in this figure represent the extremes of reservoir levels that exist only for relatively short periods within the NPP operational cycle. The extent of reservoir influence for predominant conditions representing average reservoir water levels would be somewhere between the two extremes depicted in Figure 5.1.2-2. Area groundwater level fluctuations due to natural seasonal variations would also influence the extent of reservoir groundwater flow influence. During dry periods when area groundwater levels would be lowest, the hydraulic gradient away from the reservoir would be greatest, and the extent of reservoir influenced groundwater flow would be greatest. Conversely, during wet periods when area groundwater levels would be highest, the hydraulic gradient away from the reservoir would be lowest, and the extent of reservoir influenced groundwater flow would be least.

The groundwater flow path lines shown in Figure 5.1.2-1 and the area of Lewiston Reservoir influence shown in Figure 5.1.2-2 represent the horizontal extents of flow for the three-dimensional flow

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model. The flow path lines depicted in Figure 5.1.2-1 are actually the surface traces of three-dimensional lines that travel outward and downward from the reservoir. The horizontal extent of reservoir influence in bedrock is greatest in Model Layer 2 and decreases with each successive model layer beneath that. The extent of reservoir-influenced groundwater flow is discussed in the following sections.

6.1.1.3.1 North of the Lewiston Reservoir

The predominant hydraulic feature in the area north of the Lewiston Reservoir is the northern groundwater divide. Predicted by groundwater modeling and verified with groundwater level data collected as part of this study (Appendix K, Figures 27 and 28), the northern groundwater flow divide (affecting the upper weathered bedrock water-bearing zone) is found between the Niagara escarpment and the reservoir. The divide represents a high in potentiometric heads, dividing groundwater flow to the north and south of this line (Figure 5.1.2-3). The divide may be represented by a line running approximately parallel to and about 2,600 feet south of the escarpment. Based on measured groundwater levels in NYPA monitoring wells GW03-001 through GW03-004, this groundwater divide also affects the Gasport/DeCew water-bearing zone (Appendix K, Figures 31 and 32). As discussed previously, the Gasport/DeCew water-bearing zone, located below the lowest groundwater model layer (Layer 10), was not included in the model.

The presence of this divide for both water-bearing zones keeps reservoir-influenced flow from reaching the Niagara escarpment. Therefore, the Lewiston Reservoir does not influence groundwater that discharges from the escarpment via seeps in the cliff face.

The northern extent of reservoir-influenced groundwater flow is limited by the presence of Fish Creek. Groundwater modeling results show that in the eastern portion of the reservoir, water flowing northward from the reservoir discharges to Fish Creek. As shown in Figures 5.1.2-1 and 5.1.2-2, however, further to the west, the extent of reservoir-influenced flow does extend north of Fish Creek to a limited extent. The natural groundwater flow divide located between the Niagara escarpment and Fish Creek (Figure 5.1.2-3) limits the northern extent of this influence. Reservoir-influenced groundwater

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flow not discharging to Fish Creek continues westward where it ultimately discharges to the forebay or the Niagara River gorge.

The presence of the groundwater divide shown by the model is also evident in the manual water elevation data recorded from the weathered bedrock (model layer 2) piezometers at GW03-001 through GW03-004. The manual elevation data indicate lower groundwater elevations immediately near the reservoir (GW03-001A-P1), with progressively higher elevations to the north (at GW03-002A-P1 and GW03-003A-P1, respectively). Both the tourist and non-tourist season data indicate that flow is to the south from GW03-003A-P1 (Table 4.3.2-1 and Appendix K, Figures 27 and 28). The groundwater surface elevation at GW03-004A-P1 is consistently lower than the elevation at GW03-003A-P1, indicating that flow is to the north. Manual water level measurements recorded from the Gasport/DeCew water-bearing zone piezometers also showed the presence of the northern divide. Groundwater surface elevations at GW03-003A-P2 are consistently higher than elevations observed at GW03-001A-P2 and GW03-004A-P2 (Table 4.3.2-1 and Appendix K, Figures 31 and 32).

6.1.1.3.2 East of the Lewiston Reservoir

The extent of reservoir-influenced groundwater flow east of the reservoir, as represented by groundwater flow model results, is also limited by the presence of a groundwater flow divide (Figure 5.1.2-3). Regional groundwater flows on Tuscarora lands, mainly controlled by topography and southward dipping stratigraphy, are generally to the southwest. Where flow originating in the topographically high recharge area of the Niagara escarpment meets reservoir-influenced flow east of the reservoir, a flow divide is created (Figure 5.1.2-3). The divide's distance from the reservoir is dependent on reservoir levels and regional groundwater levels. The roughly north-south divide line is located approximately 1,500 feet east of the Lewiston Reservoir based on long-term average groundwater level data. As mentioned in Section 4.0, the focused groundwater model was based on a 250 by 250 foot data grid. Consequently, uncertainty in model projections lies within a range of +/- 250 feet. Therefore, the position of this flow divide, based on the modeled conditions, would be within the range of approximately 1,250 to 1,750 feet east of the reservoir.

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As discussed previously, Figure 5.1.2-2 represents the modeled extent of reservoir-influenced flow for highest and lowest reservoir levels under long-term average groundwater level conditions. The extent of this influence east of the reservoir represents the location of the groundwater flow divide. Therefore, the maximum distance from the Lewiston Reservoir of this flow divide as represented by the modeled conditions is approximately 1,750 feet.

The maximum extent of reservoir-influenced groundwater flow is seen in the weathered bedrock (model layer 2). As discussed above, the extent of reservoir-influenced groundwater flow decreases for each successively lower model layer. As shown in Figures 5.1.2-4 and 5.1.2-5, the eastern extent of reservoir influence, as represented by the location of the groundwater flow divide, is less for the Eramosa dolomite (model layer 8) and the Goat Island dolomite (model layer 9), respectively, than for the weathered bedrock (model layer 2). For the Gasport dolomite (model layer 10), there is no eastern component to reservoir-influenced groundwater flow, and therefore groundwater in the Gasport dolomite (model layer 10) flows from northeast to southwest without a groundwater flow divide (Figure 5.1.2-6). Similar to the Gasport dolomite (model layer 10), the Gasport/DeCew water-bearing zone, located below the Gasport dolomite (model layer 10), is estimated to be below the extent of influence of the reservoir and is not expected to show any eastward component of reservoir-influenced groundwater flow.

In the weathered bedrock water-bearing zone (model layer 2), reservoir-influenced groundwater flows eastward from the reservoir and turns either northward or southward. During wet seasonal periods, when regional groundwater levels are higher, this groundwater flow likely discharges to either Fish (in the north) or Gill (in the south) Creeks. A similar eastward flow component to the groundwater pattern is seen in Model Layers 8 and 9, but with a lesser eastern component of reservoir-influenced groundwater flow.

In the weathered bedrock water-bearing zone (model layer 2), manual groundwater level data, collected from piezometers installed during this investigation from September 2003 to May 2004, indicate the highest elevations near the reservoir (GW03-006B-P4 and GW03-009B-P4), with elevations decreasing with distance to the east (GW03-005A-P1, GW03-007B-P4 and GW03-008B-P4) (Appendix K, Figures 27 and 28). Manual water level data recorded from water-bearing zone 10 exhibit no pattern, with levels in three piezometers (GW03-007A-P2, GW03-008A-P2 and GW03-009A-P2) within 0.3 feet

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in elevation for both the tourist and non-tourist seasons (Appendix K, Figures 29 and 30). Measured groundwater levels for water-bearing zones 2 and 10 are generally lower than those predicted by the groundwater model. The observed elevations in GW03-006B-P2 are relatively high, presumably due to a more extensive connection to the reservoir. Observations in GW03-005A-P2 indicate a reduced hydraulic connection at that location. Manual water levels recorded from the water-bearing zone piezometers at the Gasport/DeCew contact are consistent with a general flow direction to the west-southwest (Appendix K, Figures 31 and 32) for both the tourist and non-tourist seasons.

6.1.1.3.3 South of the Lewiston Reservoir

South of the Lewiston Reservoir, the extent of reservoir-influenced groundwater flow in the upper water-bearing zones is greater due to overall regional groundwater flows being from northeast to southwest. Reservoir-influenced flow extends to the NYPA conduits through the towns of Lewiston and Niagara and the City of Niagara Falls (Figure 5.1.2-1). As discussed previously, the CDS acts as a linear sink for groundwater flow.

6.1.1.3.4 West of the Lewiston Reservoir

The NYPA forebay is located immediately west of the Lewiston Reservoir. As discussed above, reservoir-influenced groundwater flow from the northwest portion of the reservoir flows westward, north of the forebay, toward either the forebay or the gorge (Figure 5.1.2-1). Surface Water

As discussed above, both Fish and Gill Creeks receive reservoir-influenced groundwater discharge. Fish Creek originates approximately two miles east of the Lewiston Reservoir, flowing to a cut channel at the toe of the eastern reservoir dike where it then flows around the northeast corner of the reservoir. North of the Lewiston Reservoir, Fish Creek travels along the channel located at the toe of the reservoir dike until approximately the midway point of the reservoir, where the dike angles off to the south and the creek continues westward (Figure 5.1.2-1). Reservoir-influenced groundwater discharge to Fish Creek occurs along the cut channel at the toe of the dike, and further upstream. The maximum

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extent of reservoir influenced groundwater discharge to Fish Creek is likely approximately 1,500 feet east of the reservoir. Fish Creek likely continues to receive reservoir-influenced groundwater flow for approximately another 3,000 feet downstream at the point where the reservoir dike turns to the southwest.

Gill Creek originates in a wetland area on the Tuscarora Nation, flowing to the southwest until it enters a cut channel at the toe of the eastern reservoir dike. It then follows this channel around the southeast reservoir corner and travels westward for approximately 8,000 feet. Gill Creek likely receives reservoir-influenced groundwater discharge from a point approximately 1,500 feet east of the Lewiston Reservoir. Gill Creek likely continues to receive reservoir-influenced groundwater flow for approximately another 9,000 feet downstream where the Creek turns toward the southwest away from the reservoir dike in the vicinity of the Gill Creek augmentation flow discharge.

As indicated by field observations, groundwater discharge to Fish and Gill Creeks varies seasonally. During dry summer and fall months, flows for both creeks east of the Lewiston Reservoir were observed to be considerably less than in the wetter months. Groundwater levels in piezometer GW03-005A-P1 (Appendix K, Figure 5), set in the weathered bedrock water-bearing zone, were observed to be near or above ground surface (El. 612.60 feet) during wet months. Groundwater levels in this piezometer were above ground surface at the time of drilling in July 2003 until August 20, 2003 when levels dropped below ground surface. Groundwater levels again rose above ground surface in December 2003. During dry months, groundwater discharge to Fish and Gill Creeks is reduced due to lower groundwater levels. Under these conditions, reservoir influenced groundwater likely flows beneath the creeks.

6.1.2 Forebay and Conduit Drainage System Effects

Alterations of groundwater levels and flow patterns in the vicinity of the forebay and CDS predominantly reflect influence from the NPP. As depicted in Johnston 1964 and Yager 1996, and confirmed in the updated model presented in Sections 4.0 and 5.0 of this report, the forebay and CDS act as drains for intersected water-bearing zones (Figures 4.1.2-4 and 5.1.3-1). Consequently, water levels are generally depressed in the immediate vicinity of the forebay, and CDS groundwater potentiometric

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contours show that groundwater on either side flows toward the conduits. The primary cause for creation of this linear sink is the very high hydraulic conductivity of the CDS relative to the surrounding bedrock, and the groundwater discharge from the CDS to either the FST or the forebay.

6.1.2.1 Forebay Water Level Fluctuations

NPP operations result in wide fluctuations of surface water elevations in the forebay. The maximum and minimum observed water levels in the forebay for 2003 were El. 568.21 feet and 537.18 feet, respectively, resulting in an annual maximum difference of 31.03 feet.

Forebay water level fluctuations do not exhibit a predictable weekly cycle but a rudimentary daily water level cycle can be recognized, with the highest elevations occurring near 10:00 am and the lowest near 10:00 pm each day. Water levels in the forebay exhibit a high degree of variability throughout each 24-hour period, making the prediction of fluctuations problematic. Seasonally, average water levels in the forebay changed from El. 555.0 feet to El. 552.4 feet from tourist to non-tourist cycles, respectively (Figure 6.1.2-1). A summary of daily surface water elevation statistics is presented in Table 6.1.2-1, which shows annual daily fluctuations ranging between a minimum of 3.43 feet to a maximum of 26.49 feet.

6.1.2.2 Conduit Drainage System and Pump Stations

Hydraulic head data for wells along the conduits were analyzed with respect to the relative gradients prevailing within the drainage pipes. A detailed discussion of the hydraulic gradient analysis within the CDS is presented in Appendix O. Results are presented in Figure 6.1.2-2. Flow regimes differ slightly for the tourist and non-tourist seasons. During the tourist season, flow in the CDS pipes is northward between the upper Niagara River and the FST at all times. North of the FST, flow direction is variable, although the average direction appears to be north. In the northernmost segment of the system, closest to the forebay, flow direction reverses frequently, and dominant gradients are difficult to establish. During the non-tourist season, flow is always to the north in the southern and central portions of the

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system. In the northern portion, close to the forebay, frequent flow reversals occur in the same manner as during the tourist season.

At the conduit pump stations (Pump Stations A and B), the differences in hydraulic heads between the conduits and the CDS fluctuate over time as indicated by measurements recorded at each pump station (Figures 5.3.3-1 and 5.3.3-2). At Pump Station A, however, the hydraulic head measured in the conduits is predominantly higher (approximately 97% of the time for the monitoring period) than that measured in the CDS. As shown on Table 6.1.2-2, hydraulic heads at Pump Station A in the conduits are, on average, 1.51 feet higher than in the CDS. In Pump Station B, the hydraulic head measured in the CDS is predominantly higher (approximately 88% of the time for the monitoring period) than that measured in the conduits. At Pump Station B, hydraulic heads in the CDS are, on average, 1.21 feet higher than in the conduits (Table 6.1.2-2).

In the area of Pump Station A, the head differences discussed above indicate a predominant hydraulic gradient from the conduits to the CDS. Assuming that this condition is representative of the immediate vicinity, the inferred flow of water at the two damaged areas of conduit floor slab south of Pump Station A (Figure 2.2.1-4) would be from within the conduits outward to the CDS. Conversely, in the area of Pump Station B, the head differences indicate a predominant hydraulic gradient from the CDS into the conduits. Therefore, the inferred flow of water in the damaged area of conduit floor slab near Pump Station B (Figure 2.2.1-4) would be from the CDS into the conduits.

The weirs separating the conduits from the CDS at Pump Station A are set at El. 560 feet. As discussed above, hydraulic heads measured at Pump Station A are predominantly greater in the conduits than in the CDS. Therefore, whenever water level in the conduit rises above El. 560 feet and is also greater than the CDS head, water flows from the conduits to the CDS via the pump station sump. Based on analysis of water level data collected in Pump Station A, conduit water levels are above the weir elevation approximately 52% of the time during tourist season and approximately 4% of the time during non-tourist season (Table 6.1.2-3). Typically, when the hydraulic gradient reverses (3% of the time, when the CDS head is greater than the conduits), the water levels for both are below the weir elevation, and no flow occurs. On the conduit side (upstream side), the weirs are sealed by a flap gate (not fully effective).

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Flow through the gate and over the weir has been observed during site visits. During a single visit to Pump Station A, which took place during the tourist season (June 13, 2002), the flow rate over the weirs was estimated at 160 gpm (see Appendix P).

The weirs separating the conduits from the CDS at Pump Station B are set at El. 550 feet. As discussed above, at Pump Station B, hydraulic heads in the CDS are predominantly greater than in the conduits. Therefore, whenever the CDS hydraulic head rises above El. 550 feet, and CDS head is greater than the conduit head, water flows from the CDS to the conduits (and then to the forebay) via the pump station sump. Based on analysis of water level data collected in Pump Station B, flow occurs in this direction approximately 70% of the time during tourist season and approximately 60% of the time during non-tourist season (Table 6.1.2-3). The Pump Station B weirs cannot be observed from within the pump station as was done in Pump Station A. Flow capacity through the Pump Station B weirs from the CDS to the conduits has been estimated, based on the predominant hydraulic head (i.e., average CDS water level is 1.2 feet higher than conduit water level) and the weir dimensions, to be on the order of 7,000 gpm (see the calculation included in Appendix P). This rate is estimated to be sufficient to transmit all CDS flow.

6.1.2.3 Groundwater Level Fluctuations

Forebay-induced water level fluctuations transmitted along the conduits via the CDS are reflected in groundwater monitoring wells installed near the conduits. Forebay efficiencies were calculated for wells and piezometers installed along the length of the conduits (Figure 4.2.1-1). The calculated efficiencies of forebay/CDS induced/conveyed fluctuations and well/piezometer water level fluctuations ranged between just less than 6% to almost 70% (Table 6.1.2-4). The forebay efficiencies are generally high due to the close proximity of the wells and piezometers to the CDS and the high hydraulic conductivity between the forebay and CDS.

In general, piezometers screened at or near the elevation of the bottom of the CDS at each cluster exhibit the greatest forebay efficiency for their cluster, with two notable exceptions. At location GW03-012 the elevation of the bottom of the CDS (approximately El. 477 feet) is approximately 18-feet below the lowest piezometer (GW03-012A-P3, screen interval El. 495.41. 505.41 to feet), and therefore is not

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intercepted by any one piezometer at that location (Figure 5.2-1). For this reason its forebay efficiency cannot be determined. The piezometer with the greatest forebay efficiency (GW03-012B-P6) is screened at the same elevation as the top of the conduits (approximately El. 543 feet). The second exception is at location GW03-017 with piezometer GW03-017C-P9 showing 33.8% forebay efficiency.

6.1.2.4 Groundwater Flow

Numeric groundwater model results demonstrate the CDS acting as regional drains for groundwater of the upper weathered bedrock water-bearing zone south of the forebay (Figure 4.1.2-1).

The forebay induced groundwater level fluctuations discussed above exhibit an influence on groundwater potentiometric surface gradients toward the conduits as well as gradients within the CDS. Lower groundwater levels caused by lower forebay levels cause steeper groundwater flow gradients toward the conduits, while higher groundwater levels cause flatter groundwater gradients toward the conduits. However, the overall and predominant groundwater flow direction is determine to be toward the conduits.

The influence of the CDS as a groundwater flow sink exists for all water-bearing zones along the length of the conduits with the exception of portions of model layers 8, 9, and 10 and the Gasport/DeCew water-bearing zone (discussed below). In the northern portion of the conduits, the upper water-bearing zones (model layers 2 and 8) reside above the level of the conduits themselves, but intersect the backfilled conduit trench. As discussed in Section 2.2, the conduit trench backfill is directly connected to the CDS.

Model layers 8 and 9 dip below the bottom of the CDS in the vicinity of monitoring well GW03-017. Model layer 10 dips below the bottom of the CDS at a point somewhere between groundwater monitoring wells GW03-013 and GW03-014. North, and up-dip, of the point where these layers go below the conduits, groundwater flow in these zones discharges to the CDS and ultimately to the FST or forebay. The effect of the CDS as a groundwater sink for these layers diminishes toward the south and disappears as these stratigraphic units dip below the bottom of the CDS (Figure 5.2-1). In this area,

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groundwater flow within these zones is either to the southwest beneath the conduits towards the Niagara River with reduced effect of the CDS or westward and upward to the CDS.

Groundwater flow for the Gasport/DeCew water-bearing zone was not included in groundwater modeling conducted as part of this study. Moreover, due to an insufficient number of data points, groundwater flow patterns for this zone cannot be estimated using water levels measured during this study. Based on Johnston's inference that potentiometric surfaces for deeper water-bearing zones are parallel to the gently southward dipping strata, and on groundwater flow patterns modeled by Yager and as part of this study, groundwater flow in this water-bearing zone is inferred to be similar to that modeled in Model Layer 10. The Gasport/DeCew water-bearing zone dips below the CDS at a point between wells GW03-012 and GW03-013. Therefore, as in Model Layer 10, groundwater flow south of this point is estimated to be to the southwest beneath the conduits.

As discussed above, average forebay water levels are approximately 2.6 feet higher in tourist season (April 1 to October 31) than in non-tourist season (November 1 to March 31). The effect of the lower water levels during non-tourist season is transmitted along the CDS to groundwater levels in the immediate vicinity of the conduits. This overall lowering of potentiometric surface along the conduits results in a steeper groundwater flow gradients toward the conduits. This effect is magnified during the wetter months of the natural seasonal cycle that coincide with non-tourist season operations (November through March) when regional groundwater levels are higher.

Conversely, during tourist season, the higher groundwater levels in the CDS associated with the higher forebay level, result in a lower groundwater flow gradient to the CDS. This effect is magnified during the drier months of the natural seasonal cycle that coincide with tourist season operations (May through October), when regional groundwater levels are lower.

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6.1.2.5 GW03-015 Chloride Monitoring Discussion

The response of each groundwater parameter (elevation, temperature, barometric pressure, pH, ORP, DO and Salinity/Conductivity) measured in GW03-015 piezometers P1 through P7 during the week before and after the April 1, 2004 switchover varied in each model layer.

Determining the relationships between water levels and individual parameters was occasionally problematic due to a variety of possible interferences, which include:

- Large travel times between CDS and probes, which could induce lag times that make correlation of water level and parameter value fluctuations erroneous,
- Potential mixing of indigenous groundwater and near-conduit (presumably mixed with former surface water) groundwater muting probe response, and
- Ambiguous or erroneous measurements by the probes possibly caused by sensor drift, interferences, disturbances from daily chloride calibration or poor sensor response.

Time lags greater than 30 minutes were not observed in upper zone piezometers (i.e. GW03-015A-P1, GW03-015B-P4 through GW03-015A-P7) and efficiencies were relatively high (Table 6.1.2-4). The short lags and high efficiencies prove the existence of a hydraulic connection, but do not provide an indication of the rate or travel time of flow between the CDS and the piezometers. However, given the very short horizontal distances between the piezometers and the CDS (approximately 50-feet), it is reasonable to assume that the travel time is relatively short, typically less than 2-hours (significantly less than the duration of forebay tourist season cycles [i.e. 24-hours])

The specific responses for selected parameters (e.g. water level, chloride and conductivity) are discussed (by model layer or water bearing zone as appropriate) in the following sections.

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6.1.2.5.1 GW03-015A-P1 – Model Layer 8A

Groundwater Elevation

Prior to the April 1st switchover, groundwater levels did not exhibit discernable cycle, and after April 1st a strong daily (24-hour) sinusoidal cycle is exhibited in a plot of the data (Appendix N), which reflect water level operational changes in the Forebay.

The average groundwater elevation in P1 increased by approximately 2.7 feet as a result of the switchover. Average elevation went from approximately 554.4 ft elev. prior to April 1st to approximately 557.1 feet elev. after April 1st (Table 6.1.2-5).

Chloride

For the entire time period of the ion study, chloride ion concentrations in GW03-015A-P1 ranged between 23.7 ppm and 58.6 ppm and did not change appreciably as a result of the change in water elevations caused by the switchover (Appendix N). Prior to April 1st, average chloride concentrations were approximately 46.3 ppm and after April 1st chloride concentrations were approximately 39.3 ppm (Table 6.1.2-5), a decrease of approximately 15%.

Concentrations exhibit an apparent inverse relationship with water level both before and after the switchover for a majority of measurements with some intervals of contravening (i.e. direct) responses to the general pattern.

Conductivity

Groundwater conductivity values in GW03-015A-P1 exhibited an apparent inverse relationship with water level (i.e. decreasing concentrations with increasing water levels) as shown on Appendix N.

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The average conductivity dropped approximately 5.8% from 699.3 to 659.0 microsiemens per centimeter (uS/cm), before and after the switchover respectively.

Other Parameters (pH, ORP and DO)

Prior to the switchover the relationships between pH, ORP and water elevation are unclear and exhibit both direct and inverse responses. After the switchover, pH exhibited an apparent inverse response to water level and ORP exhibited an apparent direct response to water level (Appendix N).

The concentrations of DO were typically low and periodically punctuated by pronounced increases in concentration apparently in inverse response to rapid decreases in water level when groundwater elevations fell below 554.0 feet Elev (Appendix N).

6.1.2.5.2 GW03-015A-P2 – Model Layer 10

Groundwater Elevation

Groundwater levels did not exhibit discernable responses to forebay fluctuations either before or after the April 1st switchover (Appendix N). Water levels did exhibit a "slug effect" due to the displacement of water within the piezometer after the return of the probe after each daily chloride calibration and the low conductivity of the water-bearing zone. This effect is commonly observed when using dataloggers in piezometers and wells screened in low hydraulic conductivity aquifers.

The average groundwater elevation in P2 increased by approximately 2.5 feet during the study period (Table 6.1.2-5). Groundwater elevation went from approximately 548.0 feet Elev. on March 26th to approximately 550.5 feet Elev. on April 5th.

Chloride

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Chloride ion concentrations ranged between 8,954.1 ppm and 67,820.2 ppm and decreased approximately 49.3% from an average of 30,169.0 ppm to an average of 15,302.0 before and after the switchover, respectively (Table 6.1.2-5). Chloride concentrations exhibited a "recovery response" to the daily calibration presumably due to residual rinse water or calibration fluid on the probe being flushed by groundwater after probe reinsertion (Appendix N).

Conductivity

Groundwater conductivity ranged between 79,697.8 uS/cm and 83,607.6 uS/cm and increased by less than 1% from an average of 81,202.0 uS/cm to an average of 81,341.4 uS/cm before and after the switchover, respectively (Table 6.1.2-5). Conductivity exhibited a "recovery response" at the beginning of each data set presumably due to residual rinse water being flushed by groundwater after probe reinsertion (Appendix N).

Other Parameters (pH, ORP and DO)

The relationships between pH, ORP, DO and water elevation are unclear. The responses of ORP and DO did not exhibit direct or inverse relationships with water levels and were punctuated by "recovery responses" at the beginning of each data set presumably due to residual rinse water being flushed by groundwater after probe reinsertion. The fluctuation of pH was minimal with generally stable readings ranging between 6.1 and 6.3 (Appendix N).

6.1.2.5.3 GW03-015A-P3 – Gasport/DeCew Water Bearing Zone

Groundwater Elevation

Groundwater levels did not exhibit discernable responses to forebay fluctuations either before or after the April 1st switchover (Appendix N).

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In general, groundwater elevations in P3 exhibited a steady increase during the study period. Groundwater elevations went up by approximately 1.8 feet from approximately 438.5 feet Elev. on March 25th to approximately 440.2 feet Elev. on April 6th.

Chloride

Chloride ion concentrations ranged between 17,534.6 ppm and 96,762.1 ppm and decreased approximately 38.2% from an average of 33,872.9 ppm to an average of 20,936.1 before and after the switchover, respectively (Table 6.1.2-5). Chloride concentrations exhibited a "recovery response" to the daily calibration presumably due to residual rinse water or calibration fluid on the probe being flushed by groundwater after probe reinsertion (Appendix N).

Conductivity

Groundwater conductivity ranged between 55,989.2 uS/cm and 55,998.1 uS/cm and increased by less than 1% from an average of 55,993.1 uS/cm to an average of 55,993.2 uS/cm before and after the switchover, respectively (Table 6.1.2-5). Conductivity exhibited a "recovery response" at the beginning of each data set presumably due to residual rinse water being flushed by groundwater after probe reinsertion (Appendix N).

Other Parameters (pH, ORP and DO)

The relationships between pH, ORP, DO and water elevation are unclear. Responses for these parameters did not exhibit discernable relationships with water level. ORP measurements were punctuated by "recovery responses" at the beginning of each data set presumably due to residual rinse water being flushed by groundwater after probe reinsertion. The fluctuation of pH was minimal with generally stable readings ranging between 6.5 and 6.65 (Appendix N).

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6.1.2.5.4 GW03-015B-P4 - Model Layer 8B

Groundwater Elevation

Prior to the April 1st switchover, groundwater levels did not exhibit discernable cycle, and after April 1st a strong daily (24-hour) sinusoidal cycle is exhibited in a plot of the data (Appendix N).

The average groundwater elevation in P1 increased by approximately 2.6 feet as a result of the switchover. Average elevation went from approximately 555.6 ft elev. prior to April 1st to approximately 558.2 feet elev. after April 1st (Table 6.1.2-5).

Chloride

Measurement of chloride ion concentrations were limited to the week prior to April 1st, due to a failure of the ion probe in GW03-015B-P5, which required replacement using the GW03-015-P4 probe. For the week chloride ion concentrations ranged between 187.3 ppm and 458.0 ppm and did not exhibit a discernable relationship with water levels (Appendix N).

Conductivity

Groundwater conductivity in GW03-015B-P4 ranged between 1,355.5 uS/cm and 1,444.8 uS/cm and decreased by approximately 2.8% from an average of 1,405.3 uS/cm to an average of 1,366.5 uS/cm before and after the switchover, respectively (Table 6.1.2-5). However, the concentrations prior to April 1st exhibited minimum and maximum concentrations both less than and greater than the minimum and maximum of concentrations measured after April 1st, respectively.

Conductivity concentrations measured in GW03-015B-P4 exhibited a muted but generally parallel relationship with water levels (Appendix N).

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Other Parameters (pH, ORP and DO)

Determining the relationships between pH, ORP, DO and water elevation is problematic due to high variations in parameter background concentrations, low probe response, "recovery responses", and possibly due to the absence of a relationship with water level. In general, ORP concentrations exhibited an apparent inverse relationship with water level that was difficult to qualify due to variations in background concentrations and possible probe response drift. The fluctuation of pH was nominal with generally stable readings ranging between 6.50 and 7.11 (Appendix N).

6.1.2.5.5 GW03-015B P5 – Model Layer 9A

Groundwater Elevation

Prior to the April 1st switchover, groundwater levels in GW03-015B P5 did not exhibit discernable cycles, and after April 1st a strong daily (24-hour) sinusoidal cycle is exhibited in a plot of the data (Appendix N).

The average groundwater elevation in P5 increased by approximately 2.7 feet as a result of the switchover. Average elevation went from approximately 554.3 ft elev. prior to April 1st to approximately 557.0 feet elev. after April 1st (Appendix N).

Chloride

Chloride ion concentrations ranged between 451.6 ppm and 2081.6 ppm and decreased significantly as a result of the change in water elevations caused by the switchover. Prior to April 1st, average chloride concentrations were approximately 1647.2 ppm and after April 1st chloride concentrations were approximately 953.4 ppm, a decrease of approximately 42.1%.

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Chloride results track inversely with water levels in GW03-015B-P5 as vividly represented by the plot of water levels and chloride concentrations immediately before and after the switchover (Appendix N).

Conductivity

Groundwater conductivity in GW03-015B-P5 ranged between 1,565.4 uS/cm and 3,230.5 uS/cm and decreased by approximately 4.9% from an average of 2,702.9 uS/cm to an average of 2,569.7 uS/cm before and after the switchover, respectively (Table 6.1.2-5). However, the concentrations prior to April 1st exhibited minimum and maximum concentrations both less than and greater than the minimum and maximum of concentrations measured after April 1st, respectively.

Conductivity concentrations measured in GW03-015B-P5 exhibited a strong direct relationship with water levels (Appendix N).

Other Parameters (pH, ORP and DO)

Between March 25 and 29, 2004, the pH, ORP and DO probes malfunctioned and recorded erroneous data (e.g. negative values for pH) prior to the replacement of the chloride probe.

Determining the relationships between pH, ORP, DO and water elevation is problematic due to malfunctioning probes, multiple interferences such as high variations in parameter background concentrations, low or poor probe response, “recovery responses”, and possibly due to the absence of a relationship with water level (Appendix N).

The pH probe malfunctioned and recorded negative values between March 25 and March 29, 2004, and generally flat line responses after that between March 29 and April 6, 2004 (Appendix N).

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6.1.2.5.6 GW03-015 P6 – Model Layer 9B

Groundwater Elevation

Prior to the April 1st switchover, model layer 9B groundwater levels did not exhibit a discernable pattern however, after April 1st a strong daily (24-hour) sinusoidal cycle was observed and is presented in a plot of elevation data (Appendix N).

The average groundwater elevation in the P6 piezometer increased by approximately 2.8 feet as a result of the switchover. Average elevation went from approximately 554.1 ft elev. prior to April 1st to approximately 556.9 feet elev. after April 1st (Table 6.1.2-5).

Chloride

Chloride ion concentrations ranged between 141.0 ppm and 352.4 ppm and did not change appreciably as a result of the change in water elevations caused by the switchover. Prior to April 1st, average chloride concentrations were approximately 227.9 ppm and after April 1st chloride concentrations were approximately 196.9 ppm (Table 6.1.2-5), a decrease of approximately 14%.

Prior to the switchover, chloride concentrations exhibited a generally direct fluctuation with water levels with and after the switchover a muted cyclic response, also directly correlated with water level cyclic fluctuations was observed and are shown in Appendix N. While the post switchover range in chloride fluctuations is small, generally between 225 and 250 ppm, the correlation is strong.

Conductivity

Groundwater conductivity in GW03-015B-P6 ranged between 700.2 uS/cm and 1,037.8 uS/cm and decreased by less than 1% from an average of 933.4 uS/cm to an average of 931.2 uS/cm before and after the switchover, respectively. However, the concentrations prior to April 1st exhibited minimum and

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maximum concentrations both less than and greater than the minimum and maximum of concentrations measured after April 1st, respectively (Table 6.1.2-5).

Conductivity concentrations measured in GW03-015B-P6 exhibited a strong direct relationship with water levels (Appendix N).

Other Parameters (pH, ORP and DO)

The responses between pH, ORP, DO concentrations and water elevation fluctuations in GW03-015B-P6 were variable and did not follow similar patterns.

In general, pH exhibited stable values both before and after the switchover with a decline in average pH from 7.30 (March 25 to March 31, 2004) to 6.35 (April 1 to April 6, 2004) (Appendix N). Between 9:00 PM on April 4, 2004, and 5:00 AM on April 5, 2004, there was an inexplicable drop in pH values from approximately 6.4 to 4.23 followed by reduced average pH values (average pH of approximately 5.6) for the remainder of the study period.

Oxygen reduction potentials exhibited apparent direct responses with water level fluctuations both before and after the switchover (Appendix N).

Determining the relationship between dissolved oxygen and water level fluctuations was problematic due to some erroneous results and an apparent complex response to water level fluctuations. Before the switchover, DO concentrations exhibited a strong indirect correlation with water levels. After the switchover, the correlation apparently switches from indirect to direct when water levels exceed 556.0 ft Elev. (Appendix N).

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6.1.2.5.7 GW03-015C P7 – Model Layer 2

Groundwater Elevation

Prior to the April 1st switchover, groundwater levels did not exhibit a discernable cycle, and after April 1st a strong daily (24-hour) sinusoidal cycle is exhibited in a plot of the data (Appendix N).

The average groundwater elevation in P7 increased by approximately 2.3 feet as a result of the switchover. Average elevation went from approximately 554.9 ft elev. prior to April 1st to approximately 557.3 feet elev. after April 1st (Table 6.1.2-5).

Chloride

Chloride ion concentrations exhibited a wide ranged of concentrations from a low of 8.4 ppm to high of 80,418.2 ppm throughout the study period (Appendix N). The average chloride concentration before the switchover was 54.0 ppm and 608.2 ppm after (Table 6.1.2-5), apparently rising by a factor of approximately 11.3. However, between 4:30 AM and 1:00 PM on April 1, 2004, immediately after the switchover, a very large spike in chloride concentrations occurred. In less than 4 hours, chloride concentrations went up from approximately 30 ppm, to slightly greater than 80,000 ppm before returning to an average of approximately 24 ppm for the remainder of the study. The chloride spike likely resulted from a slug of road salt dissolved and carried by precipitation to the weathered bedrock which was subsequently pushed away from the conduits toward the piezometers by the increased water levels. It was observed that to the west of the GW03-015 piezometers and directly above the conduits is an access road for the nearby Niagara High School ball fields. It is reasonable to assume that the access road is the source of the road salt. Excluding the data collected from the period of the spike, average post-switchover chloride concentrations were lower than pre-switchover concentrations, a drop of approximately 55% from 54.0 ppm to 24.4 ppm.

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Conductivity

Groundwater conductivity in GW03-015C-P7 ranged between 544.9 uS/cm and 757.3 uS/cm and increased by approximately 4.8% from an average of 581.9 uS/cm to an average of 611.1 uS/cm before and after the switchover, respectively (Table 6.1.2-5).

Conductivity concentrations measured in GW03-015B-P7 exhibited a strong direct relationship with water levels (Appendix N).

Other Parameters (pH, ORP, DO, Temperature and Barometric Pressure)

In general, pH exhibited a limited range of values both before and after the switchover between 7.0 and 7.4. Prior to the switchover, pH values did not exhibit a cyclic pattern and after the switchover pH values responded inversely to the induced water level fluctuations (Appendix N).

ORP exhibited an apparent direct response, albeit muted, with the general rise in water level fluctuations before and after the switchover (Appendix N).

Determining the relationship between dissolved oxygen and water level fluctuations is problematic due to some erroneous results (negative DO values) and an apparent complex response to water level fluctuations. Direct or inverse relationships are not discernable either before or after the switchover (Appendix N).

6.2 Niagara Power Project Impacts on Groundwater Infiltration into the Falls Street Tunnel

Average dry-weather flow rates measured at all three monitoring locations are presented on Table 6.2-1. The sum of dry-weather flows at the Drop Shaft 12 weir and at the West Bypass must represent the groundwater flow entering the FST between Drop Shafts 14 and 12. Infiltration through the walls of the 84-inch pipe directly over the NYPA conduits is considered negligible (Richard Roll, City of Niagara

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Falls,, John Goeddertz, URS Corporation, September 3, 2003, personal communication). The infiltration measured at Drop Shaft 12 and at the West Bypass must therefore be entering the FST primarily west of the conduits. Flow rates measured at the East Bypass are representative of the groundwater infiltration rates into the FST between drop Shafts 14B and 13A, east of the NYPA conduits.

The total average groundwater infiltration rate from east and west of the conduits, estimated on the basis of results of the October-November 2003 monitoring program, varied between approximately 4,100 gpm (non-tourist season) and approximately 5,100 gpm (tourist season) This is equivalent to approximately 5.9 to 7.3 mgd, respectively. This range of infiltration is slightly higher than the estimated infiltration of approximately 5 mgd following the 2000 grouting effort. This may be due in part to shifting of infiltration from the grouted downstream side to the upstream side. The infiltration generated east of the NYPA conduits amounts to 65-70 percent of total.

6.2.1 Evaluation of the Infiltration Path

In addition to the FST flow monitoring program, the October-November 2003 study incorporated data from other elements of this study. Potentiometric heads in the Lockport aquifer in the vicinity of the FST and CDS were measured by means of monitoring wells as described in Section 4.3. Surface water elevations were obtained from existing gauges in the Niagara River and the NYPA forebay. Water level gauges were also installed in the dewatering pump stations (Pump Stations A and B) of the CDS. In each pump station, potentiometric head was monitored in the central sump, hydraulically connected to the CDS, and in the outside sump, hydraulically connected to the inside of the conduits (Section 2.2.1).

Three major pathways that may contribute to infiltration into the FST were identified. The first is the CDS. Water from the Niagara River can enter the drainage system via the surrounding bedrock in its upstream (i.e., southern) section. From there it can be transferred into the area of the conduit/FST crossing and infiltrate into the FST. The second pathway is the high-transmissivity zone in the Lockport dolomite aquifer, identified between the upper Niagara River and the FST. Because hydraulic heads in the river are higher than the heads in the FST, the flow within this zone should be from the river towards the FST. The third pathway is from the conduits into Pump Station A (upstream end of conduits). This

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flow enters the central sump of the pump station through the overflow weirs between the station and the conduits. Since the central sump is hydraulically connected to the CDS, flow can infiltrate into the aquifer and from there enter the FST.

The main objective of this part of the study was to evaluate the pathway by which water infiltrates into the FST. Evaluation results obtained by integrating the information from all available data sources are presented below.

6.2.1.1 Infiltration vs. Potentiometric Head in the Lockport Aquifer

The invert of the FST in the study area is located at approximately El. 537 to 539 feet. The potentiometric head of the Lockport dolomite aquifer adjacent to the tunnel is approximately El. 553 to 560 feet. The tunnel therefore penetrates into the water-bearing zone of the Lockport. Because the tunnel is cut directly into rock, it constitutes a groundwater sink, inducing infiltration from the surrounding aquifer.

Under normal (i.e., dry-weather) flow conditions, the water depth in the tunnel is low compared to the tunnel cross-sectional area. The inside of the tunnel therefore remains essentially under atmospheric pressure, which is relatively constant. The infiltration rate should be proportional to the difference between the average elevation of the tunnel walls and the hydraulic head of the aquifer. As a result, the infiltration rate should mimic fluctuations in the hydraulic head.

The hydraulic head in the aquifer immediately adjacent to the FST east of the conduits has been monitored at two locations: OW-139 and GW03-016 (Figure 6.2.1-1). Monitoring well OW-139, screened across several water-bearing zones of the Lockport, is located approximately 30 feet north of the tunnel. Well GW03-016 is located approximately 175 feet north of the tunnel, and consists of 8 piezometers screened in different water-bearing zones. It was found that the water levels obtained at OW-139 and in all monitored water-bearing zones in GW03-016 were similar (maximum difference of approximately one foot at any given moment). For simplicity, therefore, a measurement from a single

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location (GW03-016-P2) has been selected to represent the hydraulic head in the aquifer adjacent to the tunnel.

Figure 6.2.1-2 presents the infiltration rate into the FST and the potentiometric head within the aquifer plotted as a function of time over the entire period of the flow monitoring study. As shown in the chart, infiltration in the east closely follows fluctuations of hydraulic heads. A detail of Figure 6.2.1-2, shown as Figure 6.2.1-3, indicates that the response of the infiltration rate to the hydraulic head fluctuation is essentially instantaneous. West of the conduits, fluctuation in flow rate is also evident. The fluctuation west of the conduits, however, is very low in comparison with the average infiltration rate. The magnitude of fluctuation is of the same order as the scatter of data (see Figure 6.2.1-3). The difference in the behavior of the system east and west of the conduits is likely an effect of the grouting of the FST west of the conduits by the City of Niagara Falls. The introduction of grout into the fractures within the Lockport west of the conduits altered the flow regime in the immediate vicinity of the FST. Instead of entering large fissures where flow can occur at relatively high velocities and can change quickly in response to hydraulic gradients, groundwater now percolates through low-permeability grout material. This not only reduces the overall infiltration rate to approximately 45% of that on the east side of the conduits, but also effectively dampens most of the effect of fluctuation of the water table outside the FST walls, making the infiltration dependent predominantly on the long-term average hydraulic head.

Observation of the infiltration rate and the potentiometric head indicates that the driving force for infiltration is the potentiometric head in the Lockport aquifer above the elevation of the FST walls. The east side of the tunnel, which has not been grouted, shows an instantaneous response to hydraulic head fluctuation, infiltration correlating closely with the height of the potentiometric surface above the tunnel walls (Figure 6.2.1-4). At the west side, the grouting project has both reduced the magnitude of infiltration and dampened its fluctuations. Here the infiltration is lower than in the east and is maintained at a relatively uniform level over time.

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6.2.1.2 Source of Fluctuation of Potentiometric Head in the Lockport Aquifer

Potentiometric surface in the Lockport aquifer in the vicinity of the FST fluctuates between approximately El. 553 and 560 feet. Daily fluctuations of up to approximately 5 feet have been observed. The fluctuation pattern appears to be relatively regular. The total infiltration rate into the FST is closely correlated with the fluctuation of potentiometric head in the aquifer. Determining the source of the fluctuations is essential to understanding the mechanism of FST infiltration.

The high magnitude and the regular pattern of the fluctuations indicate that they are not caused by such natural phenomena as, for example, a change in recharge pattern. Rather, the pattern is indicative of a boundary effect. Under this scenario, a surface water body forming the boundary of the aquifer experiences rapid changes of depth, transferring energy in the form of pressure waves into the aquifer. Potentiometric head in the aquifer essentially follows the elevation of the water surface at the boundary, with the amplitude gradually diminishing with distance from the fluctuating source.

The only surface water bodies in the area that may impart such a change to the Lockport aquifer are the Niagara River and the NYPA forebay. In addition to these two bodies, however, the CDS network of pipes surrounding the conduits may also transfer river and forebay surface fluctuations to the aquifer, since this network is in direct hydraulic contact with the aquifer.

Figure 6.2.1-5 shows potentiometric heads throughout the flow study observed at key locations: the Niagara River at the conduit intakes, the forebay, within the aquifer in the vicinity of the FST, and in the CDS in the vicinity of the FST (as measured in the central sump of Pump Station A). Figure 6.2.1-6 shows a detail from Figure 6.2.1-5, facilitating a more accurate visual analysis. From this detail, the following observations may be made:

- Fluctuations of the water level in the Niagara River are on the order of one foot.

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- Fluctuation patterns of the potentiometric head in Lockport adjacent to the FST and of the head in the CDS are essentially identical. Their amplitude is up to 5 feet, which is higher than the amplitude of river surface fluctuations and lower than the 20-foot fluctuations occurring in the forebay.

- The forebay fluctuations and the fluctuation of the potentiometric heads in the aquifer and the drainage system display essentially the same pattern, with a phase shift of approximately two hours. (The forebay change precedes the aquifer/CDS change.)

It appears that the motive force for the fluctuations of the potentiometric head in the Lockport aquifer in the immediate vicinity of the FST is the changing elevation of the water surface in the NYPA forebay. The forebay fluctuations are transferred into the FST area via the pipes of the CDS with a lag of approximately two hours. The drainage system in turn imparts these fluctuations to the aquifer. The response of the aquifer in the vicinity of the FST to the fluctuations in the CDS is essentially instantaneous. The Niagara River plays a minimal role in generating the potentiometric head fluctuations in the aquifer.

6.2.1.3 Flow in the Conduit Drainage System

It has been established that the fluctuations of water surface elevation in the forebay are transferred along the CDS into the area where the respective alignments of the conduits and the FST cross one another. The head in the drainage system, in turn, controls the hydraulic head in the Lockport aquifer in that area. The hydraulic head in the aquifer governs the infiltration of groundwater into the FST.

The primary CDS components are four horizontal pipes (two ½-round and two square), installed along the longitudinal axis beneath each of the conduits' floors (total of eight pipes). The pipes are non-circular each with an equivalent diameter on the order of one foot. The pipes offer a combined flow capacity that is estimated to be orders of magnitude higher than that of the aquifer (see Appendix P). Because of the high flow capacity of the CDS pipes and the link between the fluctuation of head in the

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CDS in the study area and infiltration into the FST, the pipes may be considered as one of the major routes of water eventually infiltrating into the FST.

Hydraulic head in the drainage pipes can be measured directly at the central sump of Pump Station A. A piezometer cluster, GW03-016, has also been installed in the immediate vicinity of Pump Station A, approximately 40 feet east of the eastern conduit. Hydraulic heads in the drainage system are compared to the potentiometric heads in the Lockport at the level corresponding to the elevation of the CDS pipes (GW03-016B-P6). The two values are very similar, as shown in Figure 6.2.1-7.

Piezometer clusters similar to the GW03-016 cluster have been installed at various locations along the conduits. Based on the similarity of hydraulic heads between the CDS at Pump Station A and the aquifer immediately next to the drainage system, it may be inferred that the potentiometric data collected at these wells can be used to approximate the hydraulic heads in the CDS.

Hydraulic head data for wells along the conduits were analyzed with respect to the relative gradients prevailing within the drainage pipes (see Appendix O). Results are presented in Figure 6.1.2-2. The flow regimes differ slightly for the periods of the tourist and non-tourist seasons. During the tourist season, flow in the pipes is directed from the upper Niagara River towards the FST at all times. North of the FST, the flow direction is variable, although the dominant direction appears to be north. In the northernmost segment of the system, closest to the forebay, flow direction reverses frequently, and dominant gradients are difficult to establish. During the non-tourist season, flow is always to the north in the southern and central portions of the system. In the northern portion, close to the forebay, frequent flow reversals occur in the same manner as during the tourist season.

Based on this analysis, it appears that the majority of flow reaching the area of the FST/conduit crossing via the CDS originates at the Niagara River (a small fraction may come from the north during flow reversals of the tourist season, although the predominant direction immediately north of the FST is to the north and away from the FST). A portion of this flow exits the CDS and infiltrates into the FST. The remainder continues north toward the forebay. Flow rates in the CDS in the vicinity of the FST have been estimated based on physical properties of drainage pipes and gradients obtained from piezometers

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screened immediately adjacent to the conduits. Details are presented in Appendix O. During the tourist season, the average values of the flow rates towards the FST from the river and away from the FST to the north have been estimated at approximately 5,400 gpm and 1,600 gpm, respectively. The remaining 3,800 gpm infiltrates into the FST. During the non-tourist season, flow from the river is approximately 7,100 gpm, and the northward flow away from the FST is 4,100 gpm. Approximately 3,000 gpm, therefore, infiltrates into the FST.

6.2.1.4 Flow in the High Transmissivity Zone

Flow within the CDS is not the single source of water infiltrating into the FST. The tunnel, at the intersection with the conduits, is located within a high-transmissivity zone of the Lockport aquifer. Wells screened within that zone are capable of yields of several thousand gallons per minute (Johnston 1964). The high-transmissivity zone is hydraulically connected with the Niagara River. See Figure 6.2.1-8.

Potentiometric surface in the Lockport adjacent to the FST is shown in Figure 6.2.1-9. The figure also shows water surface elevations in the Niagara River at the intakes. The head in the river is approximately 6 to 8 feet higher than the aquifer, for the tourist and non-tourist seasons, respectively. Using historical data for pumping wells located in the high-transmissivity zone, the head differential observed during this study, as well as the infiltration rate in the area of the high-transmissivity zone established by the USGS model (Yager 1996), the flow rate within the Lockport between the river and the FST has been estimated to be just under 1,000 gpm (770 gpm during the tourist season and 980 gpm during the non-tourist season - see Appendix P).

6.2.1.5 Flow over the Weir in Pump Station A

An additional source of water entering the aquifer via the CDS is the flow over the weir in Pump Station A. As discussed in Section 6.1.2, the flow rate over the weirs was estimated at approximately 160 gpm. Because this rate is one to two orders of magnitude lower than the overall infiltration rate into the

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FST, no attempt was made to make a more accurate estimate. A value of 100 gpm is assumed for the tourist season. The flow rate during the non-tourist season is negligible.

6.2.1.6 Summary of FST Infiltration Rates

Total magnitude of sources identified as contributing to infiltration into the FST at the conduit/FST crossing has been estimated by analyzing available data and corresponding calculations. Infiltration rates of approximately 4,600 gpm and 4,000 gpm were obtained for the tourist and non-tourist seasons, respectively (Table 6.2.2-1). Approximately 15 to 25% of the flow has been estimated to originate as flow from the Niagara River through the high-transmissivity zone in the Lockport aquifer. The remaining 75 to 85% is thought to come via the drainage system of the NYPA conduits, predominantly from the Niagara River, with a small contribution from the conduits by way of the weirs at Pump Station A.

A flow monitoring program was undertaken in October-November 2003. Infiltration rates into the FST were measured at approximately 5,100 gpm and 4,100 gpm for tourist and non-tourist seasons, respectively.

The measured infiltration rates and the calculated magnitude of possible sources compare favorably. The measured infiltration rates and calculated magnitude of sources are as follows: tourist season: measured 5,100gpm, calculated 4,600 gpm; non-tourist season: measured 4,100 gpm, calculated 4,000 gpm. Also, the approach applied to flow estimating correctly captures the difference between the magnitude of infiltration rates during the tourist and non-tourist seasons (higher infiltration during the tourist season). Based on this, it appears that conclusions pertaining to the flow distribution within the system, as obtained on the basis of data analysis and calculations, can be applied to the flow measured directly during the study.

It appears that the long-term average infiltration rate into the FST at the conduit/FST crossover is approximately 4,500 gpm. Under current conditions, approximately 20% of that rate, or 900 gpm, can be

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attributed to the flow through the high transmissivity zone of the Lockport dolomite. The remaining fraction of approximately 80%, or 3,600 gpm, reaches the FST via the drainage system of the NYPA conduits.

6.2.2 Uncertainties in Flow Analysis

Three major sources of uncertainty can be identified in the process of estimating the infiltration into the FST at the confluence with the conduits. They are: (1) the accuracy of measurement, (2) the need for calculations to represent the physical systems, and (3) the presence of unquantifiable sources/sinks of water.

All estimates presented in this section are based on measurements. Examples of quantities that were measured are: hydraulic heads in monitoring wells, flow depths and velocities, and elevations of reference points. All these measurements carry degrees of error. These errors are attributable to a variety of factors, including the limits of measuring instruments and the nature of field conditions (temperature, humidity, etc). These errors can be carried into the calculations used to estimate quantities of interest.

Standard engineering/geologic practices were used in performing all measurements. Errors of measurement are therefore considered to be within acceptable limits. There is one measurement, however, whose accuracy is difficult to ascertain, namely, the hydraulic heads used to estimate head losses in the conduit drainage pipes. The hydraulic heads in the relevant wells were found to fluctuate on a relatively short time scale. However, only a very limited number of hand measurements at these wells are available. The averages of these measurements, used to represent typical heads at these locations, are therefore not well established. This uncertainty does not affect the flow measured in the FST, although it may affect the way in which this flow can be apportioned among various sources.

Ultimately, the quantities of interest are arrived at by means of calculations. During this process, physical systems are simplified, introducing yet another source of potential error. Examples of simplifying assumptions include the use of a symmetrical, idealized velocity profile based on two

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measurements to estimate the flow rates at bypass pipe locations in the FST and, the approximation of hydraulic heads within the CDS using potentiometric heads measured in nearby piezometers. Slight differences in heads between the CDS and adjacent piezometers (as was noted at Pump Station A), may not strictly represent flow gradients or flow volumes within the CDS.

Most calculations performed during the process of flow estimation follow standard engineering/geologic practices and are therefore expected to yield relatively accurate results. One calculation; however, based on very limited data, may constitute an oversimplification. The transmissivity of the high-transmissivity zone in the Lockport aquifer was estimated based on a report of stabilized flow rate and drawdown obtained during pumping from a single well located in the study area. The original time-drawdown data were not available. The system was therefore approximated as a steady-state system, and therefore the accuracy of the transmissivity estimate may be low. Transmissivity was used to calculate the flow rate of water reaching the FST from the Niagara River via the Lockport aquifer. The potential error does not affect the flow measured in the FST, although it may affect the way in which this flow can be attributed to various sources.

Lastly, the aquifer may contain sinks and sources unaccounted for in this estimate. There may be an exchange of water between the aquifer and small bodies of water, such as ponds, drainage basins, or creeks. The aquifer may also lose water to storm or sanitary sewers or to extraction wells located in the area. The aquifer may gain water from leaky water supply lines. These secondary sources or sinks were not considered in the estimate. Calculations were performed with the assumption that these elements are negligible, and that their effects are likely to cancel out. The potential error does not affect the flow measured in the FST, although it may affect the way in which this flow can be attributed to various sources.

One possibly significant element that has not been accounted for in the estimate of the water budget near the FST is the damage to the concrete floor of the east conduit, which may permit additional flow. During the conduit inspection of 1994, a 40-foot long section of the bottom was observed to be buckled and fractured. Flow was seen to enter the east conduit through the damaged section. Unfortunately, no flow estimates were made.

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The observations regarding the concrete floor were made during conduit inspection with a submersible vehicle. To facilitate the operation, the upstream gates of the conduits had been closed, eliminating direct Niagara River inflow. This may have created a water surface elevation inside the conduits that was different from elevations prevailing during operational conditions. Therefore, although the inspection established that flow occurs through the damaged floor, the direction of the flow during normal operations could not be determined.

Measurements of the hydraulic heads in the conduits and the CDS were made in Pump Station A, located close to the area of damaged conduit floor. In addition, hydraulic heads in the aquifer were monitored in nearby wells. It was established that the head in the conduits is approximately 1.5 feet higher than the heads in the drainage system (Section 6.1.2). This is true for both the tourist and non-tourist seasons. Flow, therefore, moves out of the conduits and into the aquifer or CDS, or both. This flow, whose magnitude is unknown, would have to be added to the estimated magnitude of sources. It is not clear what effect this would have on the overall agreement between the estimated magnitude of sources and the flow actually measured in the FST.

6.3 Water Quality In the Vicinity of the Niagara Power Project

6.3.1 Regional Groundwater Quality

Groundwater in the study area may be conceived of as two systems; a freshwater flow system, and a deeper saline water flow system. The regional freshwater flow system has been characterized as a wedge that thins to the south above the denser saline water (Kappel and Tepper 1992). The primary source of the freshwater flow system is recharge in the area of the Niagara escarpment. The Lewiston Reservoir also acts as a substantial source of recharge to the freshwater flow zone. The freshwater wedge thins southward due to increases in hydraulic head in the regional flow system that cause brackish water to move up-dip (Kappel and Tepper, 1992). Beneath the freshwater flow system wedge, the saline water system pushes upward into the Lockport Group due to hydrostatic pressure exerted from the source area in the Allegheny Plateau region (LaSala 1968). A freshwater/saline water mixing zone occurs at the interface between the two flow systems.

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Generally, groundwater in the freshwater flow system is moderately to highly mineralized, containing sulfates dissolved from soluble gypsum within the dolomite, and calcium and magnesium bicarbonate, also dissolved from dolomite. Johnston (1964) noted the slight mineralization of groundwater near the Niagara River where it has been infiltrated by river water. Figure 6.3.1-1 shows the chemistry of water sampled from an industrial groundwater well located on Buffalo Avenue as being very similar to water sampled from the conduit at the pump station on Royal Avenue. Johnston (1964) categorized water in the Lockport away from the river as either having a chloride content of less than 100 mg/L, or being saline water with a chloride content of >500 mg/L. He also noted brines having a chloride content as great as 123,000 mg/L isolated in the lowest two fracture zones. The deeply circulating saline water may account for the brines found in the lower Lockport and DeCew piezometers. Generally, the most mineralized waters are found in the lowest two fracture zones. There is a wide range of mineralization within these two fracture zones. That is, the water in the lowest fracture zones is not uniformly mineralized. There is probably freshwater infiltrating into these zones from shallow bedrock near the escarpment and from the Lewiston Reservoir. For piezometers GW03-007A-P2, GW03-008A-P2, GW03-009A-P2, and GW03-010A-P2, all in deeper water-bearing zone 10, chloride concentrations are all below 300 mg/L.

The nomograph shown in Figure 6.3.1-1 illustrates the variations in water chemistry within the study area. Conduit water (Niagara River water) is shown as the lowest curve on the graph. The analytical data for conduit water shows calcium and magnesium content derived from contact with carbonate bedrock exposed in the riverbed. The chloride content of the river water is relatively low (20 ug/L). Water sampled from GW03-015B-P5 in October 2003 shows a chloride content of <100 mg/L. Water sampled from this well in December 2003 shows >500 mg/L, along with calcium, magnesium, sodium, and sulfate. The seasonal increase in salinity in this piezometer was also accompanied by an increase in target analyte concentrations. Typical Lockport saline water (from Johnston 1964) is the upper curve on the graph with a chloride content of approximately 1,200 mg/L.

Groundwater sampled from all the piezometers in the study area in October and December 2003 showed some seasonal variation in salinity. In October/November 2003, 41% of the samples (33 of 79) had a chloride content of <100 mg/L, and 30% (24 of 79) had a chloride content of > 500 mg/L. Six

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piezometers screened in the DeCew dolomite were very saline, with chloride contents ranging from 24,200 to 90,500 mg/L. Water from one piezometer in the lower Lockport was also very saline, showing 21,000 mg/L chloride. These samples are similar in salinity to seawater and oil-field brines (see Table 6.3.1-1).

In December 2003, 35% of the samples (28 of 79) showed a chloride content of <100 mg/L, and 37% (30 of 79) had a chloride content of > 500 mg/L. Six piezometers screened in the Gasport/DeCew water-bearing zone were very saline, with chloride levels ranging from 7,710 to 96,600 mg/L. Chloride concentrations in the very saline piezometer in the lower Lockport rose from 21,000 to 33,400 mg/L.

In December 2003, the chloride levels in these seven piezometers varied widely from the October/November 2003 concentrations suggesting the dense brines are not isolated as Johnston (1964) thought. Declining chloride levels may be due to an influx of less saline water from above. Freshwater infiltrates downward through the overburden soil and into a network of vertical and horizontal rock fractures. Water infiltrating into shallow bedrock in the escarpment area flows down-dip south of the groundwater divide and mixes with deeper saline water. Rising chloride levels suggests lateral movement within the briny lower Lockport and DeCew. Variations in chloride concentration along the CDS may also be related to forebay-induced changes in the hydraulic gradients, causing formation water to move toward the CDS, and to displace river water within the CDS and surrounding fractured rock.

6.3.2 Groundwater Quality in the Vicinity of the Conduits

As shown in Figure 2.2.4-2, groundwater in the vicinity of the conduits is affected by numerous contaminant plumes associated with former and active industrial sites. Analytical results for groundwater samples collected in September/October 2003, December 2003, and March 2004 identified numerous chemical contaminants in samples collected from piezometers located along the conduits (well locations GW03-012 through GW03-017). Contaminants detected during these sampling events may be classified into the different contaminant groups associated with the known contaminant plumes and discussed in Section 2.2.

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The chemical contaminants groups detected during the September/October, December 2003, and February/March 2004 sampling events include the following:

- Group 1 – Chlorinated Volatiles: 1,2-DCE (cis), TCE, PCE, vinyl chloride, 1,1,1-TCA, dichlorobenzenes, 1,1-DCA, and 1,1-DCE.
- Group 2 – BTEX Compounds: benzene, toluene, ethylbenzene, xylenes
- Group 3 – Nonchlorinated Volatiles: acetone, methyl ethyl ketone, cyclohexane, methylcyclohexane, carbon disulfide, and isopropylbenzene.
- Group 4 – Phenol and Methylphenols: phenol, 2,4-dimethylphenol, 2-methylphenol, and 4-methylphenol.
- Group 5 – Chlorophenols: 2-chlorophenol
- Group 6 – Chlorobenzenes and Chlorotoluenes: chlorobenzene
- Group 7 – PAHs: naphthalene, pyrene,
- Group 8 – Highly Chlorinated Non-Aromatic Semivolatile Compounds: No Compounds Detected
- Group 9 – Phthalates: bis(2-ethylhexyl) phthalate, Di-n-octylphthalate
- Group 10 – Pesticides/PCBs/Dioxins: alpha-BHC, beta-BHC, delta-BHC, Aroclor 1242
- Group 11 – Heavy Metals: arsenic, cadmium, lead

The contaminant plumes discussed in Section 2.2.4 have been thoroughly characterized by past and ongoing investigation and remediation efforts. Movement of contaminants associated with these plumes is influenced by many factors, including regional groundwater flow patterns, relative effectiveness of remediation programs, area groundwater extraction activities, vertical fracturing, contaminant characteristics (e.g. specific gravity and solubility), and vertical hydraulic gradients. In many cases, contaminants have been identified throughout the entire thickness of the Lockport Group. In some cases, dense non-aqueous-phase liquids (DNAPLs) have migrated downward and act as continuing sources of dissolved-phase groundwater contamination.

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Several chemical contaminants detected in surface water and groundwater samples during this investigation are common laboratory contaminants. The compounds methylene chloride, ketones (e.g., acetone, methyl ethyl ketone), and some phthalates are often associated with laboratory settings and can be introduced into the sample during analysis. As a result, these compounds may be detected in samples at low concentrations even though they are not present at the time of sample collection. These compounds were detected at relatively low concentrations in some groundwater and surface water samples during this investigation. These detections may be indicative of laboratory contamination rather than the presence of these compounds in groundwater.

The discussion of groundwater quality and NPP effects on groundwater quality presented in the following subsections is organized by water-bearing zone.

6.3.2.1 Water-Bearing Zone 2 - Upper Weathered-Bedrock Zone

6.3.2.1.1 Southern Wells (GW03-014 through GW03-017)

Chemical contamination levels detected in the weathered bedrock water-bearing zone were generally lower than those detected in deeper zones (Figure 5.5.2-19). For wells GW03-014 through GW03-017, the contaminants detected generally consisted of compounds in Groups 1, 3, and 10. One compound, 1,2-dichloroethene (cis) was detected in all four well locations in water-bearing zone 2. Other compounds detected in at least two piezometers include PCE, TCE, and beta-BHC. For Group 1 compounds (chlorinated volatiles), detected concentrations ranged from 0.37 ug/L (TCE in GW03-015C-P7) to 90 ug/L (vinyl chloride in GW03-015C-P7). Pesticide compounds were detected at concentrations up to 0.1 ug/L (4,4-DDT) in GW03-015C-P7. Other contaminants detected were benzene (1.6 ug/L in GW03-015C-P7) and cadmium (3.4 ug/L in GW03-014C-P7) (Figure 5.5.2-19).

Based on inferred groundwater flow patterns and hydraulic gradients within the CDS, contaminants detected in these piezometers likely migrate into the CDS. Once in the CDS, contaminants in the vicinity of piezometer GW03-017C-P7, likely flow northward and discharge either to the FST or

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the forebay. For piezometer GW03-016C-P7, located north of the FST, hydraulic heads are lower than the CDS. Therefore, contaminants detected in this well likely discharge directly to the FST. In the vicinity of piezometers GW03-014C-P7 and GW03-015C-P7, contaminants within the CDS likely flow northward toward the forebay (Figure 6.1.2-2).

For the piezometers of water-bearing zone 2 discussed above, no substantial changes in groundwater quality were observed between results for tourist and non-tourist operating periods. In some cases, contaminant concentrations increased slightly and decreased slightly, while in other cases no pattern was discernible. As observed in hydraulic heads measured in these piezometers, during non-tourist season, the hydraulic gradients between all these piezometers were observed to be to the north toward the forebay. During tourist season, periods of gradient reversal were observed among piezometers GW03-014C-P7, GW03-015C-P7, and GW03-016C-P7. During these periods, contaminants in these areas may flow southward toward the FST (Figure 6.1.2-2).

6.3.2.1.2 Northern Wells (GW03-012 through GW03-013)

Only four analytes, caprolactum (6 ug/L in GW03-012C-P7), cadmium (1.1 ug/L in GW03-012C-P7), carbon disulfide (0.21 ug/L in GW03-013C-P7), and lead (7.4 ug/L in GW03-013C-P7 and 10 ug/L in GW03-012C-P7) were detected in samples collected from the upper weathered-bedrock zone in piezometers GW03-012C-P7 and GW03-013C-P7 (Figure 5.5.2-19). No sample was collected from piezometer GW03-012C-P7 in October 2003 due to insufficient water in the well. In well GW03-013C-P7, lead was not detected in October 2003 or March 2004, but lead was detected at 7.4 ug/L during the December 2003 sampling event (non-tourist season).

During non-tourist season, CDS hydraulic gradients in the vicinity of these piezometers fluctuate somewhat with the predominant flow being north toward the forebay. During tourist season, hydraulic gradients fluctuate more evenly between north and south. Contaminants in this area likely flow mainly northward and discharge to the forebay.

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6.3.2.2 Water-Bearing Zones 6 and 7 – Eramosa Units D and C

Water-bearing zones 6 and 7, representing water-bearing zones at the tops of Eramosa Unit D and Eramosa Unit C, respectively, occur only in the southern portion of the study area. Water-bearing zone 6 is encountered only in well GW03-017C-P8, and water-bearing zone 7 occurs in the area of both piezometers GW03-016B-P4 and GW03-017B-P4. Contaminants detected in these piezometers fall into Contaminant Groups 1 (chlorinated volatiles), 3 (non-chlorinated volatiles), 6 (chlorobenzenes), 7 (PAHs), and 10 (pesticides, PCBs, dioxins). Chlorinated solvents, the most predominant contaminants detected in these two water-bearing zones, include 1,1-dichloroethene, 1,2-dichloroethene (cis and trans), PCE, TCE, and vinyl chloride. Other compounds detected include benzene, naphthalene, alpha-BHC, and delta-BHC. The predominant chlorinated solvents detected in GW03-017C-P8 (water-bearing zone 6) included vinyl chloride (16 ug/L in September), TCE (130 ug/L in September 2003), PCE (12 ug/L in September 2003), and 1,2-dichloroethene (cis) (160 ug/L in September 2003) (Figures 5.5.2-20 and 5.5.2-21). Concentrations of 1,2-dichloroethene (cis) and TCE detected in these zones are some of the highest detected compared to other zones. Other compounds detected in these zones are generally lower, and are consistent with concentrations detected in other zones.

Contaminants detected in water-bearing zones 6 and 7 are similar, with the exception that Contaminant Group 6 – chlorobenzenes, while absent in water-bearing zone 6, is detected in water-bearing zone 7 for well GW03-016B-P4. Concentrations of chlorinated solvents detected in water-bearing zone 7 are generally lower than those detected in water-bearing zone 6. TCE was detected in piezometer GW03-017B-P4 at concentrations of 39 ug/L, 85 ug/L, and 180 ug/L for the September 2003, December 2003, and March 2004 sampling events, respectively. Concentrations of vinyl chloride detected in water-bearing zone 7, higher in GW03-016B-P4, were 14 ug/L, 7.5 ug/L, and 4.1 ug/L for the September 2003, December 2003, and March 2004 sampling events, respectively. Concentrations of chlorobenzene detected in GW03-016B-P4 ranged from 1.5 ug/L to 2.8 ug/L.

As with water-bearing zone 2, these piezometers for water-bearing zones 6 and 7 are within the hydraulic influence of the CDS. Groundwater from these areas to the CDS likely discharges mainly to the FST, with a lesser amount flowing northward to the forebay. For piezometer GW03-017B-P4, concentrations of 1,2-DCE (cis) and TCE approximately doubled from the December 2003 to the March 2004 sampling events. No other substantial changes in groundwater quality were observed between

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tourist and non-tourist seasons. In some cases, contaminant concentrations increased, and in others they decreased.

6.3.2.3 Water-Bearing Zones 8A and 8B – Eramosa Units A and B

For the purpose of evaluating and discussing groundwater quality, water-bearing zone 8 was divided into water-bearing zones 8A and 8B. Water-bearing zone 8A, the screened interval in the upper portion of water-bearing zone 8, targeted the water-bearing zone at the Eramosa C/Eramosa B contact. Water-bearing zone 8B, the screened interval in the lower portion of water-bearing zone 8, targeted the water-bearing zone at the Eramosa B/Eramosa A contact. Analytical results for samples collected from water-bearing zones 8A and 8B are summarized in Figures 5.5.2-22 and 5.5.2-23, respectively.

6.3.2.3.1 Southern Wells (GW03-014 through GW03-017)

Water-bearing zone 8A

Chemical contaminant groups represented in water-bearing zone 8A are similar to those of water-bearing zones 6 and 7 and include Contaminant Groups 1 (chlorinated volatiles), 3 (non-chlorinated volatiles), 6 (chlorobenzenes), 9 (PAHs), and 10 (pesticides, PCBs, dioxins). In addition to these, piezometer GW03-015A-P1 contained contaminants in Group 4 (phenol and methylphenols). Concentrations of chlorinated VOCs in these piezometers were generally lower than in water-bearing zone 7, ranging from 0.35 ug/L (PCE in GW03-015A-P1) to 11 ug/L (TCE in GW03-016A-P1). Benzene was detected in GW03-016A-P1 at a maximum concentration of 5.7 ug/L in March 2004. The pesticides alpha-BHC, beta-BHC, and delta-BHC were detected in piezometers GW03-015A-P1, GW03-016A-P1, and GW03-017B-P5 at concentrations ranging from 0.029 ug/L to 0.079 ug/L. In October 2003, the PCB Aroclor 1242 was detected in well GW03-015A-P1 at a concentration of 0.44 ug/L. Chlorinated solvents were detected at higher concentrations in piezometers GW03-016A-P1 and GW03-017B-P5 than in piezometers GW03-014B-P4 and GW03-015A-P1 located further to the north (Figure 5.5.2-22).

All these piezometers are located within the hydraulic influence of the CDS and probably discharge groundwater to the CDS. Contaminants identified in piezometers GW03-016A-P1 and GW03-

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017B-P5 discharge to either the FST or the forebay, while contaminants identified in the other piezometers likely discharge mainly to the forebay. No substantial changes were observed between analytical results for tourist and non-tourist seasons except for GW03-015A-P1. Four contaminants, PCE, 2-chlorophenol, pyrene, and delta-BHC, that were not detected in October 2003 (tourist season) were detected in December 2003 (non-tourist season) (Figure 5.5.2-13). Vinyl chloride was detected (4.5 ug/L) in piezometer GW03-015A-P1 for the first time in the March 2004 sampling event. A steeper hydraulic gradient toward the CDS, caused by the lowered average forebay levels maintained during non-tourist season, may be responsible for this apparent increase in contaminants.

Water-bearing zone 8B

Contaminants identified in Water-bearing zone 8B are generally consistent with those detected in water-bearing zone 8A, with the following exceptions: (1) increased frequency in 8B of gasoline-related compounds such as benzene, toluene, xylenes, cyclohexane, and methylcyclohexane; (2) phenol compounds, including 2,4-dimethylphenol, 2-methylphenol, and 4-methylphenol, are detected in GW03-017C-P9; and (3) no contaminants were detected during any sampling event in piezometer GW03-015B-P4 (Figure 5.5.2-23). Concentrations of gasoline-related compounds listed above ranged from 0.26 ug/L cyclohexane (GW03-016B-P5) to 8.4 ug/L benzene (GW03-016B-P5). Concentrations of chlorinated VOCs in these piezometers ranged from 0.26 ug/L PCE (GW03-017C-P9) to 5.4 ug/L TCE (GW03-016B-P5). Phenol compounds detected in piezometer GW03-017C-P9 ranged from 2 ug/L 2,4-dimethylphenol to 30 ug/L phenol. Carbon disulfide was detected in three piezometers, GW03-014A-P1 (7.2 ug/L), GW03-016B-P5 (0.34 ug/L), and GW03-017C-P9 (1.8 ug/L). Arsenic was detected in piezometer GW03-014A-P1 at concentrations of 30.7 ug/L, 32.3 ug/L, and 26.8 ug/L during the September/October 2003, December 2003, and March 2004 sampling events, respectively.

At piezometer GW03-017C-P9, water-bearing zone 8B dips below the level of the CDS but is still probably influenced by the CDS due to its proximity. Contaminants detected in piezometer GW03-016B-P5 likely discharge directly to the FST. Everywhere else (piezometers GW03-014A-P1 and GW03-015B-P4) water-bearing zone 8B is in direct connection with the CDS. As a result, contaminants likely discharge to either the FST or the forebay. Some minor differences were noted among analytical results for samples collected during the tourist and non-tourist season. In piezometer GW03-017C-P9, the phenol compounds generally increased from October to December 2003, but decreased from December

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2003 to March 2004. In piezometers GW03-014A-P1, GW03-016B-P5, and GW03-017C-P9, several VOCs dropped to non-detect in the December results (Figure 5.5.2-14).

6.3.2.3.2 Northern Wells (GW03-012 and GW03-013)

Water-bearing zone 8A

No chemical contaminants were detected in water-bearing zone 8A for piezometers GW03-012B-P4 and GW03-013B-P4 for any of the three sampling events (Figure 5.5.2-22).

Water-bearing zone 8B

No chemical contaminants were detected in water-bearing zone 8B at piezometers GW03-012A-P1 and GW03-013A-P1 during any of the sampling events (Figure 5.5.2-23)

6.3.2.4 Water-Bearing Zones 9A and 9B – Goat Island Dolomite

For the purposes of evaluating and discussing groundwater quality, water-bearing zone 9 was divided into water-bearing zones 9A and 9B. Water-bearing zone 9A, the screened interval in the upper portion of water-bearing zone 9, targeted the water-bearing zone at the Eramosa/Goat Island stratigraphic contact. Water-bearing zone 9B, the water-bearing zone in the lower portion of model layer 9, targeted the water-bearing zone at the stratigraphic contact between the Vinemount and Ancaster units of the Goat Island Formation (Figure 5.2.2-1). Analytical results for samples collected from water-bearing zones 9A and 9B are summarized in Figures 5.5.2-24 and 5.5.2-25, respectively.

6.3.2.4.1 Southern Wells (GW03-014 through GW03-017)

Water-bearing zone 9A

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Contaminants detected in these piezometers are numerous, falling into Contaminant Groups 1 (chlorinated volatiles), 3 (non-chlorinated volatiles), 6 (chlorobenzenes), 7 (PAHs), 9 (phthalates), and 10 (pesticides, PCBs, dioxins), and 11 (cadmium, lead). Chlorinated VOCs, the most predominant group detected in these piezometers, include 1,1,2-trichloroethane, 1,2-dichloroethane, 1,2-dichloroethene (cis and trans), chloroform, PCE, methylene chloride, TCE, and vinyl chloride. Other compounds detected include benzene, chlorobenzenes, alpha-BHC, and beta-BHC. In piezometers GW03-014B-P5, GW03-016C-P8, and GW03-017B-P6, chlorinated VOCs were detected at concentrations ranging from 0.46 ug/L (1,2-dichloroethene [cis] GW03-014B-P5) to 7.7 ug/L (1,2-dichlroethene [cis] GW03-016C-P8) (Figure 5.5.2-24).

In the vicinity of well GW03-017, model layer 9 – Goat Island dolomite (represented by water-bearing zones 9A and 9B) lies below the bottom of the CDS (Figure 5.2-1), and therefore, is probably not in direct hydraulic connection with the CDS. Water-bearing zone 9 groundwater flow in this area likely flows beneath the conduits. For areas along the conduits north of well GW03-017, water-bearing zone 9 is directly connected with the CDS and likely discharges either to the FST or the forebay.

A notable change was observed in analytical results for piezometer GW03-015B-P5 for the September/October (tourist season) and the December (non-tourist season) sampling events. For the September/October 2003 sampling event, only three compounds, cyclohexane, methylcyclohexane, and TCE were detected in this well, all at concentrations of 1 ug/L or less. For the December sampling event, there was a sharp increase in the number of contaminants detected from three to 18. The most substantial increases were vinyl chloride, which increased from non-detect in September/October to 720 ug/L in December, and methylene chloride, which increased from non-detect to 190 ug/L. No notable changes were observed between tourist and non-tourist season in either the number of compounds or their concentrations for the other piezometers in this group. One possible cause for this increase is the increase in hydraulic gradient toward the CDS, possibly resulting from lower forebay levels relative to regional groundwater levels. Under such conditions, contaminants from nearby hazardous waste sites would be more likely to flow toward the CDS. Another possible cause is simply the variable nature of contaminants in groundwater.

Water-bearing zone 9B

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The predominant contaminant groups detected in water-bearing zone 9B are Group 1 (chlorinated volatiles) and Group 6 (chlorobenzenes). With the exception of well GW03-017A-P1, contaminants in these two groups were detected at relatively low concentrations, ranging from 0.26 ug/L PCE to 3.2 ug/L chlorobenzene. The highest contamination was detected in well GW03-017A-P1 where vinyl chloride was detected at 180 ug/L, 130 ug/L, 130 ug/L for the October 2003, December 2003, and March 2004 sampling events, respectively. Additionally, 1,2-dichloroethene (cis) was detected at 130 ug/L, 100 ug/L, 92 ug/L respectively, for the October 2003, December 2003, and March 2004 events (Figure 5.5.2-25). For piezometer GW03-017A-P1, lead increased from non detect in December 2003 to 498 ug/L in March 2004. Other compounds detected include alpha-BHC, beta-BHC, delta-BHC, benzene, carbon disulfide, cadmium, and phenol.

As discussed above, in the vicinity of well GW03-017, model layer 9 – Goat Island dolomite (represented by water-bearing zones 9A and 9B) occurs below the bottom of the CDS (Figure 5.2-1), and therefore is not likely in direct hydraulic connection with the CDS. Hydraulic head contours shown in Figure 5.1.3-2 demonstrate that groundwater flow for model layer 9 in the immediate area of well GW03-017 and further south is to the southwest, and is not altered by the influence of the CDS. For areas along the conduits north of well GW03-017, water-bearing zone 9 is directly connected with the CDS and likely discharges to either the FST or the forebay.

Analytical results for well GW03-017A-P1 indicate a general decrease in contaminant concentrations between the September/October and December sampling events with similar results between the December 2003 and March 2004 sampling events (with the exception of lead in GW03-017A-P1). With the exception of GW03-017A-P1, all piezometers represent water-bearing zones that are probably in direct connection with the CDS, and therefore discharge to it.

6.3.2.4.2 Northern Wells (GW03-012 and GW03-013)

Water-bearing zone 9A

Predominant contaminants detected in these piezometers include gasoline-related compounds cyclohexane, methylcyclohexane, and toluene. Other contaminants detected include acetone, carbon

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disulfide, caprolactum, bis (2-ethylhexyl) phthalate, cadmium, and lead. Detected concentrations of gasoline related compounds ranged from 0.24 ug/L cyclohexane (GW03-012B-P5) to 1.4 ug/L toluene (GW03-012B-P5).

The piezometers monitoring water-bearing zone 9A are located within the area of influence of the CDS and along flow paths projected from the Lewiston Reservoir. Based on inferred groundwater flow patterns, contaminants in these piezometers likely enter the CDS where they discharge to the forebay. Analytical results for well GW03-012B-P5 indicate a general increase in contaminants from the September/October (tourist season) to the December (non-tourist season) sampling events and a general decrease in concentrations from December 2003 to March 2004. Concentrations of lead increased from non-detect in October to 55 ug/L in December and were non detected again in March 2004. Similarly, concentration of the SVOC caprolactum increased from 17 ug/L in October to 60 ug/L in December, and decreased to 8 ug/L in March 2004. No noteworthy changes in contaminant concentrations were noted between the tourist and non-tourist seasons for well GW03-013B-P5 (Figure 5.5.2-24).

Water-bearing zone 9B

Contaminants detected in these piezometers include gasoline-related compounds benzene, cyclohexane, and xylenes. Other contaminants detected include acetone, carbon disulfide, caprolactum, and lead. Detected concentrations of gasoline-related compounds ranged from 0.59 ug/L cyclohexane (GW03-012B-P6) to 1.3 ug/L xylenes (GW03-013B-P6). Lead was detected in well GW03-013B-P6 at a concentration of 10.7 ug/L in October 2003. Due to insufficient water in the piezometer, no sample was collected from GW03-013B-P6 during the December sampling event. Again in March 2004, no sample was collected for metals analysis due to insufficient water in the well.

Similar to piezometers installed in water-bearing zone 9A, these two piezometers are located within the area of influence of the CDS and along flow paths projected from the Lewiston Reservoir. Based on inferred groundwater flow patterns, contaminants in these piezometers likely enter the CDS, from which they discharge to the forebay. For well GW03-012B-P6, analytical results indicate a general increase in contaminants, with all contaminants detected increasing from non-detect in October to detectable in December, with a general decrease in March 2004. The SVOC caprolactum increased from non-detect in October to 9 ug/L in December and 8 ug/L in March 2004 (Figure 5.5.2-25).

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6.3.2.5 Water-Bearing Zone 10 – Gasport Dolomite

Contaminants detected in piezometers completed in water-bearing zone 10 (Figure 5.5.2-26) fall into Contaminant Groups 1 (chlorinated volatiles), 3 (non-chlorinated volatiles), 6 (chlorobenzenes), 7 (PAHs), 9 (phthalates), 10 (pesticides, PCBs, dioxins), and 11 (heavy metal).

6.3.2.5.1 Southern Wells (GW03-014 through GW03-017)

Contaminants in Group 1 - chlorinated volatiles, are the predominant contaminants identified in piezometers GW03-016A-P2 and GW03-017A-P2, while gasoline related compounds predominate in piezometers GW03-014A-P2 and GW03-015A-P2. The highest contaminant concentrations were detected in groundwater samples collected from GW03-017A-P2. The compound 1,2-dichloroethene (cis) was detected at 92 ug/L, 270 ug/L, and 160 ug/L for the September 2003, December 2003, and March 2004 sampling events, respectively. Vinyl chloride was detected at 24 ug/L, 170 ug/L, and 340 ug/L, respectively, for the September 2003, December 2003, and March 2004 events. Other compounds detected in all four of these piezometers include chlorobenzenes, beta-BHC, and delta-BHC, benzene, PCE, and TCE. For piezometers GW03-014A-P2 and GW03-015A-P2, gasoline-related compounds (benzene, toluene cyclohexane, and methylcyclohexane) and naphthalene were detected at concentrations ranging from 0.31 ug/L cyclohexane (GW03-014A-P2) to 8.5 ug/L cyclohexane (GW03-014A-P2). The metals arsenic, cadmium, and lead were also detected in piezometers GW03-014A-P2 and GW03-015A-P2.

Due to the gently southward dipping strata, water-bearing zone 10 dips below the CDS level at a point between piezometers GW03-014 and GW03-013. The CDS groundwater flow influence therefore probably diminishes toward the south in this water-bearing zone. In the southern portion of the study area, groundwater flow for water-bearing zone 10 likely continues from east to west unimpeded by the influence of the CDS (Figure 5.1.3-3). Some instances of changes in groundwater analytical results are notable, but there are no recognizable overall patterns. For instance, in well GW03-017A-P2, both 1,2-dichloroethene (cis) and vinyl chloride show substantial increases in concentration from the September/October to December sampling events, and then again from the December 2003 to March

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2004 sampling events. But, for the same well, TCE shows a notable decrease in concentration over the same time periods.

6.3.2.5.2 Northern Wells (GW03-012 and GW03-013)

Contaminants detected in these two piezometers (GW03-012A-P2 and GW03-013A-P2) include di-n-octylphthalate, cadmium, lead, PCE, and TCE. Contaminant concentrations are generally low, with no notable differences between the September/October and December analytical results. Groundwater in this water-bearing zone is likely under the influence of the CDS and along flow paths projected from the Lewiston Reservoir and probably discharges to the CDS.

6.3.2.6 Gasport/DeCew Water-Bearing Zone

Contaminants detected in piezometers completed in the Gasport/DeCew water-bearing zone (Figure 5.5.2-27) fall into Contaminant Groups 1 (chlorinated volatiles), 3 (non-chlorinated volatiles), 6 (chlorobenzenes), 7 (PAHs), 9 (phthalates), 10 (pesticides, PCBs, dioxins), and 11 (heavy metals).

6.3.2.6.1 Southern Wells (GW03-014 through GW03-017)

Due to insufficient water, no sample was collected from piezometer GW03-017A-P3 during any of the three sampling events . BTEX and other gasoline-related compounds are the most predominant contaminants identified in the Gasport/DeCew water-bearing zone in this area. Benzene concentrations ranged from 9.2 ug/L in well GW03-015A-P3 to 160 ug/L in well GW03-014A-P3. Vinyl chloride was also identified in piezometer GW03-016A-P3 (51 ug/L). Arsenic was identified in all three piezometers sampled in this area at concentrations ranging from 10.3 ug/L to 23.3 ug/L, both of these in GW03-014A-P3. Notably, phenolic compounds were also identified in the Gasport/DeCew water-bearing zone (GW03-014A-P3). These compounds had not been detected in any of the other water-bearing zones at well location GW03-014.

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Groundwater flow in this area is not likely influenced by the CDS. Groundwater contaminants in this area likely discharge to industrial pumping operations or the Niagara River. No noteworthy changes in the analytical results were observed between the tourist and non-tourist seasons.

6.3.2.6.2 Northern Wells (GW03-012 and GW03-013)

Contaminants identified in piezometers GW03-012A-P3 and GW03-013A-P3 also indicate gasoline-related contamination, including BTEX, cyclohexane, and methylcyclohexane. Contaminants were more predominant in piezometer GW03-013A-P3 than in GW03-012A-P3. Also detected were chlorobenzenes, phenols, acetone, MEK, and bis (2-ehtylhexyl) phthalate. Benzene ranged from 0.48 ug/L in GW03-013A-P3 to 110 ug/L in GW03-012A-P3.

Groundwater in this water-bearing zone is likely under the influence of the CDS and probably discharges to the CDS.

6.3.3 Groundwater Quality in the Vicinity of the Lewiston Reservoir

Effects of the NPP on groundwater quality within the various identified water-bearing zones in the vicinity of the Lewiston Reservoir are discussed below. As identified in rock cores from the borings surrounding the reservoir (piezometers GW03-001 through GW03-011), only water-bearing zones 2, 8, 9, and 10 occur in this area. North of the northern edge of the Lewiston Reservoir, only water-bearing zones 2 and the Gasport/DeCew water bearing zone occur. In addition, the Gasport/DeCew contact water-bearing zone, which is not included in the groundwater model, occurs in the area of all piezometers surrounding the Lewiston Reservoir. Beneath and east of the reservoir, water-bearing zones 8A, 8B, 9A, 9B, and 10 subcrop or pinch out beneath the overburden. Figure 5.2.4-1 is a map of the reservoir area showing the surface traces of approximate locations of stratigraphic contact subcrops.

Discussion of groundwater quality and NPP effects on groundwater quality presented in the following subsections is organized by water-bearing zone.

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6.3.3.1 Water-Bearing Zone 2

Groundwater quality in the upper weathered-bedrock water-bearing zone (water-bearing zone 2) in the area of the Lewiston Reservoir was generally indicative of the freshwater flow zone. Chloride levels in this zone ranged from 12.1 mg/L in well GW03-006B-P4 to 1,240 mg/L in GW03-005A-P1 Figure 5.5.2-10. Higher chloride levels may indicate water-bearing zones within a zone of mixing of fresh and saline water.

In the vicinity of the Lewiston Reservoir, groundwater of the upper weathered-bedrock zone exhibited generally very low levels of chemical contaminants. Contaminants detected in groundwater samples from water-bearing zone 2 include VOCs, monomethyl mercury, and cadmium. VOCs detected include typical gasoline components (benzene, cyclohexane, methylcyclohexane, total xylenes, and MTBE) (Figure 5.5.2-19).

6.3.3.1.1 North of the Lewiston Reservoir

As discussed in Section 6.1, Lewiston Reservoir water infiltration north of the reservoir mainly discharges to Fish Creek via the upper weathered bedrock water-bearing zone (water-bearing zone 2) (Figure 5.1.2-1). As indicated by water level data collected during 2003 and by the focused groundwater model prepared as part of this study, a groundwater flow divide exists between the Lewiston Reservoir and the Niagara escarpment (Figure 5.1.2-3). Based on manual water levels, the divide is located between well locations GW03-002 and GW03-004. South of the divide, groundwater flows south toward Fish Creek and west. North of the divide, groundwater flows northward toward the escarpment.

For piezometers GW03-001 through GW03-004, the largest number of gasoline-related compounds were identified in well GW03-001A-P1. Concentrations of gasoline related compounds were generally low and were detected between 0.48 ug/L benzene and 2.1 ug/L cyclohexane. The fact that groundwater flow in the vicinity of well GW03-001 is toward the west-southwest indicates a contaminant source east of that well location. Further north (north of the groundwater flow divide), two compounds,

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chloroform and monomethyl mercury were detected in samples collected from well GW03-004A-P1 located on Tuscarora lands north of the northern groundwater flow divide. For this well location, located north of the groundwater flow divide, groundwater flows northwest toward the Niagara escarpment. Thus, possible sources of contamination identified in this well would be east or southeast of the well but north of the flow divide. Due to its proximity, another possible source of contamination identified in piezometer GW03-004A-P1 is the former Stauffer Whittaker Subdivision site located immediately west of this piezometer. The compounds carbon disulfide and chloroform are associated with Stauffer Chemical.

6.3.3.1.2 East of the Lewiston Reservoir

For upper weathered bedrock piezometers located east of the Lewiston Reservoir (piezometers GW03-005 through GW03-008), groundwater quality parameters are representative of a freshwater flow system. All piezometers except GW03-005A-P1 showed chloride concentrations less than 500 mg/L (Figure 5.5.2-10). One possible explanation for raised chloride concentrations at well GW03-005A-P1 is the fact that water-bearing zone 10, representing a deeper water-bearing zone associated with the Goat Island/Gasport contact, subcrops in the vicinity of this boring (Figure 5.2.4-1, thus providing a connection between the deeper saline water and shallow freshwater.

No chemical contaminants were detected in any of the three sampling events in samples collected from water-bearing zone 2 piezometers located east of the reservoir on Tuscarora Lands (Figure 5.5.2-19). As shown in Figure 5.1.2-3, water infiltrating beneath the Lewiston Reservoir flows eastward within the upper weathered bedrock until it turns either northward toward Fish Creek or southward toward Gill Creek, thus creating a north-south groundwater flow divide east of the reservoir.

6.3.3.1.3 South of the Lewiston Reservoir

In piezometers located south of the Lewiston Reservoir (GW03-009 through GW03-011), chemical parameters for water-bearing zone 2 are generally indicative of a freshwater flow system mixing

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with brackish water. Chloride levels in these three piezometers ranged from 35.2 mg/L in well GW03-011C-P7 to 872 mg/L in GW03-010C-P7 (Figure 5.5.2-10).

In piezometers located south of the Lewiston Reservoir (GW03-009 through GW03-011), four compounds were detected. The compound detected at the highest concentration, MTBE, at 86 ug/L, was detected in piezometer GW03-009B-P4, located in the Town of Lewiston. Other compounds detected south of the reservoir include cadmium at 3 ug/L (GW03-009B-P4) and 4.8 ug/L (GW03-010C-P7), 1,1,1-TCA at 0.25 ug/L (GW03-010C-P7), and carbon disulfide at 0.33 ug/L (GW03-0011C-P7).

Based on groundwater flow direction, piezometer GW03-009B-P4, where MTBE was detected, is located within the area of influence of the Lewiston Reservoir. This well is, however, also located in the immediate vicinity of an operating service station.

6.3.3.2 Water-Bearing Zones 8A and 8B

Chemical parameters for samples collected from water-bearing zones 8A and 8B generally indicate a freshwater flow system (Figure 5.5.2-13 and 5.5.2-14). Chloride concentrations are below 500 mg/L, with one exception: well GW03-009B-P5.

6.3.3.2.1 North of the Lewiston Reservoir

Model Layer 8 is not seen in piezometers GW03-001 through GW03-004 located north of the reservoir.

6.3.3.2.2 East of the Lewiston Reservoir

The northern extent of water-bearing zone 8 terminates between well locations GW03-007 and GW03-008. For well location GW03-008, only the lower screened interval (water-bearing zone 8B)

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occurs. No compounds were detected in this piezometer (GW03-008A-P1) during any of the three sampling events.

On Tuscarora lands east of the Lewiston Reservoir, groundwater flow direction in Model Layer 8 is generally to the southwest. However, based on focused groundwater modeling results, some eastward flow occurs from the reservoir outward (Figure 5.1.2-4). On the other hand, the eastern extent of this reservoir-influenced flow is less than that for water-bearing zone 2. South of the reservoir, groundwater flows to the southwest.

6.3.3.2.3 South of the Lewiston Reservoir

At GW03-009, only the lower screened interval (water-bearing zone 8B) occurs. Wells GW03-010 and GW03-011 are screened in water-bearing zones 8A and 8B (Figure 5.2.2-1). The only two analytes detected in samples collected from piezometers screened in water-bearing zone 8A were arsenic and carbon disulfide. Carbon disulfide was detected only in December 2003, in a sample collected from GW03-011B-P4 (0.34 ug/L). Arsenic was detected at 19.9 ug/L and 16.3 ug/L for piezometer GW03-010B-P4 in September and December 2003, respectively. Neither of these compounds were detected in these piezometers during the March 2004 sampling event.

Analytes detected in water-bearing zone 8B include MTBE, cadmium, lead, and methylene chloride. MTBE was detected in piezometer GW03-009B-P5 at 48 ug/L, 110 ug/L, and 28 ug/L, respectively, for the September/October 2003, December 2003, and March 2004 sampling events. MTBE was also detected in GW03-010B-P5, located downgradient of GW03-009, at 0.37 ug/L. Well GW03-009B-P5 also exhibited concentrations of cadmium (3.2 ug/L) and lead (9 ug/L). Wells GW03-009B-P5 and GW03-010B-P5 are located downgradient of the above mentioned fuel service station.

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6.3.3.3 Water-Bearing Zones 9A and 9B

In the area of the Lewiston Reservoir, model layer 9 extends only as far north as well GW03-006. Results for chemical parameters indicate a freshwater flow zone for water-bearing zone 9A, as demonstrated by chloride levels all below 500 mg/L (Figure 5.5.2-15). Chemical parameters for water-bearing zone 9B indicate generally a freshwater flow zone with some mixing. Chloride concentrations in piezometers GW03-007B-P5, GW03-008B-P6, and GW03-010B-P6 are all below 500 mg/L, and, in piezometers GW03-006A-P5 and GW03-009B-P6, above 500 mg/L (Figure 5.5.2-16).

6.3.3.3.1 North of the Lewiston Reservoir

Model Layer 9 is not seen in piezometers GW03-001 through GW03-004, located north of the reservoir.

6.3.3.3.2 East of the Lewiston Reservoir

Compounds identified in piezometers GW03-006 through GW03-008 in water-bearing zone 9A include MTBE, monomethyl mercury, cyclohexane, and methylcyclohexane. The gasoline-related compounds MTBE, cyclohexane, and methylcyclohexane were all detected at concentrations below 1.5 ug/L (Figure 5.5.2-24).

For water-bearing zone 9B, analytes identified in piezometers GW03-007B-P5 and GW03-008B-P6 include, acetone, MEK, caprolactum, monomethyl mercury, toluene, and lead. Lead was detected in piezometer GW03-008B-P6 at a concentration of 78.9 ug/L (Figure 5.5.2-25).

In Model Layer 9, groundwater flow direction east of the Lewiston Reservoir is characterized by a groundwater flow divide immediately east of the reservoir (Figure 5.1.2-5). Eastward groundwater flow influence from the Lewiston Reservoir is similar to that in Model Layer 8, with the predominant flow

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paths in this area being to the north or south. Piezometers 03-007B-P5 and GW03-008B-P6 are probably not within the eastward influence of the reservoir.

6.3.3.3.3 South of the Lewiston Reservoir

For water-bearing zone 9A, three compounds, carbon disulfide (0.41 ug/L), acetone (6.8 ug/L), and caprolactum (12 ug/L) were detected in piezometer GW03-010A-P1, immediately south of the Lewiston Reservoir. No compounds were detected in piezometers GW03-009A-P1 or GW03-011A-P1.

For water-bearing zone 9B, MTBE, cadmium, and lead were detected in wells south of the Lewiston Reservoir. MTBE was detected in piezometers GW03-009B-P6 at concentrations of 32 ug/L, 120 ug/L, and 5.4 ug/L for the September 2003, December 2003, and March 2004 sampling events, respectively.

Groundwater flow direction for Water-Bearing Zone 9 in this area is to the southwest (Figure 5.1.2-5).

6.3.3.4 Water-Bearing Zone 10

Wells GW03-006 through GW03-011 each contain piezometers that are screened in water-bearing zone 10 in the area of the Lewiston Reservoir. Johnston (1964) characterized this water-bearing zone as a zone of bedding joints "open locally with only slight seepage amounts" indicating a zone of relatively low groundwater flow flux. Analytical results indicate a mixture of fresh and saline water quality conditions. Piezometers GW03-007A-P2, GW03-009A-P2, and GW03-010A-P2 exhibit chloride concentrations below 500 mg/L (Figure 5.5.2-17). The remainder of the piezometers, GW03-006B-P2, GW03-008A-P2, and GW03-011A-P2, all exhibit chloride levels above 500 mg/L. Concentrations of TDS in these piezometers are all greater than 1,000 mg/L, ranging from 1,390 mg/L (GW03-009A-P2) to 9,100 mg/L (GW03-011A-P2) (Figure 5.5.2-8).

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Chemical compounds detected in water-bearing zone 10 piezometers in the vicinity of the Lewiston Reservoir included MTBE, cyclohexane, methylcyclohexane, and carbon disulfide.

6.3.3.4.1 North of the Lewiston Reservoir

Water-Bearing Zone 10 does not occur in the area of piezometers GW03-001 through GW03-004, located north of the reservoir.

6.3.3.4.2 East of the Lewiston Reservoir

East of the Lewiston Reservoir, Water-Bearing Zone 10 occurs in the area of piezometers GW03-006B-P2, GW03-007A-P2, and GW03-008A-P2 (Figure 5.5.2-17). Two analytes, cyclohexane and methylcyclohexane, were detected (0.27 ug/L and 0.42 ug/L respectively), both in piezometer GW03-008A-P2. No compounds were detected in either piezometer GW03-006B-P2 or GW03-007A-P2.

6.3.3.4.3 South of the Lewiston Reservoir

MTBE was detected in well GW03-009A-P2 at concentrations of 180 ug/L, 100 ug/L, and 180 ug/L in October 2003, December 2003, and March 2004, respectively. MTBE was also detected in well GW03-010A-P2 at 2.1 ug/L, 3.2 ug/L, and 2.5 ug/L for the October 2003, December 2003, and March 2004 sampling events, respectively.

As discussed in Section 6.1, groundwater flow direction for water-bearing zone 10 is from northeast to the southwest, with no eastward component from the Lewiston Reservoir (Figure 5.1.2-6). Piezometers GW03-009A-P2, GW03-010A-P2, and GW03-011A-P2 are all located immediately downgradient of an operating fuel service station.

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6.3.3.5 Gasport/DeCew Contact Water-Bearing Zone

As discussed previously, the water-bearing zone identified at the contact between the Gasport Member of the Lockport Group and the DeCew Member of the Clinton Group is not included in the groundwater model. This water-bearing zone occurs at all piezometer locations in the Lewiston Reservoir area (i.e., GW03-001 through GW03-011). Analytical results indicate a substantial difference in general water quality for this water-bearing zone as compared to the layers above. In all piezometers except GW03-003A-P2 and GW03-004A-P2 chloride concentrations are higher than in other water-bearing zones (Figure 5.5.2-18). Chloride concentrations in this water-bearing zone (excluding piezometers GW03-003A-P2 and GW03-004A-P2) range from 3,240 mg/L in piezometer GW03-005A-P2 (October 2003) to 141,000 mg/L in well GW03-007A-P3 (March 2004). TDS concentrations in the piezometers south of the northern groundwater flow divide are all greater than 1,000 mg/L, ranging from 7,340 mg/L (GW03-009A-P3) to 108,000 mg/L (GW03-007A-P3) (Figure 5.5.2-9). Chloride concentrations for piezometers GW03-003A-P2 and GW03-004A-P2 ranged from 313 mg/L in GW03-004A-P2 (October 2003) to 902 mg/L in GW03-003A-P2 (March 2004). TDS concentrations for these two piezometers ranged from 1,070 mg/L (GW03-004A-P2) to 2,020 mg/L (GW03-003A-P2). Due to the northern groundwater flow divide, occurring in this water-bearing zone as well as water-bearing zone 2, it appears that the saline/brackish water moving up-dip from the south does not influence these piezometers.

Contaminant compounds identified in this water-bearing zone are numerous, and include gasoline-related VOCs (BTEX, cyclohexane, isopropylbenzene, methylcyclohexane), metals (arsenic, cadmium, and lead), and other miscellaneous compounds (including acetone, caprolactum, monomethyl mercury, bis [2-ethylhexyl] phthalate, and phenols).

6.3.3.5.1 North of the Lewiston Reservoir

Contaminants detected in piezometers GW03-001 through GW03-004 included gasoline-related compounds such as cyclohexane, ethylbenzene, methylcyclohexane, toluene, and xylenes, as well as monomethyl mercury (Figure 5.5.2-27). As discussed in Section 6.1, these piezometers are not located within the area of influence of the Lewiston Reservoir. Gasoline-related compounds in piezometers

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monitoring the Gasport/DeCew water-bearing zone were detected at concentrations ranging from 0.32 ug/L to 7 ug/L. Toluene was also detected in piezometer GW03-002A-P2 at a concentration of 0.4 ug/L.

In December 2003, Cadmium and lead were identified in piezometer GW03-002A-P2 at concentrations of 2.7 ug/L and 10.7 ug/L. Due to insufficient water, piezometer GW03-002A-P2 was not sampled in either the September/October 2003 or the March 2004 sampling events.

Several gasoline compounds were detected in piezometer GW03-001A-P2 during March 2004 sampling event. Benzene, cyclohexane, ethylbenzene, toluene and xylenes were all detected at concentrations up to 3 ug/L in March 2004.

6.3.3.5.2 East of the Lewiston Reservoir

The greatest concentrations of contaminants were identified in piezometer GW03-005A-P2, where gasoline-related compounds were detected. Benzene was detected at 280 ug/L, 160 ug/L, and 150 ug/L during the September/October 2003, December 2003, and March 204 sampling events, respectively. Toluene, ethylbenzene, and xylenes were also detected at concentrations ranging from 12 ug/L to 270 ug/L. Other gasoline-related compounds identified in this well included cyclohexane, isopropylbenzene, and methylcyclohexane.

BTEX compounds were also identified in piezometer GW03-007A-P3, and lesser concentrations of gasoline related compounds were identified in well GW03-008A-P3.

Arsenic was detected in piezometers GW03-005A-P2, GW03-007A-P3, and GW03-008A-P3 at concentrations ranging from 16.7 ug/L to 75.9 ug/L. Lead was also detected in well GW03-005A-P2 at 43.3 ug/L, 21.5 ug/L, 35 ug/L in the September/October 2003, December 2003, and March 2004 sampling events, respectively. Lead detected in this piezometer may be associated with relatively high gasoline contamination also detected here.

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6.3.3.5.3 South of the Lewiston Reservoir

BTEX concentrations were identified in well GW03-009A-P3. Lesser concentrations of gasoline-related compounds were identified further downgradient in piezometers GW03-010A-P3 and GW03-011A-P3.

Arsenic was detected in piezometers GW03-009A-P3 and GW03-011A-P3 at concentrations ranging from 12.1 ug/L to 20.3 ug/L. Lead was also detected in well GW03-0010A-P3 in December 2003 at 7.2 ug/L.

Based on the modeled groundwater flows in water-bearing zone 10, groundwater flow direction in Gasport/DeCew water-bearing zone in the vicinity of the Tuscarora Lands is also inferred to be to the southwest. Therefore, contaminants identified in piezometers east of the reservoir most likely originate from an upgradient source located to the northeast or near surface sources within the general vicinity of the piezometers.

6.3.4 Surface Water Quality

As discussed in Section 5.5.1, the surface water sampling program focused on 11 locations, which can be divided into two groups: "river-sourced" (six locations) and "local-sourced" (five locations). The river-sourced group comprises samples collected from the upper Niagara River at the conduit intakes, the conduits at the air intake vents, the forebay, and the Lewiston Reservoir (two sample locations).

Monomethyl mercury was detected at concentrations ranging from 0.04 ng/L to 1.59 ng/L during at least one sampling event in all but two (SW03-006 and SW03-007) of the surface water sample locations. The highest concentration, 1.59 ng/L, was detected in a sample collected from the wetland at the head of Gill Creek (Figures 5.5.1-3).

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The pesticide 4,4-DDT was detected in a surface water sample collected from the NYPA conduits, during the March 2004 sampling event. The pesticide delta-BHC was detected in both samples collected from Lewiston Reservoir during the November 2003 sampling event (Figure 5.5.1-3). The concentrations of delta-BHC were detected below the practical quantitation limit (PQL), but above the method detection limit (MDL), and are therefore qualified as "estimated" values.

The source of delta-BHC in the reservoir is unknown. The sole source of water in the reservoir, other than precipitation, is the forebay, and delta-BHC was not detected in the forebay during any of the sampling events. The presence of organochlorine pesticides in the upper Niagara River has historically been established. As indicated by the Niagara River Upstream/Downstream Program which sampled river water locations near Fort Erie, Ontario and near Niagara-on-the-Lake, Ontario, DDT and BHC compounds have historically been detected in both the upper and lower Niagara River sections (Environment Canada, 2000). The detection of 4,4-DDT and delta-BHC in water samples collected from the conduits and reservoir, respectively, is likely due to contamination of the upper Niagara River.

As mentioned above, no contaminants were detected in water samples collected from the forebay. These results indicate that contaminated groundwater within the CDS, which has been shown to discharge to the forebay, does not have an adverse impact on forebay water quality.

Other than monomethyl mercury, two contaminants were detected in one local-sourced surface water sample during the October 2003 sampling event (Figure 5.5.1-3). These were acetone and carbon disulfide, which were detected (2.4 ug/L and 1.1 ug/L, respectively) in the sample (SW03-001) collected from Fish Creek, north (and downgradient) of the reservoir. The source of these contaminants is unknown. Due to the lack of flowing water in Fish Creek upstream of the reservoir, no sample was collected there in October 2003. These two compounds were not detected in either of the samples collected from the reservoir. Carbon disulfide was, however, detected in groundwater in piezometer GW03-002A-P1 in the December 2003 sampling event at a concentration of 0.38 ug/L, indicating groundwater as a possible source of carbon disulfide in Fish Creek. As discussed in Section 5.1, a portion of Fish Creek flow downstream of the reservoir consists of reservoir water infiltrating into the upper bedrock water-bearing zone and then discharging to the creek as groundwater. As mentioned in Section

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2.2.4, a former inactive hazardous waste site, the Stauffer Chemical Whittaker Subdivision site, is located near Upper Mountain Road where it crosses the Tuscarora Nation boundary. As discussed, this site was used for the disposal of waste materials from the Stauffer Chemical Plant site located immediately north of the forebay. Two predominant contaminants associated with the Stauffer Chemical Plant site were chloroform and carbon disulfide. The detections of both these compounds in groundwater and surface water samples in the vicinity of the Stauffer Whittaker Subdivision site may be indicative of residual groundwater contamination associated with this former inactive hazardous waste site.

Lead was detected in sample SW03-004, located within a wetland on the Tuscarora Nation, at concentrations of 24.4 ug/L and 16.8 ug/L for the October and December sampling events, respectively. Lead was not detected in sample SW03-004 during the March 2004 sampling event. The source of lead detected in this sample is unknown. However, the wetland surface water is not located within the area of influence of reservoir influenced groundwater flow.

Heterotrophic plate count (HPC) results for these samples ranged from 360 CFU/mL (SW03-006) to 2,500 CFU/mL (SW03-010) (Figure 5.5.1-4). Changes in HPC levels from tourist season to non-tourist season were variable with some increases and some decreases. Total coliform concentrations for the "river sourced" samples ranged from non-detect (SW03-009, October 2003) to 14,000 c/100mL (SW03-009, November 2003). Total coliform results increased from 280 c/100 mL to 690 c/100 mL in SW03-006 and decreased from 860 c/100 mL to 40 c/100 mL in SW03-008. For samples exhibiting total coliform results greater than 200 c/100 mL during the September/October 2003 sampling event, analysis of fecal coliform was performed for the November 2003 sampling event. Results of fecal coliform analysis for the river-sourced samples ranged from 20 c/100 mL to 100 c/100 mL.

Results of the bacteriological testing for the local-sourced sample locations ranged from 1,200 CFU/mL (SW03-005) to 110,000 (SW03-006). In sample SW03-004, collected in the wetland at the head of Gill Creek , HPC results increased from 31,000 CFU/mL in October to 110,000 CFU/mL in November. Total coliform results ranged from 120 C/100 mL (SW03-005) to 94,000 C/100 mL (SW03-004). The relatively high bacteriological results for sample SW03-004 are likely due to the shallow and stagnant nature of the water sampled as well as the organic rich nature of wetland sediments.

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6.3.5 Possible Sources of Groundwater Contamination Near Lewiston Reservoir

As discussed, the predominant contaminants detected (in terms of highest concentrations and frequency of detection) in groundwater in the vicinity of the Lewiston Reservoir were gasoline related VOCs. The highest concentrations of these compounds were identified in piezometers located east of the reservoir, and in the deeper water bearing zones. The source or sources of gasoline related VOCs is likely fuel service stations located in the vicinity. None of these compounds were detected in any of the water samples collected from "river sourced" surface water locations associated with the NPP including the forebay or reservoir. However, several fuel service stations exist within the immediate area and within the area of reservoir influenced groundwater flow. As discussed, the two lower zones, water-bearing zones 10 and the Gasport/DeCew water-bearing zone, are not within the zone of reservoir influenced groundwater flow. Therefore, the sources of gasoline contaminants in these zones are likely located upgradient to the east/northeast, or in the immediate vicinity and have migrated vertically downward. Water quality in this zone is generally very saline indicating very little fresh water influence. It is likely that, gasoline releases near the surface would be transported by groundwater flow laterally and vertically downward. One possible explanation for the higher concentrations of gasoline contaminants in the deeper zones is that contaminants are migrating vertically downward from their near surface source areas through natural bedrock fractures and accumulating in the deeper zones where less groundwater flow occurs. The higher rate of groundwater flux in the upper water bearing zones, supported by the relatively constant recharge source of the reservoir, may act to reduce contaminant concentrations in these zones through dispersal and dilution.

Monomethyl mercury was detected at very low levels (generally less than 1 part per trillion) in 9 of 11 surface water sampling locations (all except the forebay and the western reservoir sample) and 8 of 32 piezometers. Monomethyl mercury in natural waters is likely produced by bacteria from inorganic mercury that is present in the environment naturally or from anthropogenic sources. Total mercury was not detected in any of the surface water or groundwater samples collected during this investigation. Concentrations of monomethyl mercury detected in "local sourced" surface water sample locations near the reservoir were higher than concentrations detected in the reservoir water samples. The highest detection of monomethyl mercury, 1.59 ng/L, was detected in the surface water sample collected from the

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wetland at the head of Gill Creek in November 2003. As discussed, this wetland surface water is not within the zone of reservoir influence predicted by groundwater modeling, indicating a source from within the wetland, from an upgradient surface location, or from atmospheric deposition. Possible sources of monomethyl mercury detected in "river sourced" surface water samples include (1) inorganic mercury point sources discharging to upstream sections of Niagara River, (2) regional atmospheric deposition, (3) elemental mercury naturally occurring in the ecosystem, or (3) Niagara River and/or reservoir sediments. Possible sources of monomethyl mercury in groundwater near the reservoir and in Fish and Gill Creeks include (1) regional atmospheric deposition, (2) inorganic mercury present in reservoir sediments, or (3) elemental mercury naturally occurring in the ecosystem.

Heavy metals detected in groundwater near the reservoir included arsenic, cadmium and lead. Arsenic and lead were detected with the highest concentrations and greatest frequency in the Gasport/DeCew water-bearing zone. The source or sources of these contaminants is unknown. They are known, however, to enter the environment as a result of both natural occurrence and anthropogenic activities. Arsenic is commonly associated with pesticides used in agricultural applications and cadmium can be introduced through the application of fertilizers. Other possible sources of lead, cadmium and arsenic in groundwater near the reservoir include (1) general background concentrations in soil or rock, (2) point source locations such as unknown dump areas or junk yards, (3) lead in gasoline, or (4) lead and arsenic present in reservoir sediments. All three metals occur naturally in the Lockport Dolomite, forming sulfide minerals associated with gypsum, which is disseminated throughout the formation. Dissolution of the relatively soluble gypsum deposits should be considered a likely contributing source of these metals to groundwater.

Carbon disulfide was detected at very low concentrations (4.3 ug/L maximum concentration) in several piezometers in the vicinity of the reservoir. Carbon disulfide can occur naturally at very low levels. Similar to other contaminants detected in this area, carbon disulfide was detected at the highest concentrations and greatest frequency in piezometers targeting the deepest water-bearing zone investigated, the Gasport/DeCew water-bearing zone. Concentrations detected in all zones except the Gasport/DeCew are below 0.5 ug/L. Carbon disulfide is also detected in 4 out of the 6 Gasport/DeCew piezometers installed along the conduits, possibly indicating a regional problem. The source of carbon

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disulfide detected in these wells is unknown, however, carbon disulfide is a major contaminant associated with the Stauffer Chemical located on the north side of the forebay. Although carbon disulfide was not detected in either the forebay or the reservoir surface water samples, a possible source of carbon disulfide detected in piezometers in the vicinity of the reservoir may be the Stauffer Chemical site by migration via the forebay and reservoir. An additional potential source of carbon disuldfide is the Stauffer Whittaker Subdivision located near Upper Mountain Road in Lewiston.

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TABLE 6.1.1-1

WEEKLY SURFACE WATER LEVEL STATISTICS, LEWISTON RESERVOIR 2003

Week Starting	Water Level (Elevation, feet)[1]			Difference (feet)
	Average	Minimum	Maximum	
01/01/03	648.30	635.40	658.29	22.89
01/06/03	654.42	649.60	658.38	8.78
01/13/03	644.28	626.03	658.15	32.12
01/20/03	650.98	639.96	658.43	18.47
01/27/03	647.16	637.25	658.09	20.84
02/03/03	651.93	644.09	658.30	14.21
02/10/03	646.99	631.70	658.29	26.59
02/17/03	646.43	632.82	658.31	25.49
02/24/03	648.14	638.03	656.38	18.35
03/03/03	646.91	638.87	655.95	17.08
03/10/03	647.22	633.24	658.40	25.16
03/17/03	652.83	645.73	658.33	12.60
03/24/03	653.54	646.30	658.40	12.10
03/31/03	646.15	625.62	658.38	32.76
04/07/03	643.66	629.26	658.26	29.00
04/14/03	641.55	621.04	658.35	37.31
04/21/03	643.75	628.34	658.31	29.97
04/28/03	642.62	624.17	658.29	34.12
05/05/03	641.78	621.56	658.56	37.00
05/12/03	649.51	637.74	658.43	20.69
05/19/03	644.78	629.76	658.36	28.60
05/26/03	645.67	629.67	658.09	28.42
06/02/03	642.26	622.88	658.32	35.44
06/09/03	642.91	622.31	658.40	36.09
06/16/03	642.55	622.83	658.42	35.59
06/23/03	643.49	627.76	658.54	30.78
06/30/03	642.76	623.02	658.56	35.54
07/07/03	645.52	629.09	658.53	29.44
07/14/03	645.38	632.45	658.32	25.87
07/21/03	645.74	629.17	658.37	29.20
07/28/03	640.78	622.83	658.34	35.51
08/04/03	644.34	625.52	658.55	33.03
08/11/03	641.16	625.13	655.85	30.72

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TABLE 6.1.1-1 (CONTINUED)

WEEKLY SURFACE WATER LEVEL STATISTICS, LEWISTON RESERVOIR 2003

Week Starting	Water Level (Elevation, feet)[1]			Difference (feet)
	Average	Minimum	Maximum	
08/18/03	645.13	622.54	658.30	35.76
08/25/03	641.29	621.83	658.33	36.50
09/01/03	641.79	622.99	657.58	34.59
09/08/03	638.14	622.88	657.44	34.56
09/15/03	644.21	627.76	655.05	27.29
09/22/03	644.35	628.59	658.16	29.57
09/29/03	646.17	632.25	658.49	26.24
10/06/03	636.04	620.73	655.62	34.89
10/13/03	643.91	626.68	658.25	31.57
10/20/03	639.32	620.91	658.24	37.33
10/27/03	651.83	641.54	658.38	16.84
11/03/03	649.71	637.98	658.24	20.26
11/10/03	648.23	637.48	658.31	20.83
11/17/03	643.01	630.92	658.66	27.74
11/24/03	650.98	641.32	658.51	17.19
12/01/03	644.77	623.12	658.21	35.09
12/08/03	645.96	634.45	657.42	22.97
12/15/03	648.35	636.65	658.42	21.77
12/22/03	653.82	644.57	658.57	14.00
12/29/03	654.75	648.54	658.28	9.74

1. Vertical datum is USLSD 1935.

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TABLE 6.1.1-2

DAILY SURFACE WATER ELEVATION STATISTICS, LEWISTON RESERVOIR 2003

Date/Season	Water Level (Elevation, feet)[1]		Difference (feet)
	Maximum	Minimum	
09/2/03[2]	657.58	633.37	24.21
01/8/03[3]	654.65	650.25	4.40
Average Tourist	650.42	635.39	15.02
Average Non-Tourist	653.71	642.53	11.18
Average 2003	651.78	638.35	13.43

[1]Vertical datum is USLSD 1935
[2]Date of maximum difference in daily elevation
[3]Date of minimum difference in daily elevation

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TABLE 6.1.1-3

WELL AND PIEZOMETER RESERVOIR EFFICIENCIES, AUGUST THROUGH DECEMBER 2003

Location	Well/Piezometer Water Elevation (feet)[1]			Reservoir Water Elevation (feet)[1]			Reservoir Efficiency
	Max	Min	Difference	Max	Min	Difference	
OW-189	609.32	606.82	2.51	658.30	639.62	18.68	13.42%
OW-181	611.46	609.94	1.53	658.30	639.62	18.68	8.17%
OW-180	608.72	607.44	1.27	658.30	639.62	18.68	6.82%
OW-210	613.94	612.89	1.06	658.30	639.62	18.68	5.65%
NW-10	538.81	537.78	1.02	658.30	639.62	18.68	5.48%
NW-11	593.64	592.81	0.83	658.30	639.62	18.68	4.44%
OW-104	599.22	597.79	1.43	658.30	621.83	36.47	3.92%
GW03-006B-P2	613.28	612.61	0.67	658.30	639.62	18.68	3.59%
GW03-011A-P2	594.08	593.29	0.79	645.98	622.99	22.99	3.44%
GW03-006A-P5	612.55	611.96	0.59	658.30	639.62	18.68	3.16%
GW03-009A-P1	616.21	615.65	0.56	645.98	628.21	17.77	3.15%
NW-05	617.94	617.36	0.58	658.30	639.62	18.68	3.12%
NW-07	616.44	615.87	0.56	658.30	639.62	18.68	3.02%
GW03-001A-P1	611.56	611.03	0.53	658.30	639.62	18.68	2.84%
OW-111	591.55	591.03	0.52	658.30	639.62	18.68	2.80%
OW-112	599.09	598.11	0.98	658.30	621.83	36.47	2.70%
GW03-011A-P1	581.09	580.71	0.38	645.98	628.21	17.77	2.14%
GW03-009B-P5	617.43	617.15	0.28	637.04	622.88	14.16	1.98%
GW03-011A-P1	580.77	580.43	0.34	640.47	622.99	17.48	1.95%
GW03-005A-P1	612.34	611.98	0.36	658.30	639.62	18.68	1.93%
GW03-006B-P4	617.49	617.16	0.33	658.30	639.73	18.57	1.78%

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TABLE 6.1.1-3 (CONT.)

WELL AND PIEZOMETER RESERVOIR EFFICIENCIES, AUGUST THROUGH DECEMBER 2003

Location	Well/Piezometer Water Elevation (feet)[1]			Reservoir Water Elevation (feet)[1]			Efficiency
	Max	Min	Difference	Max	Min	Difference	
GW03-002A-P1	611.66	611.33	0.33	658.30	639.62	18.68	1.77%
GW03-006A-P1	617.41	617.11	0.30	658.30	639.73	18.57	1.62%
OW-207	620.30	620.02	0.28	658.30	639.62	18.68	1.50%
OW-193	614.03	613.75	0.27	658.30	639.62	18.68	1.47%
OW-212	610.65	610.64	0.01	658.30	639.62	18.68	0.03%

1. Vertical Datum is USLSD 1935

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TABLE 6.1.1-4

WELL AND PIEZOMETER RESERVOIREFFICIENCIES, DISTANCE FROM RESERVOIR, AND INTERCEPTED WATER-BEARING ZONES, AUGUST - DECEMBER 2003

Location	Reservoir Efficiency	Distance From Reservoir (feet)	Intercepted Water-Bearing Zone(s)
OW-189	13.42%	180	Overburden
OW-181	8.17%	150	2
OW-180	6.82%	280	2
OW-210	5.65%	180	2
NW-10	5.48%	250	9B
NW-11	4.44%	765	9B
OW-104	3.92%	400	2
GW03-006B-P2	3.59%	900	10
GW03-011A-P2	3.44%	2400	10
GW03-006A-P5	3.16%	900	9B
GW03-009A-P1	3.15%	725	9A
NW-05	3.12%	270	10
NW-07	3.02%	200	9A, 9B
GW03-001A-P1	2.84%	635	2
OW-111	2.80%	360	
OW-112L	2.70%	750	2 and DeCew
GW03-011A-P1	2.14%	2400	9A
GW03-009B-P5	1.98%	725	8B
GW03-005A-P1	1.93%	2030	2
GW03-006B-P4	1.78%	900	2
GW03-002A-P1	1.77%	1200	2
OW-207	1.50%	150	2, 9A, 9B, 10 and DeCew
GW03-006A-P1	1.62%	900	
OW-193	1.47%	205	Overburden
OW-212	0.03%	150	2

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TABLE 6.1.2-1

DAILY SURFACE WATER LEVEL STATISTICS, FOREBAY 2003

Date / Season	Water Level (Elevation, feet)[1]		Difference (feet)
Date / Season	**Maximum**	**Minimum**	**Difference**
10/1/2003[2]	565.66	539.17	26.49
1/6/2003[3]	556.84	553.41	3.43
Average Tourist	560.56	547.35	13.21
Average Non-Tourist	556.61	547.55	9.06
Average 2003	558.93	547.43	11.49

[1]Vertical datum is USLSD 1935
[2]Date of maximum difference in daily elevation
[3]Date of minimum difference in daily elevation

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TABLE 6.1.2-2

AVERAGE WATER LEVEL ELEVATIONS AND ELEVATIONAL DIFFERENCES BETWEEN CONDUITS AND CDS AT PUMP STATIONS A AND B

Location		Average Elevation[1] October-November 2003	Average Elevation October 2003 (Tourist)	Average Elevation November 2003 (Non-Tourist)
Pump Station A	Conduit	558.99	560.04	558.00
	CDS	557.53	558.49	556.53
	Difference[2]	-1.51	-1.55	-1.47
Pump Station B	Conduit	551.79	554.25	549.24
	CDS	553.00	555.36	550.56
	Difference[1]	1.21	1.11	1.32

[1]Vertical datum is USLSD 1935

[2]Positive values indicate flow from CDS to conduits, and negative values indicate flow from conduits to CDS

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TABLE 6.1.2-3

PERCENTAGE OF TIME FLOW OCCURS AT PUMP STATION WEIRS

NPP Operational Cycle	Pump Station A			Pump Station B		
	Flow From CDS to Conduits	Flow From Conduits to CDS	No Flow Across Weirs	Flow From CDS to Conduits	Flow From Conduits to CDS	No Flow Across Weirs
Tourist Season	0.0%	51.8%	48.2%	69.5%	12.5%	18.0%
Non-Tourist Season	0.0%	4.2%	95.8%	60.3%	3.8%	35.9%
Entire Study	0.0%	25.8%	74.2%	64.3%	7.7%	28.0%

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TABLE 6.1.2-4

WELL AND PIEZOMETER FOREBAY EFFICIENCIES, LAG TIMES AND WATER-BEARING ZONES

Location	Forebay Efficiency	Peak to Peak Lag[1] (hh:mm)	Water-Bearing Zone
GW03-012A-P2	61.83%	0:45	10
GW03-012B-P6	69.60%	2:00	9B
GW03-013A-P1	36.93%	4:45	8B
GW03-013A-P2	61.43%	3:45	10
GW03-013A-P3	62.34%	4:00	DeCew
GW03-013B-P4	5.99%	4:15	8A
GW03-013B-P5	60.25%	4:15	9A
GW03-014B-P4	18.24%	7:15	8A
GW03-014B-P5	41.74%	2:30	9A
GW03-014B-P6	41.83%	2:30	9B
GW03-014C-P7	11.89%	7:15	2
GW03-015A-P1	29.31%	0:30	8A
GW03-015B-P4	28.57%	0:30	8B
GW03-015B-P5	29.53%	0:30	9A
GW03-015B-P6	31.01%	0:30	9B
GW03-015C-P7	23.07%	0:15	2
GW03-016A-P1	29.44%	0:00	8A
GW03-016A-P2	16.96%	0:30	10
GW03-016A-P3	7.20%	1:30	DeCew
GW03-016B-P4	13.73%	0:45	7
GW03-016B-P5	10.59%	1:30	8B
GW03-016B-P6	20.43%	0:30	9B
GW03-016C-P7	12.99%	0:30	2
GW03-016C-P8	18.20%	0:45	9A
GW03-017A-P1	8.68%	1:30	9B
GW03-017A-P2	16.79%	0:30	10
GW03-017B-P4	13.98%	0:45	7
GW03-017B-P5	21.15%	0:45	8A
GW03-017B-P6	16.87%	0:30	9A
GW03-017C-P7	12.99%	0:45	2
GW03-017C-P8	12.82%	0:30	6
GW03-017C-P9	33.78%	24:00[2]	8B
OW-139	23.11%	1:30	2[3]
OW-650D	17.93%	1:30	2[3]

[1]Accurate determination of the lag time is limited by the 1-hour interval between water level measurements in forebay.
[2]Time lag calculated using 24-hour average water level for forebay.[3]The well is an open hole boring and consequently water levels reflect all intersected water-bearing zones but are dominated by the weathered bedrock zone due to its proportionally greater storativity.

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TABLE 6.1.2-5

WELL GW03-015 TOURIST SEASON/NON-TOURIST SEASON CHLORIDE STUDY, APRIL 2004

Piezometer	Elevation (feet elev.)		Chloride (ppm)		Conductivity (uS/cm)	
	Prior to April 1	After April 1	Prior to April 1	After April 1	Prior to April 1	After April 1
GW03-015A P1	554.4	557.1	46	39	699	659
GW03-015A P2	549.4	550.5	30,169	15,302	81,202	81,341
GW03-015A P3	439.1	439.8	33,873	20,936	55,993	55,993
GW03-015A P4	555.6	558.2	270	NR	1,405	1,367
GW03-015A P5	554.3	557.0	1,647	953	2,703	2,570
GW03-015A P6	554.1	556.9	228	197	933	931
GW03-015A P7	554.9	557.3	54	608	582	611

Vertical datum is USLSD 1935.

ppm – parts per million

uS/cm – microSiemens per centimeter

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TABLE 6.2-1

AVERAGE GROUNDWATER INFILTRATION RATES INTO THE FALLS STREET TUNNEL

Measurement Location		Flow During Tourist Season		Flow During Non-Tourist Season	
		[gpm]	[% of Total]	[gpm]	[% of Total]
West of Power Authority Conduits					
	* at West Bypass Pipe	1,250		1,130	
	* at Drop Shaft 12	250		240	
Sum of Flows West of Conduits		1,500	30%	1,370	33%
East of Power Authority Conduits					
	* at East Bypass Pipe	3,580		2,740	
Sum of Flows East of Conduits		3,580	70%	2,740	67%
Total GW Infiltration Rate		5,080	100%	4,110	100%

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TABLE 6.2.2-1

SUMMARY OF FLOW RATES

Contribution	Flow During Tourist Season		Flow During Non-Tourist Season	
	[gpm]	[% of Total]	[gpm]	[% of Total]
Flow Within Conduit Drainage System				
* Flow from Niagara River Towards FST	5,390		7,090	
* Flow from FST to the North	1,620		4,110	
Net Flow from Conduit Drainage into FST [1]	3,770	81%	2,980	75%
Flow Over the South PS Weirs	100	2%	0	0%
Flow Within High Transmissivity Zone	770	17%	980	25%
Total Flow into FST [2]	4,640	100%	3,960	100%

[1]Net Flow from conduit drainage into FST is equal to the flow from the Niagara River towards the FST minus flow from the FST to the north.

[2]Total Flow into the FST is the sum of:

* Net flow from conduit drainage into FST
* Flow over the south PS weirs
* Flow within high transmissivity zone

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TABLE 6.3.1-1

OIL FIELD WATER ANALYSIS AND GASPORT/DECEW FORMATION SALINE WATER

Type	Reservoir/Aquifer Age	Cl	SO_4	CO_3	HCO_3	Na+K	Ca	Mg	Total ppm
Sea Water		19,350	2,690	150		11,000	420	1,300	35,000
East Texas	Woodbine sand/ Upper Cretaceous	40,598	259	387		24,653	1,432	335	68,964
Bradford, PA	Bradford sand/ Devonian	77,340	730			32,600	13,260	1,940	125,870
GW03-007A- P3 (10/03)	Gasport-DeCew dolomite/ Silurian	45,700	1,500		92	22,609	7,530	3,360	80,791
GW03-007A- P3 (12/03)	↓	83,100	1,040		96	23,996	8,170	3,560	119,962
GW03-014A- P3 (10/03)	↓	90,500	1,050		71	35,358	13,500	4,370	144,849
GW03-014A- P3 (12/03)	↓	96,600	1,590		69	6,643	3,010	941	108,853

Seawater and Oil field data from Levorsen 1967

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FIGURE 6.1-1

GW03-008A-P3 AND BAROMETRIC PRESSURE, AUGUST TO SEPTEMBER 2003

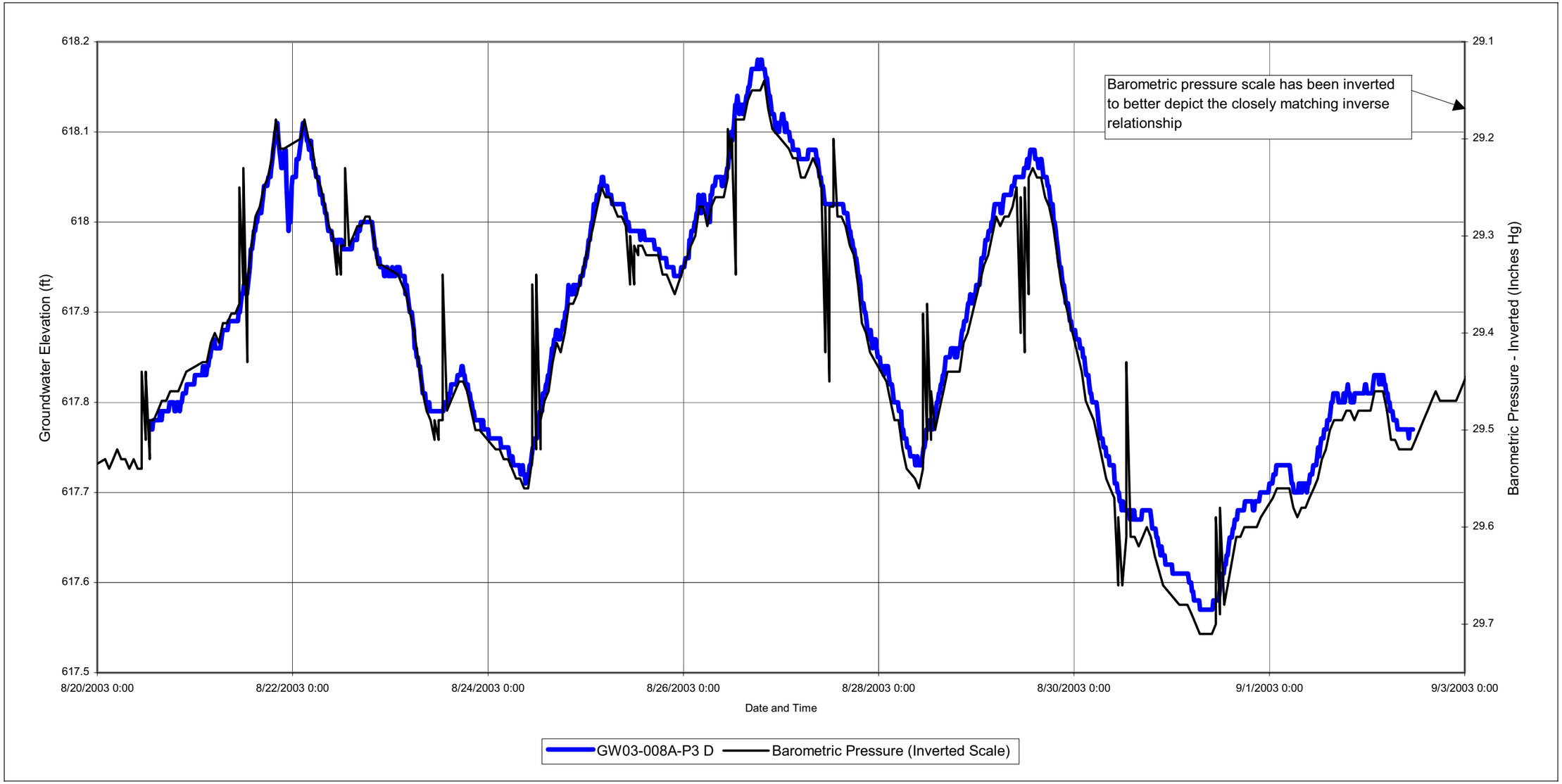

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FIGURE 6.1-2

GW03-008A-P2 AND CUMULATIVE PRECIPITATION, OCTOBER TO NOVEMBER 2003

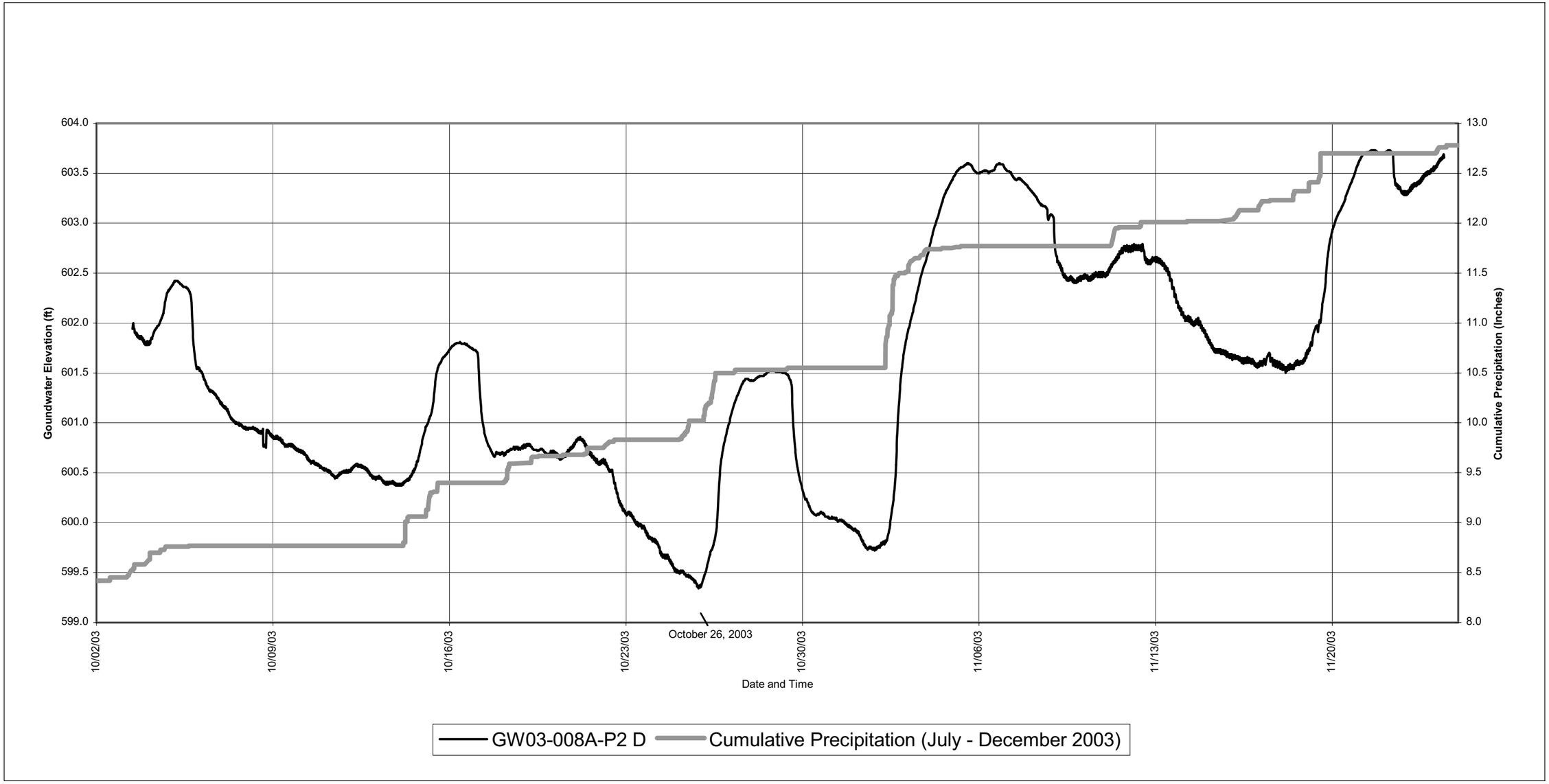

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FIGURE 6.1-3

APPARENT RESPONSE TO PRIVATE WELL WITHDRAW, GW03-006A-P1 AND GW-0-007A-P1, AUGUST 28 TO 30, 2003

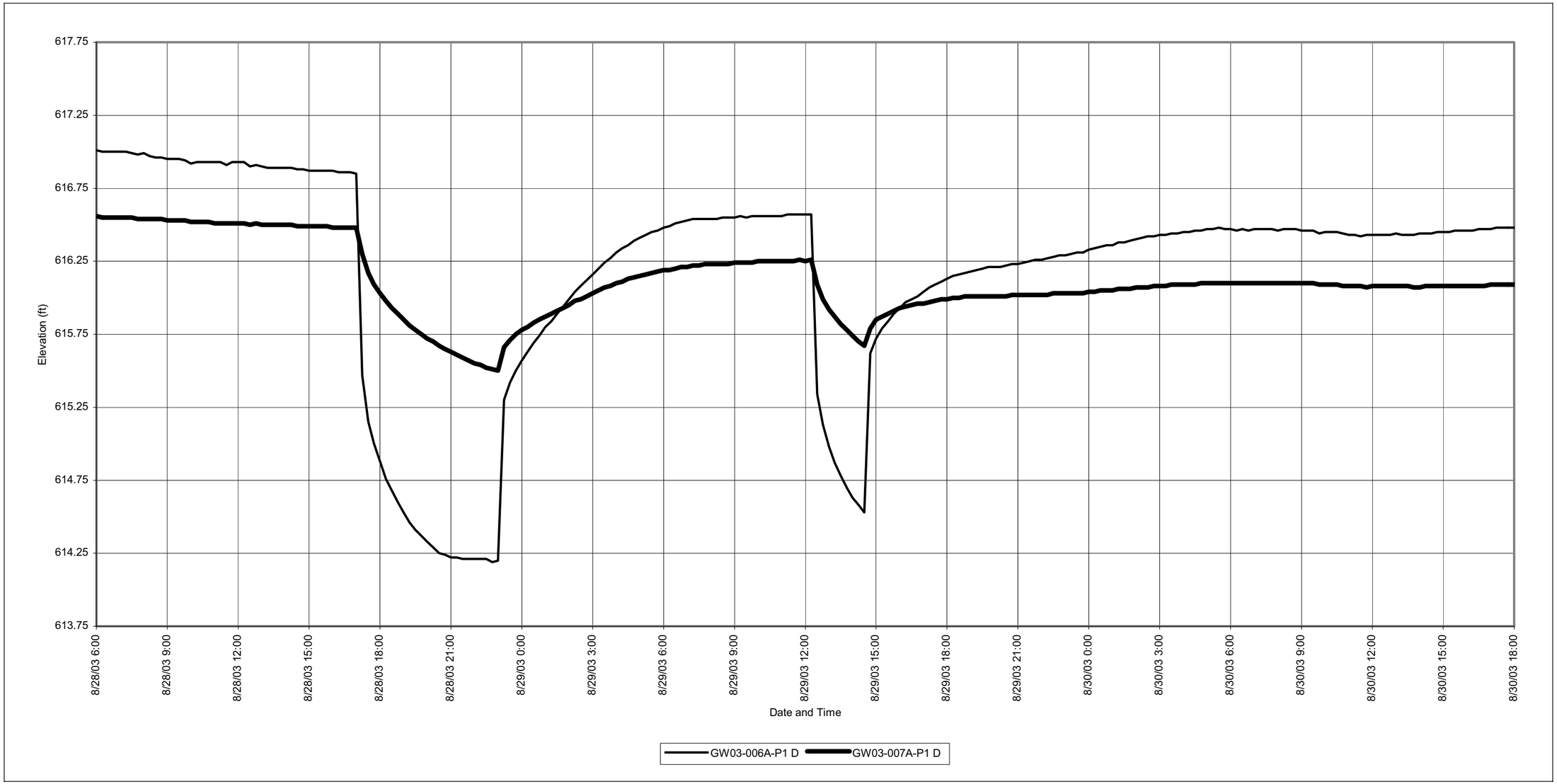

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FIGURE 6.1-4

COMPARISON OF NATURAL AND CURRENT CONDITIONS IN GROUNDWATER FLOW

[NIP – General Location Maps]

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FIGURE 6.1-5

EFFECT OF RESERVOIR FLOODING

[NIP – General Location Maps]

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FIGURE 6.1.1-1

DAY OF THE WEEK AVERAGE SURFACE WATER ELEVATION, LEWISTON RESERVOIR 2003

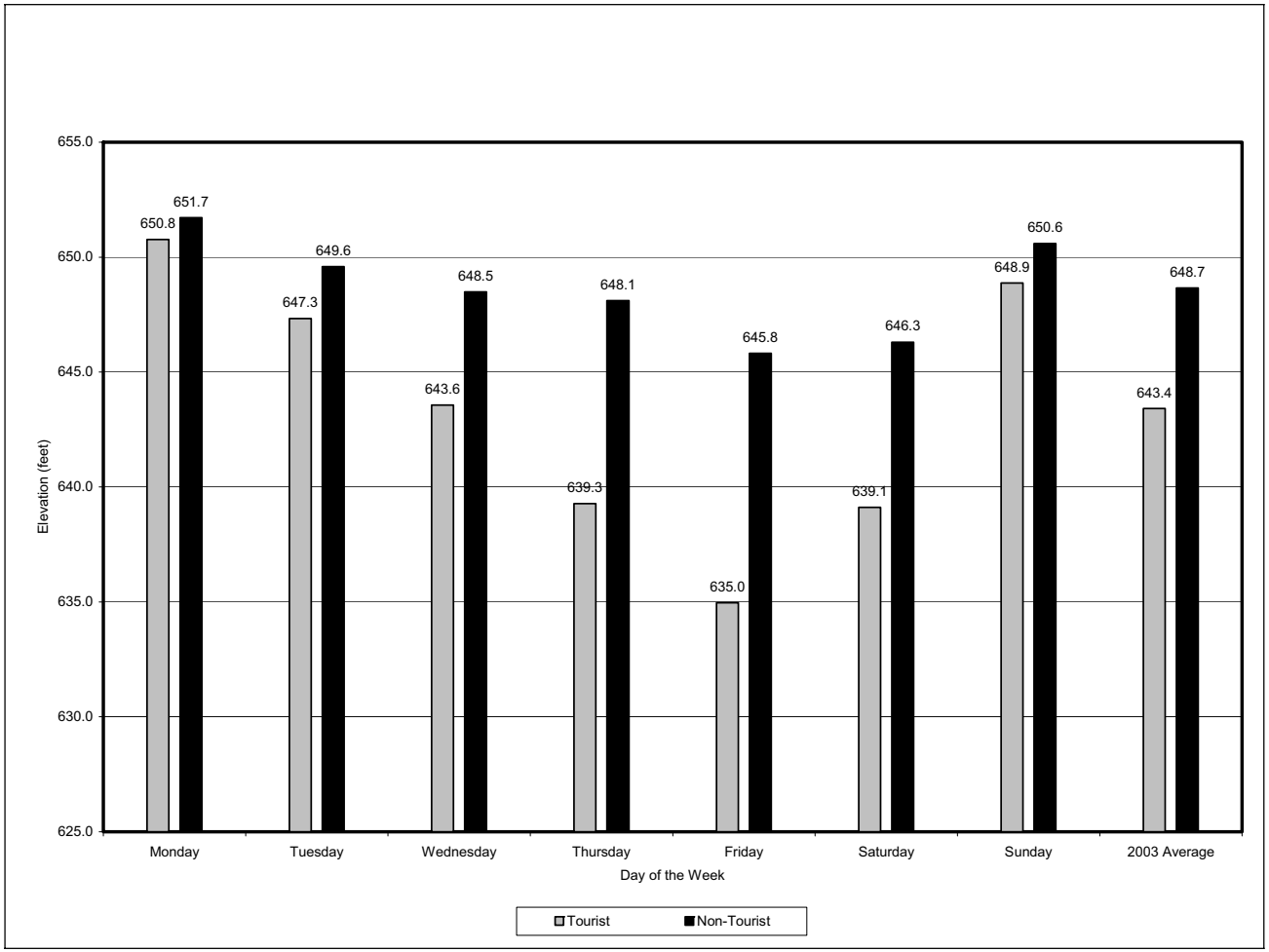

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FIGURE 6.1.1-2

WATER LEVEL FLUCTUATIONS, OW-189, OW-193, GW03-006B-P2 AND LEWISTON RESERVOIR, 2003

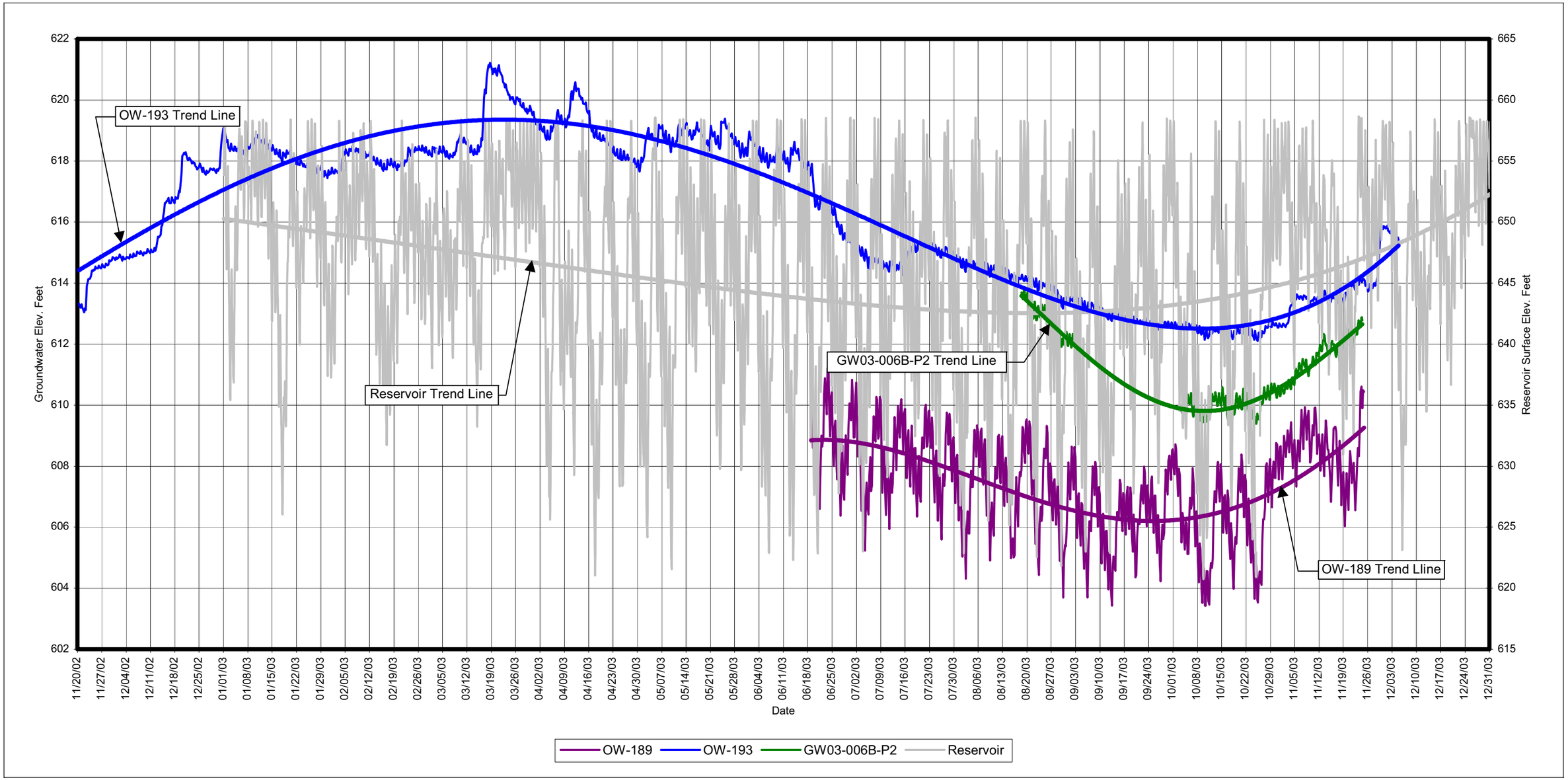

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FIGURE 6.1.2-1

DAY OF THE WEEK AVERAGE SURFACE WATER ELEVATION, FOREBAY 2003

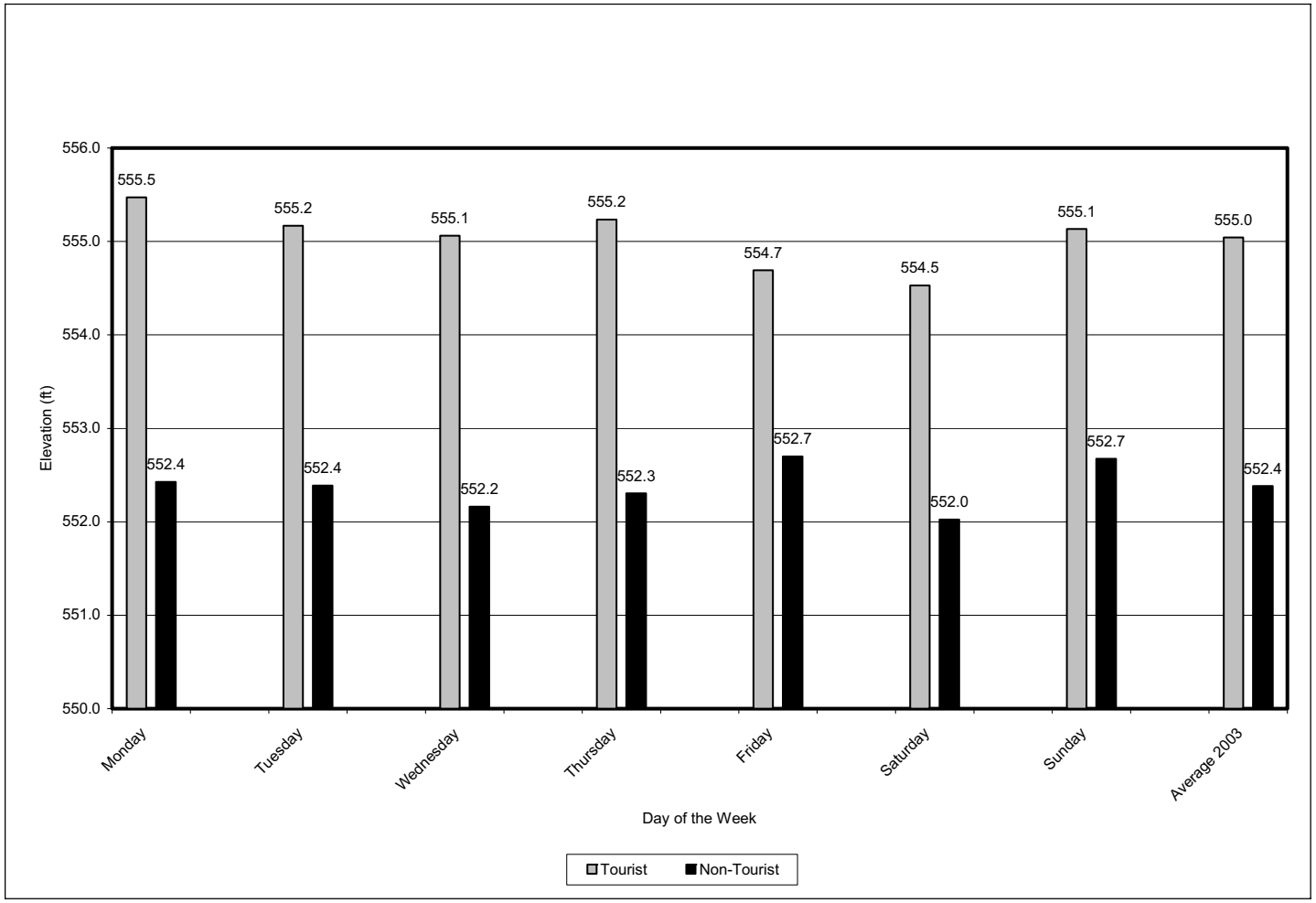

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FIGURE 6.1.2-2

GRADIENTS IN CONDUIT DRAINAGE SYSTEM

[NIP – General Location Maps]

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FIGURE 6.2.1-1

PLAN AND WELL LOCATIONS

[NIP – General Location Maps]

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FIGURE 6.2.1-2

FALLS STREET TUNNEL INFILTRATION RATE AND POTENTIOMETRIC HEAD IN THE LOCKPORT

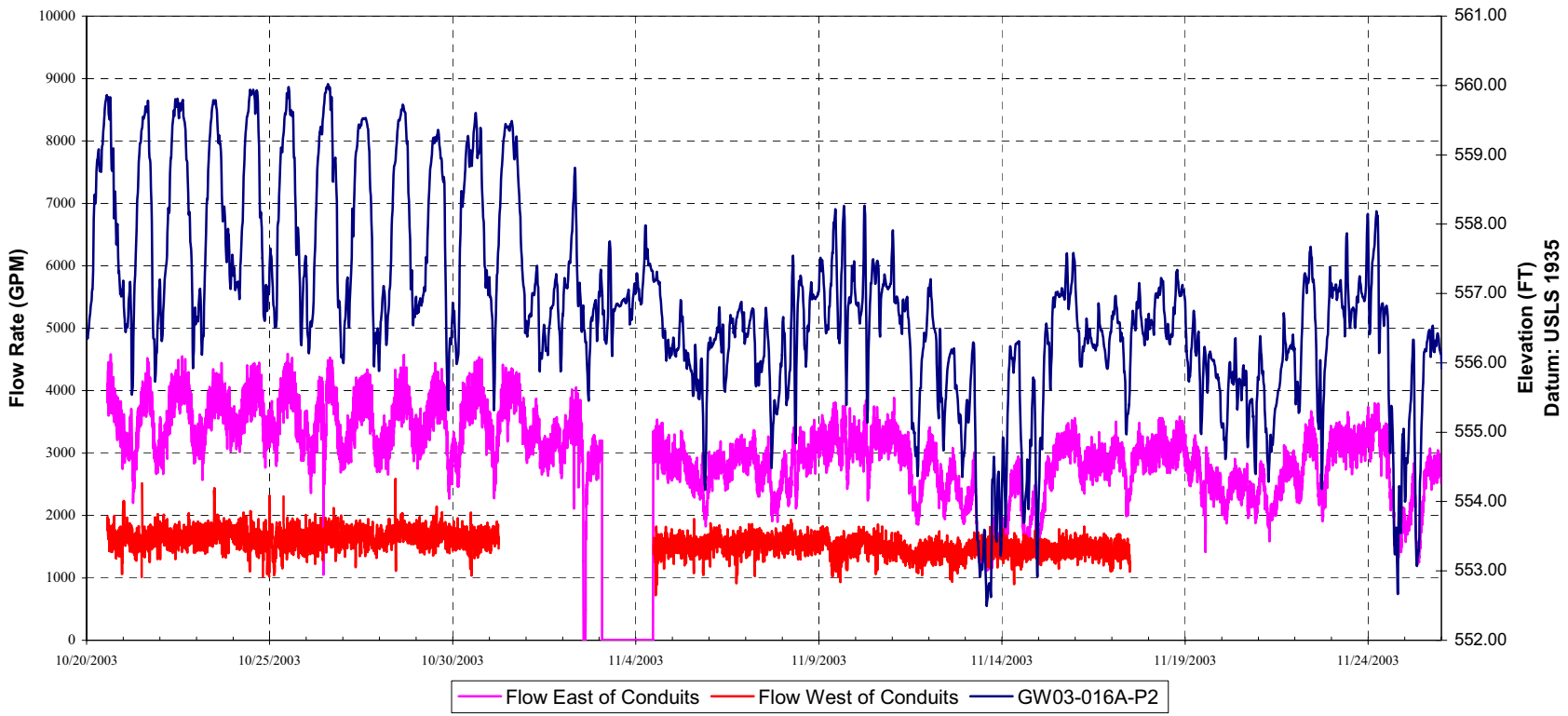

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FIGURE 6.2.1-3

DETAIL OF FIGURE 6.2.1-2

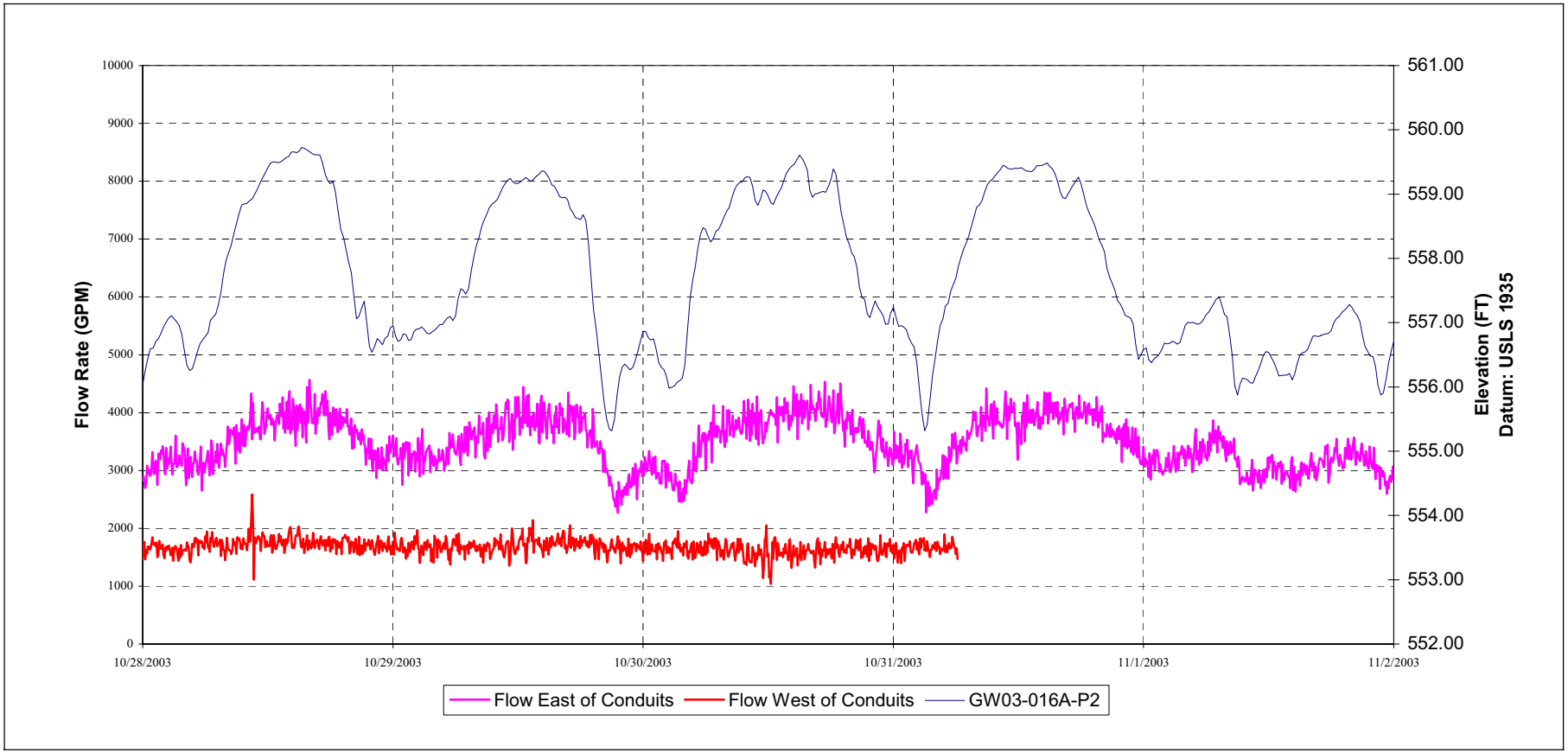

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FIGURE 6.2.1-4

INFILTRATION EAST OF CONDUITS VS. HYDRAULIC HEAD IN THE LOCKPORT

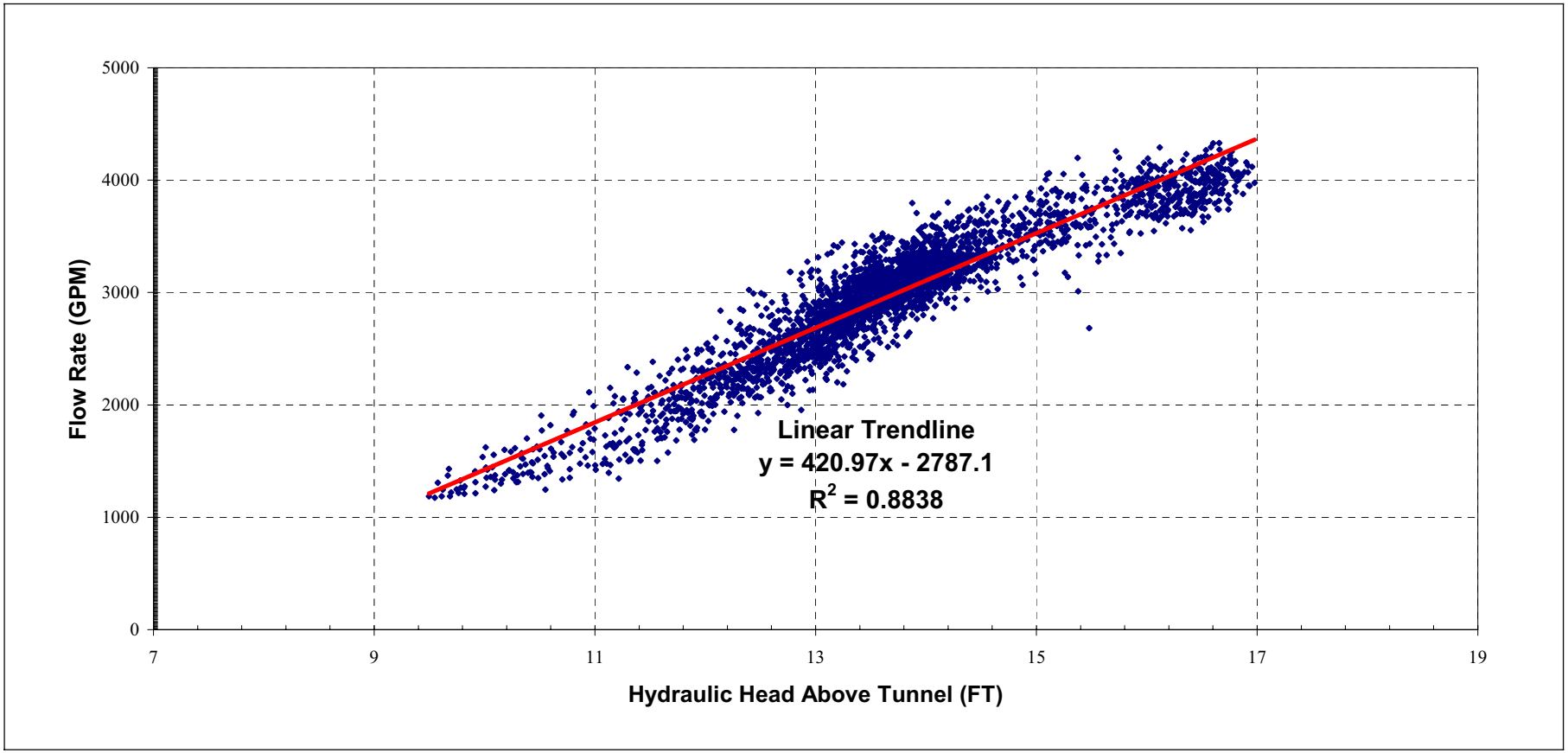

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FIGURE 6.2.1-5

POTENTIOMETRIC HEADS AT RIVER, FOREBAY, CONDUIT DRAINAGE SYSTEM, AND GROUNDWATER

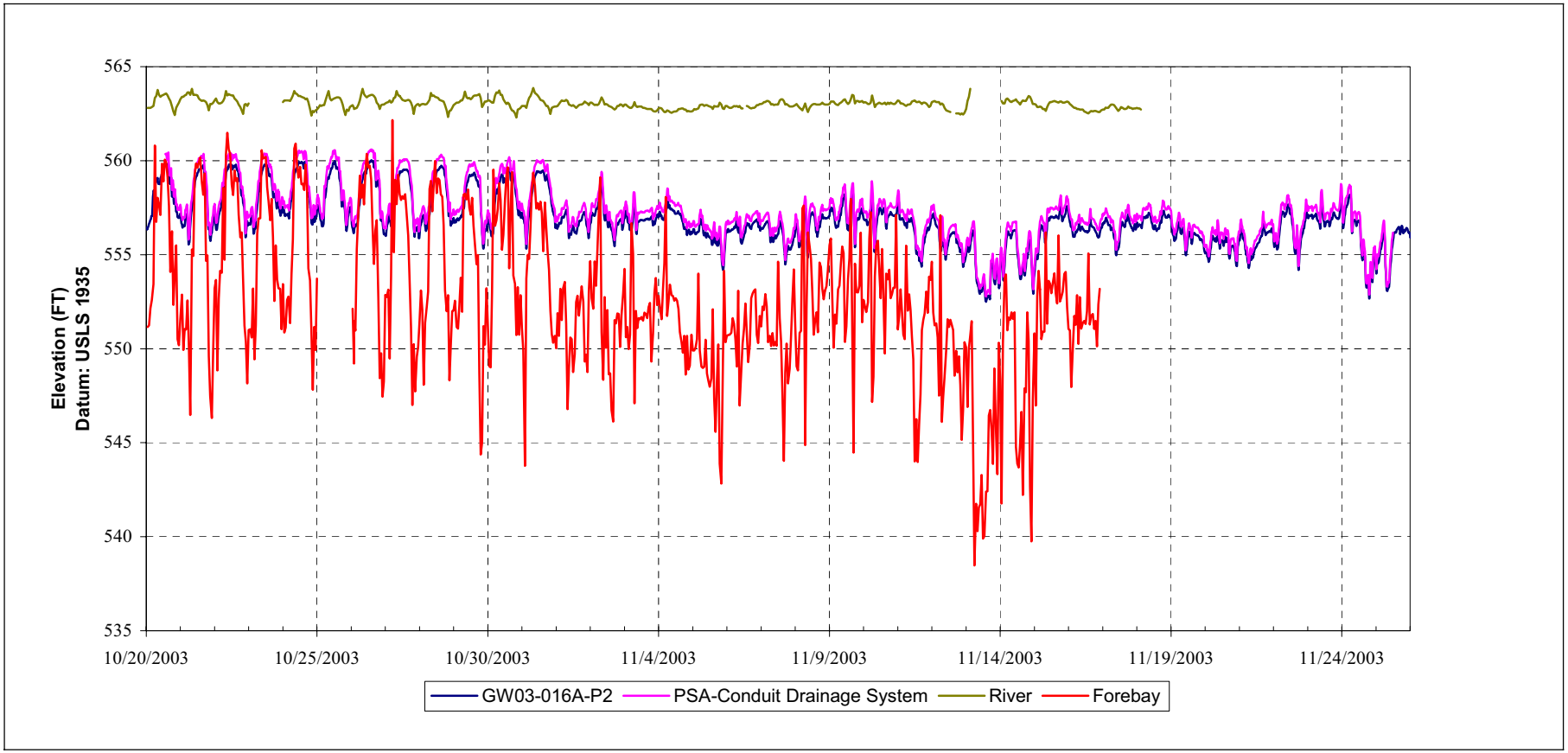

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FIGURE 6.2.1-6

DETAIL OF FIGURE 6.2.1-5

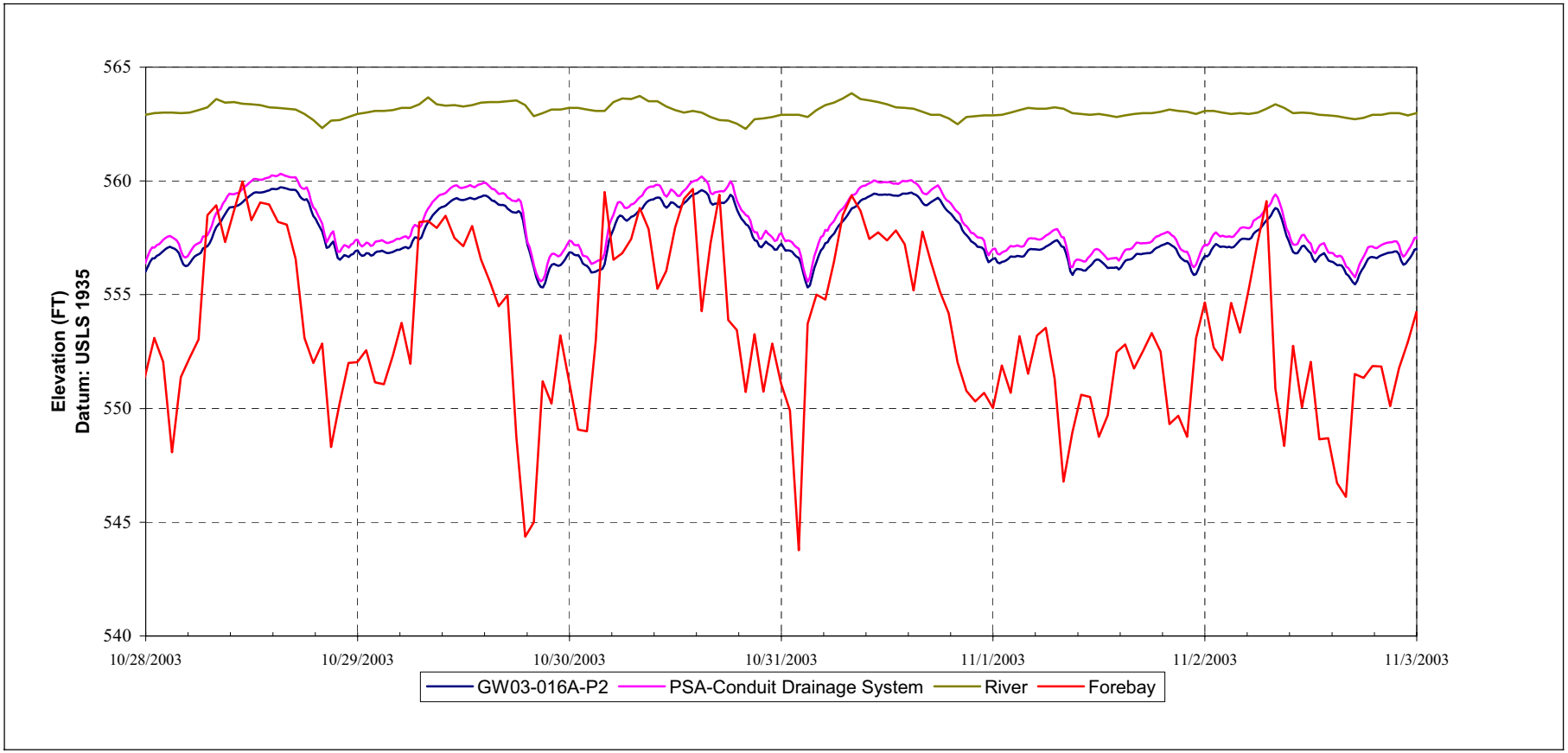

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FIGURE 6.2.1-7

COMPARISON OF HEAD IN CONDUIT DRAINAGE SYSTEM AND IN THE LOCKPORT AQUIFER

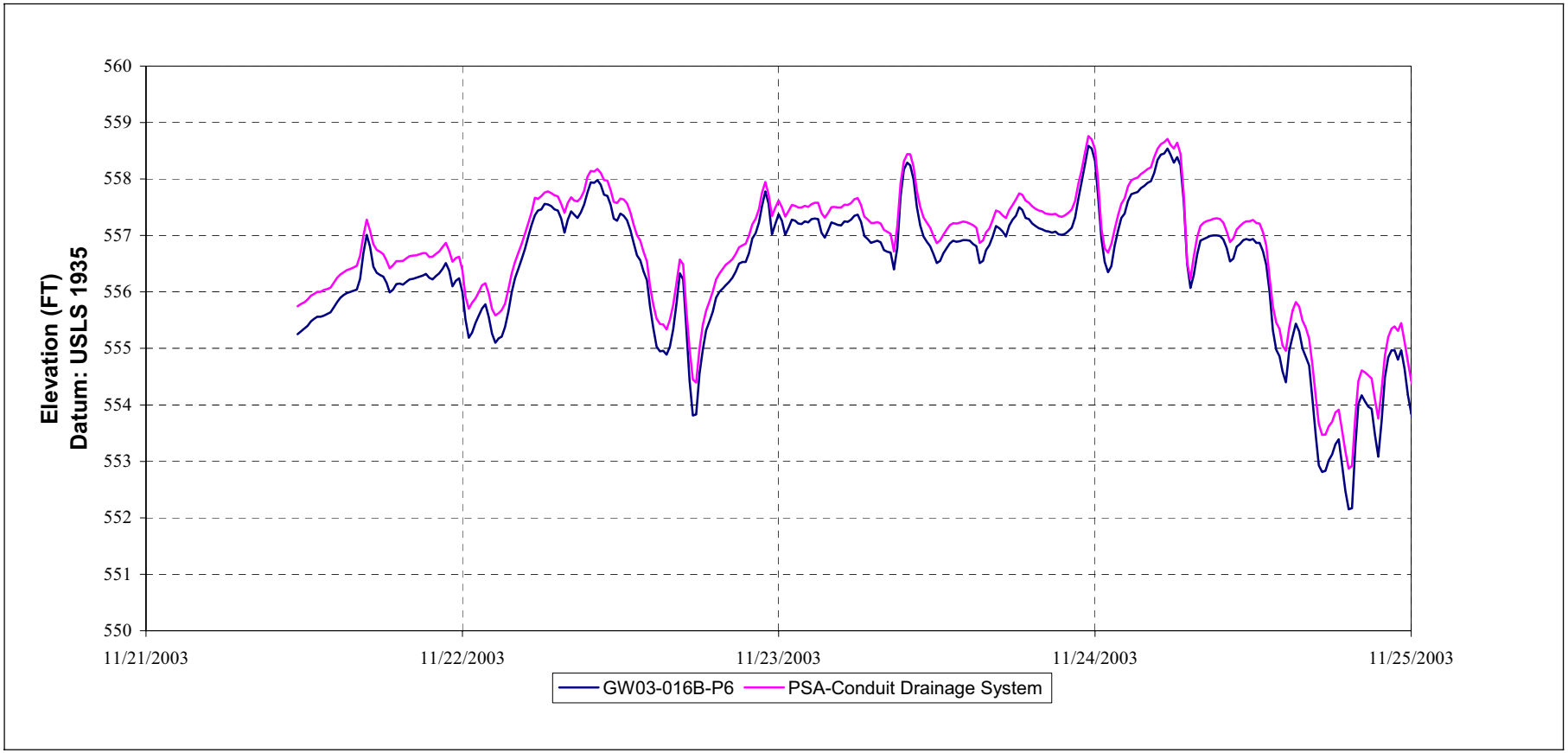

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FIGURE 6.2.1-8

HIGH-TRANSMISSIVITY ZONE

[NIP – General Location Maps]

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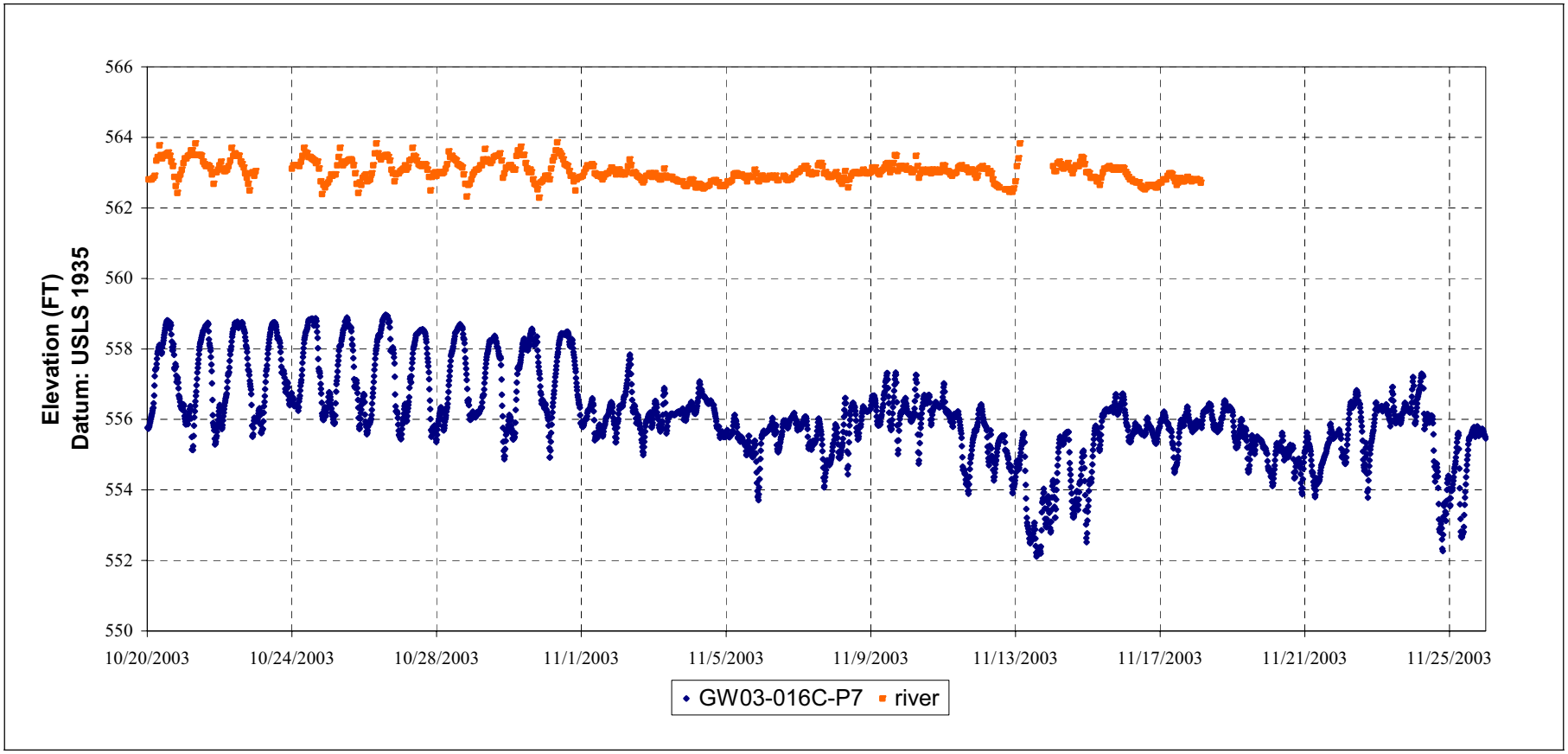
FIGURE 6.2.1-9

HEAD IN THE UPPER NIAGARA RIVER AND IN THE LOCKPORT AQUIFER AT THE FALLS STREET TUNNEL



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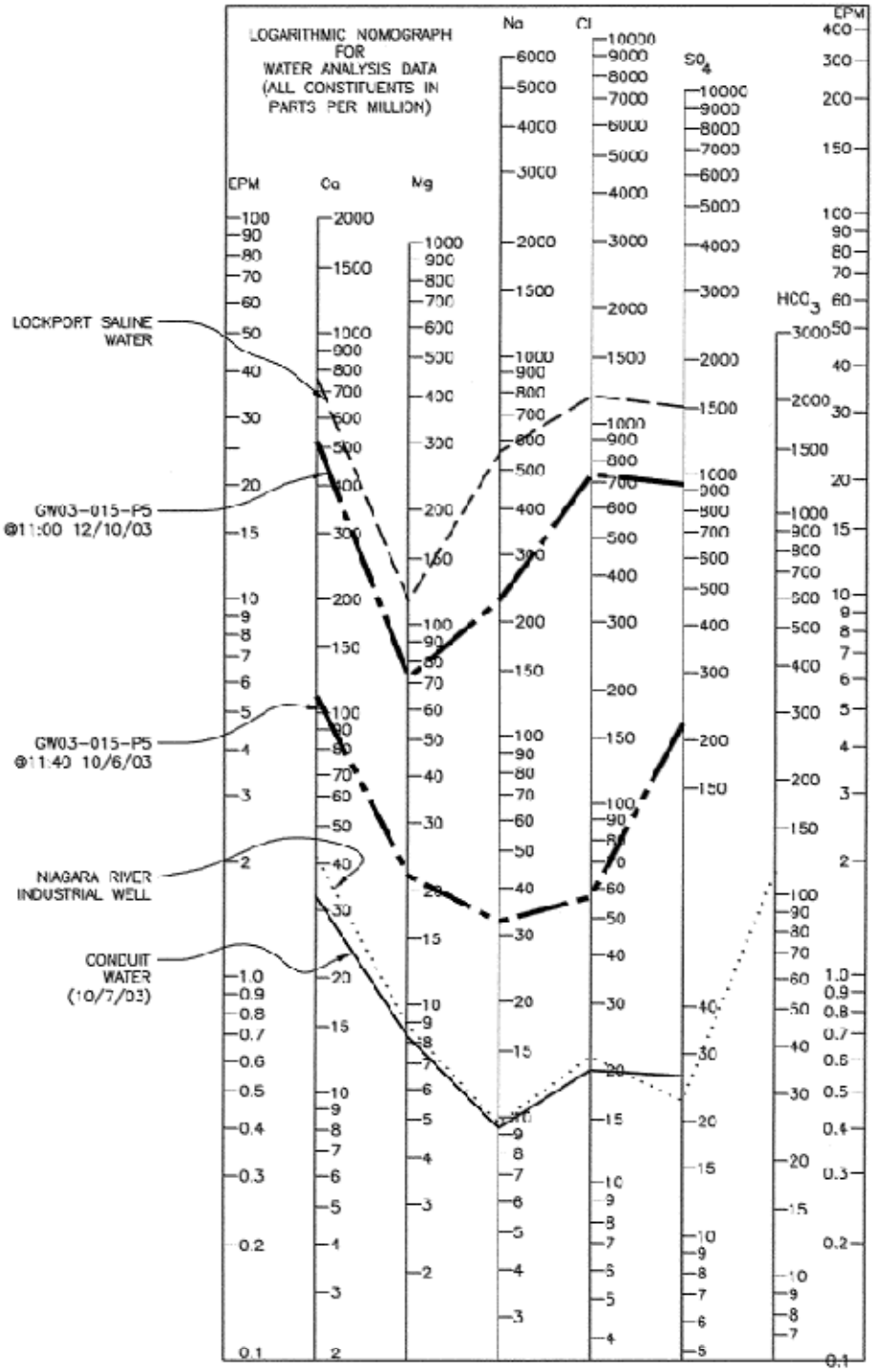
NIAGARA POWER PROJECT (FERC NO. 2216)

DETERMINE TO WHAT EXTENT PROJECT OPERATIONS AFFECT THE TRANSPORT OF GROUNDWATER AND CONTAMINANTS



Water Quality Comparison

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NIAGARA POWER PROJECT

Figure 6.3.1-1

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7.0 SUMMARY AND CONCLUSIONS

This section summarizes the findings of the investigation and presents conclusions that have been developed based on the investigation results. The discussion below is presented by NPP effects on (1) groundwater levels and flow, (2) groundwater infiltration into the FST at the conduit/FST crossover, and (3) surface water and groundwater quality.

7.1 NPP Effects on Groundwater Levels and Flow

7.1.1 Lewiston Reservoir

Groundwater modeling results and water level data collected during 2003 indicate that the Lewiston Reservoir affects area groundwater levels and flow patterns within the area of influence depicted on Figure 5.1.2-2. The reservoir, situated above ground surface, acts as a substantial and relatively stable source of groundwater recharge. Within the zone of reservoir recharge influence, this constant source of recharge likely reduces the effect of seasonal declines in groundwater levels that would have adversely affected water supply well yields.

Groundwater level fluctuations induced via the reservoir by NPP operations were observed generally to decrease with distance from the reservoir and to vary by depth, i.e., by subsurface water-bearing zone. Short-term (i.e., daily) reservoir-induced groundwater level fluctuations as much as approximately 2.51 feet were observed (NYPA overburden well OW-189 located adjacent to the reservoir dike). Of the bedrock piezometers installed as part of this study, the maximum observed groundwater level fluctuation was 0.79 feet in piezometer GW03-001A-P2. East of the reservoir, on Tuscarora lands, the maximum observed groundwater fluctuation was 0.67 feet in piezometer GW03-006B-P2. In general, wells tapping water-bearing zones that subcrop beneath the reservoir showed greater responses. The maximum groundwater level fluctuation resulting from a typical week-long (i.e., Monday through Friday) drawdown of approximately 38 feet (representing the maximum Project-induced influence) was approximately 1.5 feet in well OW-104. For comparison, groundwater level fluctuations caused by natural seasonal cycles were observed during the course of this investigation to reach 7 feet.

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The extent of reservoir influence on groundwater flow is limited to the north and east by the presence of groundwater flow divides. The groundwater flow divide to the north of the reservoir limits reservoir-influenced groundwater flow in that direction. The northern groundwater flow divide has been shown to exist for the two Lockport Group water-bearing zones occurring north of the Lewiston Reservoir. As a result of this flow divide to the north, no reservoir-influenced groundwater flow reaches the Niagara escarpment.

East of the Lewiston Reservoir, groundwater flow is limited by a flow divide occurring in the water-bearing zones of the upper Lockport Group, not in the group's two lower water-bearing zones (i.e., water-bearing zone 10 and the Gasport/DeCew water-bearing zone). Based on the results of groundwater modeling for long-term average conditions, the extent of this influence, delineated by the location of the groundwater flow divide, fluctuates between the edge of the reservoir and approximately 1,500 feet to the east depending on reservoir water levels and on seasonally variable regional groundwater levels. During dry periods, relatively low regional groundwater levels create relatively steep flow gradients away from the reservoir, tending to shift the groundwater flow divide eastward. Conversely, during wetter months, high regional groundwater levels result in a relatively shallow gradient, tending to shift the groundwater flow divide westward. Modeling results show that in the Gasport water-bearing zones (Model Layer 10), as well as in the Gasport/DeCew water-bearing zone, there is no eastward groundwater flow influence from the Lewiston Reservoir. Groundwater flow in these water-bearing zones is therefore generally to the southwest, beneath the reservoir, and remains unaffected by changing reservoir levels.

As shown by the results of groundwater particle tracking modeling, Lewiston Reservoir water infiltrates into the upper weathered bedrock water-bearing zone and flows radially outward from the reservoir. To the north, east, and south, this flow mainly discharges into either Fish Creek (to the north) or Gill Creek (to the south). Reservoir-influenced groundwater discharge to the creeks is thought to decrease to the east in dry periods when regional groundwater levels are lower, as indicated by the diminished creek flow observed immediately east of the Lewiston Reservoir in summer. It is determined, however, that the overall net effect of reservoir-induced recharge on Fish and Gill Creeks is an increase in long-term stability of streamflow. To the west, reservoir recharge flow discharges mainly to the CDS or the forebay, with some flow to the Niagara River gorge.

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7.1.2 Forebay and Conduits

Forebay level fluctuations directly affect potentiometric levels, and consequently hydraulic heads, in the CDS along most of the conduit length. The resulting fluctuation in water level and hydraulic gradient within the CDS controls hydraulic gradients in groundwater near the conduits.

During tourist season, a generally higher hydraulic head in the CDS (caused by higher average forebay levels [observed]) tends to diminish the groundwater flow gradient toward the conduits. Conversely, lower average forebay levels during the non-tourist season lead to a generally lower hydraulic head in the CDS, likely increasing the hydraulic gradient toward the conduits. As a result, groundwater flow from the Lockport water-bearing zones to the CDS is probably reduced during tourist season and increased during non-tourist season. Seasonal factors must be superimposed on this scenario; the naturally lower groundwater levels in the Lockport during summer and early fall would tend to reinforce reduction in flow from the Lockport to the CDS during tourist season.

The flow capacity of the CDS has been estimated to be orders of magnitude higher than that of the surrounding bedrock. CDS flow regimes differ slightly for the tourist and non-tourist seasons. During the tourist season, flow in the CDS pipes is northward between the upper Niagara River and the FST at all times. North of the FST, flow direction is variable, although the average direction appears to be north. In the northernmost segment of the system, closest to the forebay, flow direction reverses frequently, and dominant gradients are difficult to establish. During the non-tourist season, flow is always to the north in the southern and central portions of the system. In the northern portion, close to the forebay, frequent flow reversals occur in the same manner as during the tourist season.

Flow occurring over the Pump Station B weirs from the CDS to the conduits is the probable main route of discharge of CDS water to the forebay. During tourist season, flow over the weir occurs approximately 70% of the time, while during non-tourist season flow over the weir occurs approximately 60% of the time. During tourist season, flow over the Pump Station A weirs from the conduits to the CDS was estimated at approximately 100 gpm, a negligible volume when compared to flows within the conduits and the CDS. During non-tourist season, the predominant condition at Pump Station A is no flow between conduits and CDS.

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During the 1994 conduit inspections via submersible craft, three areas of water inflow were identified in the concrete floor slab of the east conduit. Two of these areas, where groundwater inflow was observed, were located between the conduit intakes and Pump Station A, while the third area, was identified near Pump Station B. Since hydraulic gradients in the vicinity of Pump Station A are predominantly from within the conduits to the drainage system, flow is estimated to be predominantly in that direction in the two upstream areas of damaged conduit floor slabs. At Pump Station B, hydraulic gradients are predominantly from the CDS toward the conduits, and therefore flow, too, is estimated to be mainly from the CDS into the conduits. The magnitude of flows in these three areas is unknown.

7.2 Groundwater Infiltration Into the Falls Street Tunnel Near the NYPA Conduits

Based on field reconnaissance observations, groundwater infiltration into the FST in the vicinity of the FST crossover of the NYPA conduits occurs mainly between Drop Shaft 14 and Drop Shaft 12. The most significant infiltration was observed immediately upstream (east) of the lined concrete tunnel portion at the crossover.

The total groundwater infiltration measured in the FST near the crossover averaged 5,080 gpm (7.3 mgd) for tourist season and 4,110 (5.9 mgd) for non-tourist season. The reduction of infiltration from tourist season to non-tourist season is a direct response of the lower average forebay water levels observed during non-tourist season. FST groundwater infiltration measured in the tunnel section east of the conduits was approximately twice that measured for the section west of the conduits. This is likely due to the lack of grouting in the eastern portion. Average flows measured in the eastern reach varied from tourist season (3,580 gpm) to non-tourist season (2,740 gpm) by approximately 25%, whereas flows in the western reach varied from tourist season (1,500 gpm) to non-tourist season (1,370 gpm) by approximately 10%. This reduced flow in the western reach, which is mirrored in the short-term infiltration rate response to forebay level fluctuations, is likely due to previous grouting efforts in the western reach. Overall, however, both short-term and long-term variations in groundwater infiltration rates into the FST are directly related to NPP operationally induced forebay level fluctuations.

The long-term average dry-weather flow from infiltration into the FST at the crossover is approximately 4,500 gpm (6.5 mgd). Under current conditions, approximately 20% of that flow, or 900

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gpm (1.3 mgd), can be attributed to the high transmissivity zone of the Lockport dolomite aquifer. The remaining amount of the flow, approximately 80% or 3,600 gpm (5.2 mgd), reaches the FST via the drainage system of the NYPA conduits.

7.3 NPP Effects on Water Quality

7.3.1 Lewiston Reservoir

The predominant chemical contaminants detected in groundwater samples collected from wells near the reservoir were gasoline-related compounds (BTEX, MTBE, and other VOCs). Other contaminants detected included heavy metals, phenols, and miscellaneous VOCs.

The most common indicator compounds of gasoline contamination, BTEX and MTBE, were detected in all but one water-bearing zone (the weathered bedrock zone) in the vicinity of the reservoir with the highest concentrations detected east of the reservoir. The most affected zone in terms of frequency of detection and concentrations of BTEX and MTBE was the Gasport/DeCew water-bearing zone.

The maximum lateral extent of Lewiston Reservoir influence on groundwater flow, is greatest within the upper weathered bedrock water-bearing zone. The lateral extent of reservoir influence decreases with depth of water-bearing zone below this. As indicated by three rounds of water sampling, Lewiston Reservoir water was essentially free of chemical contaminants (with the exception of delta-BHC and monomethyl mercury). The gasoline-related contaminants detected in reservoir area wells were not detected in either the forebay or reservoir water samples. Furthermore, the most affected water-bearing zone (the Gasport/DeCew), does not appear to be affected by reservoir-influenced groundwater flow east of the reservoir. Therefore, the presence of significant concentrations of these analytes is probably indicative of the proximity of these wells to active fuel service stations rather than to the reservoir.

The pesticide, delta-BHC, detected in reservoir water samples, was not detected in groundwater samples near the reservoir.

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Contaminants were detected in Lewiston Reservoir sediments, although, with the exception of lead and arsenic, these contaminants were not detected in groundwater samples collected from nearby piezometers. Lead and arsenic were detected in several reservoir area piezometers associated with different water-bearing zones within the groundwater flow influence of Lewiston Reservoir. The detection of lead may be associated with leaded gasoline contamination. The presence of monomethyl mercury in several reservoir vicinity wells may be indicative of the presence of elemental mercury, possibly from naturally occurring sources or from reservoir sediments, where mercuric compounds were also detected. Local surface water (e.g., creeks and wetlands) may also be a source of monomethyl mercury in groundwater near Lewiston Reservoir. Monomethyl mercury was detected in reservoir water samples as well. It should be noted that these three analytes (arsenic, lead, and monomethyl mercury) were also detected in piezometers that are not within the direct influence of reservoir-induced groundwater flow (namely, the Gasport/DeCew water-bearing zone), a fact that suggests another source.

7.3.2 Forebay and Conduit Drainage System

Based on analytical results from groundwater sampling performed as part of this study, groundwater between the upper Niagara River and the forebay, in the vicinity of the NYPA conduits, is significantly contaminated with organics (VOCs, including BTEX), pesticides, phenols, and metals. There is no evidence that such contamination might have been caused by Project operations. The classes of chemicals detected are, however, consistent with known contaminant plumes associated with former and active hazardous waste sites in the area. Most of these sites have been well studied, with contaminant plumes delineated, and are undergoing remediation or plume containment measures. Many of the contaminant plumes associated with these sites, are known to extend vertically through all water-bearing zones of the Lockport Group.

Contaminants within the area of groundwater flow influence by the CDS, both east and west of the conduits, migrate toward the conduits from the source areas under the influence of the CDS/FST sink and enter the CDS or the FST. Contaminants transported into the CDS are likely carried into either the FST or the forebay, depending on the section of conduit and the prevailing hydraulic gradient within the CDS. Contaminants detected in monitoring wells adjacent to the CDS are likely lower than in the surrounding area due to mixing with Niagara River water from the CDS. Contaminants detected in water-

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bearing zones that occur below the conduits are not likely influenced by the sink effect of the CDS or FST.

7.3.3 Surface Water

Results of this investigation indicate that surface water associated with and in the vicinity of the NPP are not significantly impacted by chemical contaminants. Although significant chemical groundwater contamination was detected in the immediate vicinity of the NYPA conduits, and although this contamination likely discharges from bedrock to the CDS (and subsequently to the FST or forebay), none of these contaminants was detected in water samples collected from the forebay. The pesticide, delta-BHC, detected in groundwater samples collected from wells along the conduits, was also detected at very low concentrations in water samples collected from the Lewiston Reservoir. Possible sources of delta-BHC in reservoir water samples are (1) upper Niagara River water, (2) airborne transport of pesticides resulting from area application for agricultural purposes, and (3) groundwater in the City of Niagara Falls transported via the CDS and forebay. Monomethyl mercury was also detected in several water samples from the following "river sourced" locations: the upper Niagara River, the conduits, and the reservoir (one sample).

The source of acetone and carbon disulfide, both detected at very low concentrations in sample SW03-001 (November 2003) collected from Fish Creek, is unknown. Acetone is, however, associated with laboratory operations and, when occurring in environmental samples, is frequently attributed to laboratory sources. Carbon disulfide can occur naturally at low concentrations, however, it is also a primary contaminant associated with the Stauffer Chemical site situated immediately north of the forebay. Although not detected in water samples collected from either the forebay or the reservoir, carbon disulfide detected in Fish Creek may have migrated there from the Stauffer site via the forebay and reservoir. The source of lead detected in water samples collected from the wetland at the head of Gill Creek within the Tuscarora Nation is unknown. The wetland is not within the predicted zone of influence of reservoir recharge flow. The source or sources of monomethyl mercury, detected in several "local sourced" surface water samples are unknown, as it was detected in samples from areas that lie both within and outside of the reservoir area of influence.

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Although elevated total coliform concentrations were detected in samples collected from Fish Creek and the wetland at the head of Gill Creek , low fecal coliform results for these same sample locations indicate that the high total coliform results are not associated with sewage disposal or septic system issues.

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