## 2.2 GROUND PENETRATING RADAR SURVEY

### 2.2.1 Introduction

Ground penetrating radar (GPR) surveys were conducted as part of Task 2 Phase A activities of the RI. The data provided useful information regarding the nature and extent of bedrock deformation, if any, and were considered in selecting general locations for drilling and monitoring well installation. In order to more precisely define drilling locations, additional GPR data were subsequently collected (July 1993) along traverses in the vicinity of several of the proposed monitoring well clusters. The objective of the additional GPR surveys was to attempt to delineate zones of fractured or disturbed bedrock, if such zones existed.

### 2.2.2 Methods

A Pulse EKKO IV radar system, manufactured by Sensors and Software, Inc., of Mississaugua, Ontario, Canada, was utilized for the GPR surveys. The system was configured with 50 MHz antennas, a 1000-volt transmitter, and a laptop computer. The antennas, including transmitter and receiver electronics and batteries, were carried from station to station. The main GPR console, field computer, and power supply remained in a two-wheeled hand cart that was pulled between stations. Fiber optic cables provided the link between the GPR console and the two antennas. Despite the relative portability of the GPR equipment, the presence of dense vegetation was a consideration in positioning traverses near a few proposed well locations.

Nearly 4,400 linear feet of radar images were acquired along 16 transects ranging in length from 120 feet to 795 feet. The data were collected by DUNN personnel in July 1993 at proposed well locations DC-3, DC-5 through DC-10, and DC-12. Radar recordings were made every three feet along each profile line. Labeled pin flags were used to mark locations along each transect, generally at 100-foot intervals. Station locations were determined by moving the six-foot-long antennas a distance of three feet between measurements. The two antennas were oriented side by side, parallel to the direction of the profile, and were maintained at a separation of six feet wherever field conditions permitted. Each evening, the radar data were plotted on a line printer and analyzed for quality and technical merit.

### 2.2.3 Results

The quality of the radar data ranged from fair to excellent, with penetration depths of from 30 to 70 feet. Many of the features observed in the Task 2, Phase A GPR surveys were also evident in these data; for example, dipping bedrock surfaces, thinning or thickening strata, and truncated or chaotic reflection patterns. Refer to the Task 2, Phase A Report, dated August 1992 (Figures 13 through 24 therein), for representative radar data collected during the 1992 survey.

The most interesting results of the Phase C GPR surveys were obtained in the vicinity of proposed monitoring well clusters DC-3 and DC-10. Earlier observations suggested that topographic features at these locations (a basin at DC-3; linear ridges at DC-10) might be related to bedrock subsidence, possibly as a result of dissolution of the evaporite-bearing rock known to occur at depth beneath the Study Area. The GPR data, however, suggest that the basins and ridges in these two areas are more likely to be erosional, rather than structural, features. This is in contrast to the Phase A radar data collected along Church and Flint Hill Roads (Livingston County), where well clusters DC-7R and DC-11 were later installed. These data were consistent with structural origins for the basins and ridges located near these two well clusters.

### 2.2.4 Conclusions

The radar data collected in July of 1993 provided no evidence of faulted or fractured bedrock in the surveyed areas. Although confirming the absence of local structures was important, the Phase C GPR data were not a prime factor in refining the drilling locations that had been based, in part, on the 1992 survey results.

## 2.3 DRILLING PROGRAM

### 2.3.1 Introduction

Previous sampling and Site/Study Area investigations indicated the need for an extensive drilling and monitoring well installation program to evaluate the hydrogeology, the areal and vertical extent of contamination, and contaminant transport mechanisms. A minimum of eight "clusters" of domestic wells demonstrating evidence of historical and/or recent contamination had been identified by previous NYSDOH and USEPA sampling. These wells were distributed between the spill site and Spring Creek. Refer to Figure 3-1 for their locations and to Appendix B (Volum III) for the results of historical and recent sampling at these wells. Additional sampling by NYSDEC and DUNN personnel identified other evidence of contamination in these areas, as well as at other locations within the Study Area. These results were also factored into the selection of the drilling locations.

A total of 14 initial drilling locations were selected within the Study Area. Drilling locations were selected either near or upgradient (west) of each of the eight contaminated domestic well "clusters." Six additional drilling locations were selected; one to establish an upgradient or ambient/background location (DC-4), four to investigate the possible presence of DNAPL (DC-1, DC-2, DC-3, DC-5, DC-6) and one to fill in a data gap (DC-11). Several of the drilling locations were positioned so that they could provide information relative to both the NAPL and the dissolved phase plume investigations (DC-3, DC-5, DC-6, DC-7). The baseline drilling program was also conducted to identify and document key geologic horizons and contacts, and to investigate rock conditions (stratigraphy, bedding planes, joints, "pop-ups", collapse features, solutioning, etc.) in and around the spill site and within the Study Area. One location (DC-7) was relocated as a result of information collected during the drilling and testing program (DC-7R). Three additional locations (DC-14, DC-16 and DC-17) were added to the drilling program as a result of information that was obtained while drilling at the original 14 locations. Refer to Plates 1 and 2 for the 18 drilling locations.

The drilling program was designed and conducted in two phases, and was based upon the need to collect detailed geologic information and to accommodate the emplacement of a cluster of monitoring wells (well cluster) at each drilling location. Six of the drilling locations (DC-1, DC-4, DC-7, DC-8, DC-11 and DC-12) were selected for diamond coring to obtain subsurface samples of the bedrock throughout the Study Area. The coreholes were designed to be the deepest boring at each of the six selected drilling locations so that the maximum stratigraphic interval could be studied. At the remainder of the drilling locations, downhole air hammer and/or spin casing drilling was utilized to advance each boring to the desired depth. Drill cuttings or rock chips were collected from the drill return stream for visual evaluation, volatile organic screening, comparison with rock cores, and for logging purposes.

Discrete-depth water samples were collected through a packer assemby and analyzed for TCE and related compounds with a field gas chromatograph. In addition, a hydrophobic dye test was utilized to test the samples for the presence of NAPL. As a result of the field screening of water samples from DC-7, it was decided to add an additional drilling location to the south of location DC-7. This location was designated DC-7R. A single well was installed at location DC-7, whereas a full cluster (four wells) was installed at location DC-7R.

Following the completion of bedrock coring and core logging at each of the six cored locations, a borehole geophysical and video survey was conducted (see Section 2.5). The geophysical log responses were correlated with stratigraphic, lithologic and structural information obtained from the bedrock core. The coincidence of log responses with stratigraphic and lithologic features, and fractured intervals in the core, was noted. The result of this approach was the production of six pairs of geophysical logs that were correlated to the geologic features evident in the actual bedrock samples. Similar geophysical responses, later obtained in nine non-cored borings throughout the Study Area, were interpreted to determine the stratigraphy, lithologic contacts, and fracture zones in those borings. In this manner, knowledge of the stratigraphic and structural framework of the Study Area was developed without an extensive, time consuming and costly coring program. Three additional boring locations were identified as a result of the drilling and geophysical logging program, and monitoring wells were also installed at these locations (DC-15, DC-16, DC-17). Geophysical logging was not performed at these locations.

Upon completion of the deepest boring at each drilling location, the collection of discrete-depth water samples and an evaluation of real-time analytical results, and a review of borehole geophysical results and geologic interpretation, additional borings were drilled at each drilling location for monitoring well emplacement. Details of these activities are described in subsequent sections of this report. All drilling, borehole logging, and monitoring well installation and development was completed in October 1993.

All drilling and monitoring well installation services were provided by the American Auger and Ditching Co., Inc. of Constantia, New York, under the supervision of DUNN personnel.

### 2.3.2 Methods

#### 2.3.2.1 Subsurface Soil Sampling, Classification and Volatile Organic Screening

The drilling program was initiated on July 20, 1993 and completed on October 26, 1993. Fifty-five borings were advanced at 18 locations utilizing one or a combination of overburden drilling, split spoon sampling and three rock drilling methods including: NQ coring; various size downhole hammers, and four-inch diameter spin casing.

Continuous split-barrel (split spoon) soil (overburden) samples were collected from the initial boring at each drilling location following ASTM Method D1586-84. Two 24-inch (2-inch O.D.) split-barrel samplers, consisting of a drive head, split-barrel and drive shoe, were used to collect the subsurface soil samples. The split-barrel sample was obtained by driving the sampler with a 140-pound hammer falling 30 inches until either 24 inches were penetrated or 100 blows applied. The number of blows required to effect each 6 inches of penetration was recorded. Test borings for split spoon sampling were advanced by utilizing 4-inch I.D. spin casing.

All split-barrel samples were logged as they were collected, using the Modified Burmister and Unified Soil Classification Systems (see Appendix C). The soil samples were screened with an HNU Photoionization Detector (PID) for the presence of volatile compounds as soon as the split-barrel sampler was opened. The results were recorded and are listed on test boring logs. Representative portions of all samples were placed in clean glass jars immediately after the split-barrel sampler was opened. Each jar was covered with a screw cap and retained at the Site for future reference. In compliance with ASTM methods, the sample jars were labeled with the following information: job designation, boring number, sample number, depth of sample, number of blows and length of sample recovery. Test boring logs describing the soil samples are provided in Appendix D. The test (soil) borings are designated SB-1, etc. and correspond to locations DC-1, etc.

As indicated above, DUNN personnel screened all split-barrel samples for volatile organic compounds (VOCs) using an HNU Model PI-101 Photoionization Detector (PID) equipped with a 10.2 ev lamp. The instrument uses ultraviolet light to ionize many compounds (especially organics) in order to measure the concentration of trace gases. In the PI-101, a chamber adjacent to the ultraviolet light source contains a pair of electrodes. When a positive potential is applied to an electrode, the field created drives any ions in the chamber to the collection electrode where the current is measured. The measured current is proportional to the concentration of organics sampled by the instrument's probe. The useful range of the instrument is from 0.1 to 2000 ppm. The HNU is calibrated for direct reading in ppm vol./vol. of a non-toxic calibration gas. The calibration procedure involves standardization of probe response using a calibration gas of known organic concentration, in this case, benzene.

Samples from locations DC-1 and DC-2 were also visually screened for evidence of NAPL utilizing the hydrophobic dye test described in Section 2.4.2. These samples were later disposed of as described in Section 2.3.2.5.

### 2.3.2.2 Drilling / Coring

At each boring location, a five or six-inch diameter steel surface casing was installed a minimum of two feet (or five feet at open hole wells) into bedrock. At all constructed wells (consisting of a screen and riser), a minimum two-foot bentonite seal was emplaced in the annular space around the bottom of the casing prior to the commencement of drilling. At those borings that were to become open hole wells, the two foot bentonite seal was emplaced and the surface casings were also grouted to the surface. The grout was allowed to cure a minimum of 24 hours before resuming drilling.

Bedrock coring was performed with an NQ size double-tube, wire-line core barrel at six boring locations (DC-1D, DC-4D, DC-7D, DC-8D, DC-11B and DC-12D). Bedrock coring was conducted in accordance with ASTM Method D 2113-83, "Standard Practice for Diamond Core Drilling for Site Investigation." The core was scanned with an HNU photoionization detector as it was removed from the core barrel. Bedrock core samples were described in terms of rock type/lithology, color, condition, degree of weathering, fractures, fabric, and solution features. The length of retrieved core was measured and the core recovery percentage and Rock Quality Designation (RQD) was calculated for each drill "run" (i.e. drilling distance; a standard drill or core "run" is five feet). The recovery percentage is the length of retrieved core divided by the length of the drill run. The RQD is the sum of the lengths of all core sections greater than four inches in length, divided by the length of that run. A core log form was completed (Appendix E) with RQD data for each run, as well as a complete core description. Each corehole was subsequently reamed to a larger diameter with a five-inch O.D. downhole hammer to accommodate the installation of a two-inch I.D. monitoring well assembly.

The remaining 49 borings were advanced to their total depth with either a four-inch or five-inch O.D. downhole hammer. Additionally, due to significant formation collapse at some locations or depths, spin casing was utilized at borings DC-11B, DC-12D, DC-13B and DC-17B, to reach targeted depths and to facilitate monitoring well installation.

At each of the 12 locations where NQ coring was not performed, rock chip samples were collected at approximate five foot intervals from the deepest boring at each location. The chips were logged using general descriptions of color and rock type, and placed in sealable plastic bags. The rock chips were scanned for volatiles with an HNU photoionization detector.

In-line air filters were installed on all compressors to prevent the accidental introduction of contaminants, such as lubricating oils, into the boreholes. Vegetable shortening was used to lubricate core barrels and the piston mechanism of the downhole hammers so as not to introduce any petroleum-based compounds into the borehole.

### 2.3.2.3 Decontamination Procedures

The drilling equipment that was to be used to drill and install the monitoring wells was decontaminated prior to drilling at each location. The decontamination process involved the use of a steam cleaner and water obtained from a fire hydrant located in the Village of LeRoy. All other equipment that was to come in contact with the soil, as well as water tanks, drill tools, pumps and hoses, was also decontaminated.

Temporary decontamination pads were constructed at locations DC-1, DC-3, DC-4, DC-7, DC-8, DC-9, DC-11, DC-12 and DC-13 to contain decontamination runoff. Some of the pads were used to decon equipment and materials after drilling at more than one location (e.g., the pad at DC-13 was also used to decon equipment after drilling at location DC-14). After completion of all drilling activities, all drilling equipment underwent a final decontamination process prior to leaving the Site. The temporary decon pads were then dismantled and the excess materials and plastic liners were placed in 55 gallon drums and stored within the drum storage area.

#### 2.3.2.4 Purging and Sampling During Drilling

Groundwater samples were withdrawn from discrete borehole intervals, visually examined for the presence of NAPL, and field screened for VOCs utilizing a portable GC. NAPL was not visually observed in any of the water samples; however, there was some evidence of possible NAPL on the surface of the PVC bailer after collecting an unpurged water sample from borehole DC-1R (this borehole was converted to monitoring well DC-1C), at and below the water table (60 to 80 feet below the ground surface).

After drilling 10 to 20 feet into the first water-bearing zone in the first (deepest) boring at each drilling location, the saturated interval was purged utilizing a Grundfos submersible pump. After purging and sampling the first interval, the borehole was advanced an additional 10 or 20 feet. A packer assembly was then lowered into the boring and the packer was inflated to isolate the lowermost 10 or 20 foot interval for sampling. The goals of the packer sampling program are discussed in Section 2.4.1.1.

At location DC-4, three different methods were utilized in an attempt to purge isolated zones. The first attempt to purge the packed-off zone utilized the air lift method described in the QAPjP. This method was unsuccessful due to the highly fractured nature of the bedrock which caused a significant loss of air pressure. The second method also utilized air-lift, in conjunction with a tremie system with a check valve attached at the base of the tremie pipe. This method was successful, however, it was very time consuming. Finally, purging was accomplished utilizing a Grundfos submersible pump attached via a pipe system through the center of the packer. This system was used to purge the packed-off zones at all of the remaining drilling locations.

Initially, three well volumes were purged from each interval before sampling (DC-4, DC-11). At all remaining locations, water temperature was used as a guide in determining when to terminate purging. Purging was continued until the groundwater temperature stabilized at approximately 50 - 55° Fahrenheit (F).

At locations DC-4 and DC-11, all samples were collected with a stainless steel bailer. The bailer was steam cleaned following the collection of each sample. At the request of the NYSDEC, samples from all other locations were collected directly from the discharge line of the Grundfos pump. New PVC pipe was used for the discharge system while purging with the Grundfos pump. The entire packer assembly, including the pump, was steam cleaned between purging of each subsequent sampling interval.

#### 2.3.2.5 Disposition of Drill Cuttings and Purge Water

Overburden samples, core samples and rock cuttings were screened for visual evidence of NAPL and for total VOCs utilizing an HNU. NAPL was not observed on any of the samples or cuttings. Refer to Section 2.4.2 (below) for a discussion of the NAPL screening methodology. Overburden samples from clusters DC-1 and DC-2 were containerized without screening because these clusters were located at the spill site. HNU screening at locations DC-15 and DC-17 revealed VOC levels that exceeded the action limit (10 ppm) for containerization of solids as established in the QAPjP. Therefore, all cuttings from well clusters DC-15 and DC-17 were containerized. At all of the remaining locations, VOC levels were determined to be less than the 10 ppm action limit and; therefore, the cuttings were spread on the ground in the vicinity of each respective boring.

Purge water from the first water-bearing zone at each boring was discharged on the ground in the vicinity of the boring. Purge water from all subsequent intervals was containerized in 55-gallon drums pending the results of the portable gas chromatograph (GC) field screening. If the field GC results exceeded 30 parts per billion (ppb) of total VOCs, the purge water remained in the drums. If the purge water sample exhibited total VOCs less than 30 ppb, the water was discharged on the ground in the vicinity of the boring. As a result of this procedure, purge water from locations DC-1 and DC-17 was containerized in 55-gallon drums and transported to the drum storage area.

## 2.4 FIELD SCREENING OF GROUNDWATER SAMPLES, NAPL TESTING, AND SPECIAL TESTING

### 2.4.1 Field Gas Chromatography

#### 2.4.1.1 Introduction

The selection of monitoring well completion intervals was based on available information from nearby domestic wells, on the results of field screening of ground water samples extracted from discrete zones during drilling, and on the presence of fractures and other bedrock features identified during core logging and downhole geophysical and video logging. The field screening of groundwater samples was accomplished using a portable GC that was mobilized to the Site and set up in the field officer trailer.

The goals of discrete-depth groundwater sampling and sample screening conducted concurrently with drilling were to: 1) identify and delineate the vertical extent of each contaminated ground water zone, if any, 2) minimize the potential for cross contamination between groundwater zones, 3) provide a basis for determining the necessary number of wells to be installed at each drilling location, and their completion intervals, 4) determine the level(s) of contamination for health and safety purposes, and 5) determine the disposition of drill cuttings and fluids.

### 2.4.1.2 Methods

A Photovac model 10S70 portable GC was used to screen the groundwater samples generated during the drilling program for potential spill-related volatile organic compounds (VOCs). The GC was equipped with a PID and an onboard computer programmed to analyze samples for cis-1,2-dichloroethene (c-1,2-DCE), trans-1,2- dichloroethene (t-1,2-DCE) and trichloroethene (TCE), the three potential spill-related VOCs that had been identified during previous sampling and analysis. The GC generates quantitative data specific to each compound by analyzing gaseous samples. After injection into the instrument, the sample flows through a chromatographic column prior to reaching the PID. The various VOCs pass through this column at different rates and thus reach the detector at different times relative to the injection time. A strip chart record of detector response versus time is obtained during each analysis and the presence of VOCs in the sample is manifested by peaks on this strip chart record.

The GC measures two parameters for each peak observed during the analysis. First, the length of time (known as the retention time) is measured between the initial injection of the sample and the detection of the peak; each VOC has a characteristic retention time by which it is tentatively identified. Second, the system integrates the detector response to measure the area under the peak. The area measured in millivolt seconds (mV-S) is proportional to the concentration of the compound in the sample. The concentration of the analyte in the sample is then calculated by direct comparison with the detector response to a standard of known concentration.

#### *2.4.1.2.1 Standards Preparation*

Prior to the start of field activities, the instrument was calibrated to recognize the characteristic retention times for c-1,2-DCE, t-1,2-DCE and TCE, and to convert peak areas into concentrations for these compounds. Calibration standards were then analyzed at a minimum frequency of once daily throughout the field screening program. Stock and working standards were prepared as follows. A known quantity of pure product of each analyte was added using a 10 microliter ($\mu$l) syringe to a previously tared 10 milliliter (ml) volumetric flask half-filled with reagent grade methanol. The exact weight of the analyte added was recorded to the nearest 0.0001 grams (g). Each analyte was added to the same tared flask in a similar fashion at the appropriate ratios and diluted to the 10 ml mark with reagent grade methanol to yield a stock standard mix. A 10 ul aliquot of the stock standard mix was then withdrawn using a 10 $\mu$l syringe, introduced into a second 10 ml volumetric flask half-filled with methanol, and diluted to the mark with methanol to yield a working calibration standard mix.

Calibration standards were prepared by injecting an aliquot of the working calibration standard mix into 20 ml of distilled water in a 40 ml VOA vial (50-50 headspace/sample). The VOA vial was shaken vigorously for one minute and allowed to stand for four minutes in a heated (50° Celsius) sand bath. Using a gas-tight syringe, 250 $\mu$l of headspace were then drawn off and injected into the GC for analysis.

### *2.4.1.2.2 Instrument Calibration*

Daily calibration standards were prepared at two different concentrations, or levels. A midlevel standard was prepared as described above, and used to calibrate the instrument. A low level standard was prepared at an approximate concentration of 5 $\mu$g/l, and used to verify that a reporting limit of 5 $\mu$g/l was attainable.

In order to determine the linear range of the detector, two external calibration curves were analyzed. The first, analyzed on September 7, 1993, was established by preparing calibration standards at four different concentrations and analyzing them as previously discussed. The second, analyzed on September 28, 1993, was established by preparing calibration standards at six different concentrations and analyzing them as previously discussed. The ratio of the instrument response (peak area in mv-S) to the mass of the analyte injected (in $\mu$g), defined as the response factor (RF), was calculated for each standard. Since the percent relative standard deviation of the response factors was less than or equal to 30% over the working range, linearity through the origin may be assumed. Refer to Tables 2-1 and 2-2 for the results of the daily calibration standards tests.

### *2.4.1.2.3 Sample Preparation and Analysis*

Sample preparation and analyses were conducted in the same manner as the calibration standards. Approximately 20 ml of sample was added to a 40 ml VOA vial and the VOA vial was then capped and shaken vigorously for one minute before being placed in a heated (50° Celsius) sand bath for four minutes. A 250 $\mu$l aliquot of headspace vapor was withdrawn with a gas-tight syringe and injected into the GC for analysis. When sample results were above the linear range of the detector, a smaller aliquot of sample was used, with distilled water added to bring the volume up to 20 ml (50-50 headspace/sample), and then analyzed in a similar fashion.

Sample analyte concentrations were identified and quantified using the preceding calibration standard. Sample results were corrected for the dilution factor, if applicable.

### *2.4.1.2.4 Quality Assurance/Quality Control*

Instrument/syringe blanks were analyzed at least daily to demonstrate that the instrument and injection syringe were free of contaminants. Method blanks were prepared and analyzed to verify that the distilled water, methanol, associated glassware and syringes were also free of contaminants. Method blanks were prepared and analyzed identically to standards, except that reagent grade methanol was substituted for the amount of working standard added.

The continuing calibration standards that were analyzed contained known concentrations of each analyte and were used to calculate target compound concentrations in the actual samples. A minimum of one continuing calibration standard was analyzed daily.

Samples were routinely analyzed in duplicate to demonstrate acceptable analytical precision, expressed in the form of relative percent difference (RPD). All samples exhibited acceptable analytical precision between duplicate analyses for field screening activities.

#### 2.4.1.3 Results

A method detection limit study was performed on July 21, 1993, and a lower detection limit of 5 $\mu$g/l was established. Because of the inherent variability in the results obtained with a field screening procedure, a lower confidence limit of 25 $\mu$g/l was also established. Therefore, the results reported between 5 $\mu$g/l and 25 $\mu$g/l are considered estimated and were flagged with an "E". The field screening results are presented in Table 2-3.

#### 2.4.1.4 Conclusions

The field screening program was successful in delineating the relative level of volatile organic compounds in each groundwater zone tested, thereby providing a basis for determining the number of wells to be installed at each drilling location, and their completion intervals. The data were also useful with respect to the site-specific health and safety program, and in determining the disposition of drill cuttings and purge water collected during the drilling program. The relevance of the field screening results to assessing the distribution of contamination at the spill site and in the Study Area is discussed in Section 7, Contaminant Fate and Transport.

### 2.4.2 NAPL Testing

#### 2.4.2.1 Introduction

In addition to field screening with the Photovac GC, a number of groundwater samples were tested for NAPL using a hydrophobic dye method. A single soil sample was also tested for NAPL by the dye method.

#### 2.4.2.2 Methods

A soil sample taken from a depth of 0 to 1.3 feet in the overburden at test boring DC-1 was examined for the presence of NAPL using the ultraviolet (UV) fluorescence procedure described by Cohen et.al. (1992).

Approximately 170 g of soil was placed in the inner of two sealable polyethylene bags, and 35 ml of distilled water was added to the inner bag containing the soil sample. The bags were sealed and mixed by hand manipulation for 15 seconds. The bags were reopened and resealed in order to enclose a bagful of air.

The sample was examined using a portable, battery powered, UV fluorescent lamp (Raytech Industries, Vegalume model). The examination was made in the dark by scanning the bag with the

UV light. While under the UV lamp, the bag was manipulated to squeeze the water against the inside of the bag to enhance the possiblity of detecting fluorescence.

Approximately 20 $cm^3$ of sample was transferred from the bag into a 50 ml polypropylene centrifuge tube with a spatula. Twenty ml of distilled water was added to the subsample along with approximately two mg of Sudan IV, a nonvolatile hydrophobic dye that will dye any organic fluid red upon contact. The centrifuge tube was shaken for approximately 30 seconds and examined for the presence of NAPL. Fluorescence in the soil sample would have indicated the presence of NAPL.

Water samples were tested for the presence of NAPL using the hydrophobic dye method only. This was accomplished by placing 40 ml of sample into a 50 ml centrifuge tube, adding approximately two mg of Sudan IV, and shaking the tube vigorously for approximately 30 seconds. The sample was examined for the presence of NAPL. If NAPL was not detected in the sample, two subsamples of approximately 13 ml each were transferred into 15 ml centrifuge tubes and centrifuged on high for one minute. The subsamples were then examined for the presence of NAPL.

#### 2.4.2.3 Results

Fluorescence was not detected in the soil sample tested by the UV fluorescence screening method. The sample also tested negative for NAPL using the hydrophobic dye method. NAPL was not detected in any of the water samples tested by the hydrophobic dye method. The NAPL testing results are summarized in Table 2-3.

### 2.4.3 Special Testing

#### 2.4.3.1 Introduction

"Special Testing" was performed for a variety of purposes, including obtaining real-time results for selected domestic wells and monitoring wells, to screen rock cuttings for evidence of contamination, and to provide information for special purposes (e.g. the Spring Street culvert samples - see below).

Special testing involved testing the following additional samples for VOCs using the field GC:

1) Domestic wells M-2, M-13, M-14 sampled on September 15,1993;
2) DC-2 rock cuttings on September 16,1993;
3) Limited preliminary monitoring well sampling on September 20,1993;
4) Spring Street culvert sediment sampling on September 30,1993;
5) DC-16 rock chips on September 30, 1993; and
6) DC-17 rock chips on October 1, 1993.

The locations from which these samples were obtained, with the exception of location 4, are shown on Figure 3-1 and Plates 1 and 2. Tables summarizing the results of the testing are contained in Appendix H.

### 2.4.3.2 Methods

The aqueous samples were analyzed as described in Section 2.4.1.2. The sediment samples, rock cuttings, and rock chips were analyzed by adding approximately 10 g of sample and 20 ml of distilled water into a 40 ml VOA vial (50-50 headspace/sample). The sample was then shaken vigorously for one minute and allowed to stand in a heated sand bath for four minutes. A 250$\mu$l aliquot of headspace was withdrawn, injected into the GC and analyzed as described in Section 2.4.1.2.

### 2.4.3.3 Results

All three domestic wells sampled on September 15, 1993 and analyzed for VOCs with the field GC, contained detectable concentrations of TCE. The samples from wells M-2 and M-13 exhibited estimated concentrations of 6E and 16E $\mu$g/l, respectively. The sample from well M-14 exhibited a concentration of 34 $\mu$g/l. Refer to Table H-1 in Appendix H for the screening results.

Because the location of cluster DC-2 is just to the north of the spill site, rock cuttings were collected during drilling to screen for health and safety purposes and for the possible presence of NAPL. Three composites of cuttings from five-foot intervals, over a 15 to 20 foot range (15-30', 35-55', and 60-80'), were tested for VOCs (TCE, cis- and trans-1,2 DCE) and NAPL on September 16, 1993. One individual sample was collected from a depth of 21 feet below the ground surface, and analyzed for VOCs. A portion of this sample was included in the 15-30 foot composite (No. 1) that was also tested for VOCs and NAPL. All VOC results were reported at less than 10 $\mu$g/kg with the exception of the Composite 1 sample (15-30') that was reported at an estimated concentration of 26E. All NAPL test results were reported as ND. Refer to Table H-2 in Appendix H for the screening results.

The limited preliminary monitoring well sampling performed at well cluster DC-8 on September 20, 1993, utilized a bailer to collect samples from individual wells in the cluster. This method was utilized to obtain depth-discrete samples and preliminary analytical results at this drilling location. Monitoring wells DC-8A (0-40') and DC-8B (40-60') were dry on September 20th. Wells DC-8C (67-87') and DC-8D (111-131') exhibited non-detectable concentrations at a detection limit of 5 $\mu$g/l. Samples obtained at location DC-9 were obtained from an inflatable packer installed in the original borehole. This allowed depth-discrete samples to also be collected at this drilling location. Samples were obtained from depths of 0-103 feet (the water table was at 83 feet) and 140-160 feet below the ground surface. The results from these two samples were also reported at less than 5 $\mu$g/l. Refer to Table H-3 in Appendix H for the screening results.

Sediment samples were collected from locations upstream and downstream of a culvert that conveys Spring Creek under George Street (Route 147) in the Village of Mumford. These samples were collected in relation to culvert repairs that were being performed by NYSDOT personnel. The field

GC analytical results were reported at less than 10 $\mu$g/kg for both the upstream and downstream samples. Refer to Table H-4 in Appendix H for the screening results.

Rock chips were collected from boring DC-16 at five foot intervals between the depths of 15 and 80 feet below ground surface. These chips were tested for VOCs and NAPL on September 30, 1993. Many of the sample results for VOCs were reported as estimated (E) values and were also noted with an asterisk. This notation indicated that the presence of petroleum hydrocarbons might have yielded false positive results for most of the reported VOCs. The only exceptions to this were the results of between 40 and 60 $\mu$g/kg in the samples obtained from depths of 15, 20 and 25 feet. NAPL was not detected in any of the rock chips from boring DC-16. Rock chips were also collected at five foot intervals from boring DC-17, between depths of five and 75 feet. These chips were tested for VOCs and NAPL on October 1, 1993. Similar results were obtained for VOCs, with the presence of petroleum hydrocarbons impacting the interpretation of many of the results. Exceptions to this situation occurred between depths of 40 to 50 feet and at a depth of 70 feet, where TCE results ranging from 58 to 170 $\mu$g/kg were reported. NAPL was not detected in any of the rock chips from boring DC-17. Refer to Tables H-5 and H-6 in Appendix H for the screening results.

### 2.4.3.4 Conclusions

The field GC test results for the three domestic well (M-2, 13 and 14) samples yielded VOC results (6E to 34 $\mu$g/l) that were comparable to the historical NYSDOH/EPA results for these wells. The NYSDOH/EPA results for 1991-1993 were generally in the 5-70 $\mu$g/l range. The results have also been consistent with the subsequent results obtained during the RI environmental monitoring program conducted from November 1993 to July 1994. These collective results indicate that the field GC testing was indicative of VOC concentrations in the domestic wells that were sampled.

The results of the limited sampling and analyses performed at well cluster locations DC-8 and DC-9 were all reported at less than 5$\mu$g/l. The subsequent results for wells DC-8A and DC-8B are not useful for comparative purposes since these wells were dry in September 1993 and could not be sampled. The results for well DC-8C are apparently not comparable to recent results, whereas those for well DC-8D are comparable (all ND = not detected). The samples collected from DC-9 were collected from two depth-discrete zones within the original borehole. The recent well results cannot, therefore, be expected to correlate exactly with the open borehole results. The results for location DC-9, during drilling, are not entirely comparable to recent results, as follows: the September 1993 field "shallow" (0-103') and "deep" (140-160') GC result is comparable to the November 1993 well DC-9A and DC-9B results (all less than 5 $\mu$g/l). However, the January through July 1994 well DC-9A results are between 16 and 20 $\mu$g/l, making them somewhat inconsistent with the previous ND results. This may be a result of rising water levels and contaminant mobilization from January to April 1994, which appears to be a general trend in the domestic wells and monitoring wells in the area of DC-8 and DC-9 (see Sections 6.4.2 and 6.4.3). The field GC results for the deep zone of boring DC-9 during drilling are generally comparable to the results from wells DC-9B and DC-9C for all four sampling rounds (November 1993 through July 1994).

The screening of rock cuttings and chips was generally successful for its intended purpose. However, the presence of petroleum hydrocarbons in many of the samples interfered with a determination of the presence/absence of VOCs and may have yielded false positive results for some samples.

## 2.5 BOREHOLE LOGGING

### 2.5.1 Introduction

Geophysical and video logging of boreholes provides a continuous record of the character of the rocks and fluids penetrated by a boring. The data are continuously collected by detectors as they slowly pass through a borehole, in either the downhole or uphole direction, or both. A suite of geophysical and video logs was collected and used to assist in the identification of stratigraphic units and in the delineation of potential water-bearing fractures in the subsurface.

### 2.5.2 Methods

Geophysical logging was performed utilizing Century Geophysical Corporation's Ultra-Lite borehole logging system. Two logging tools were used in the deepest boring at each of 15 locations across the Study Area to provide measurements of the variability of borehole diameter and natural gamma radiation. In addition, fluid temperature and resistivity logging was performed at two well cluster locations (DC-4 and DC-8). Neither geophysical nor video logging was performed at DC-15, DC-16, or DC-17 - locations that were added to the drilling program at a late stage. It was decided that subsurface conditions had been adequately characterized by the logging that had already been conducted.

A three-armed caliper tool was used to measure the diameter of the boreholes. Enlarged zones in a borehole usually indicate the presence of fractures or voids (although such openings are not necessarily transmissive). A second tool was used to measure borehole fluid properties and the total natural gamma radiation emitted by rocks surrounding the borehole. Because certain rock types exhibit characteristic ranges of gamma radiation, gamma logs provide lithologic information and are generally used for stratigraphic correlation. Fluid temperature and resistivity probes measure the vertical variation of water temperature and electrical resistance, respectively. Both types of fluid logs can be useful in delineating water-bearing zones in bedrock (Williams and Conger, 1990).

Despite plans to conduct fluid (temperature and resistivity) logging at all clusters, this type of logging was performed only at borings DC-4 and DC-8. The 2-1/2-inch logging tool became stuck while logging the three-inch-diameter corehole at DC-12. The tool was recovered in a damaged condition several days later and was returned to the manufacturer for repairs. The 1-5/8-inch O.D. fluid logging tool (which was originally requested for the project) was still unavailable for rent. Therefore, the fluid logging program, which was providing only marginally useful results, was discontinued with the concurrence of the NYSDEC project manager.

Video logging was performed utilizing a Laval Underground Surveys' borehole video inspection system with a 1-5/8-inch O.D. black and white camera. The logging was performed in the same 15 borings that were geophysically logged. Video images were viewed in real time on a high-resolution monitor and were also recorded on videotape. Real-time observations of borehole conditions were recorded separately by the camera operator using a small audio cassette recorder. Because the primary purpose of video logging was field identification of potential well completion zones, analysis of the data was largely limited to the real-time field observations.

The boreholes received no special preparation (e.g., development) prior to the logging runs, except that the borings in which fluid logging was to be performed were left undisturbed for at least 24 hours. The quiescent period allowed for equilibration of the borehole fluid following the drilling operations. With the exception of DC-11 (discussed below), all geophysical and video logging in the Study Area was conducted in open (uncased) boreholes. Fluid logs were the first logs collected at the two locations where that type of logging was performed. Elsewhere, the three logging tools were utilized in the most convenient and efficient order. Fluid logging was conducted in the downhole direction, while caliper and gamma measurements were made on the trip uphole. Video logging was generally performed in both the uphole and downhole directions. Geophysical logging proceeded at a rate of approximately 20 feet of borehole per minute, whereas video logging was performed at a rate of less than ten feet per minute.

Geophysical and video logs were collected in the deepest boring at each logged cluster. Some logs were run in three-inch-diameter coreholes, whereas others were collected in five-inch-diameter or larger borings. DC-7R was logged to the original total depth of the boring, but the boring was later drilled an additional 15 or so feet deeper. DC-9 was also deepened by more than 20 feet after the logging was performed. The original logged boring at DC-13 was abandoned and relocated approximately 20-25 feet to the north. The new boring was not logged.

The only operational problems (besides the stuck tool at DC-12) were impassable borehole obstructions at DC-4, DC-7, and DC-11. Boring DC-4 was blocked by collapse in the upper Camillus Formation at a depth of 107 feet. The corehole was later reamed out to a depth of 174 feet. The logging tools were again stopped by a borehole collapse (at 167 feet) just below the top of the Syracuse Formation. The bottom 10 feet of boring DC-7 (below 161 feet) were inaccessible due to a collapse in the Syracuse Formation. A collapsed corehole at the base of the Edgecliff member of the Onondaga Formation at DC-11 blocked access by the video camera at a depth of 87 feet. The corehole was later reamed out to a depth of 160 feet but the camera was again stopped by a borehole collapse at 116 feet in the Falkirk member of the Bertie Formation. Gamma logging at DC-11 was conducted to a total depth of 160 feet inside the two-inch I.D. monitoring well. Because of the unstable borehole conditions, caliper logging was not performed at DC-11.

### 2.5.3 Results

#### Gamma Logs

The geophysical logs from boring DC-1 are shown on Figure 2-1. The gamma log is on the left side of the figure; the caliper log is on the right. The vertical axis indicates depth in feet below the ground surface. The stratigraphic terms (geologic units) along the left side of the gamma log are based on the analysis of the bedrock core retrieved at location DC-1. The horizontal axis is a scale of the intensity of gamma radiation; higher radiation is plotted to the right. The gamma curve "wraps" - that is, the large gamma response ("kick") at 48 feet goes off scale to the right and is plotted on the left side of the log. The magnitude of the response at 48 feet is 250 API gamma ray units, or simply 250 units.

The likely sources of natural gamma radiation are the radioisotopes potassium-40 and the daughter products of the uranium- and thorium-decay series. Potassium is abundant in some types of feldspar and mica that decompose to clay. Uranium and thorium are also concentrated in clay minerals by adsorption and ion exchange processes. Rocks with high clay content, such as shales, or clay-rich zones in rock (such as clay-filled fractures or shaly partings) will generate a large gamma response. Coal, limestone and dolomite are usually less radioactive than shale. However, all of these rocks can contain deposits of uranium and be quite radioactive (Keys, 1989).

The gamma log recorded at boring DC-1 has several distinctive features that consistently appear, with some variability, in all of the gamma logs. Low and relatively uniform radiation levels characterize the Nedrow and Clarence limestone members of the Onondaga Formation. The large gamma kick at 48 feet always occurs somewhere in the Edgecliff member. In core DC-1, the kick marks the top of a dark gray argillaceous (shaly) zone in the lighter gray limestone.

A moderately-high gamma zone of variable thickness (at a depth of 57 feet in DC-1) always occurs below the Edgecliff limestone. This zone is generally in the Bois Blanc Formation (which contains two, two-inch-thick shale layers at DC-1) and the Scajaquada member of the Bertie Formation. The nine-foot separation between the two high-gamma zones in Figure 2-1 (at 48 and 57 feet) supports the existence of an unconformity below the Bois Blanc. The same two gamma peaks are 19 feet apart (at 18 and 37 feet) at location DC-8. Refer to Figure 2-2 for the geophysical logs for boring DC-8. The thicker section includes the Akron Formation and the Williamsville member of the Bertie Formation (both of which are missing at DC-1), and a thicker Scajaquada member.

The lower 30 or so feet of the Bertie Formation (Falkirk member) is a dolomite and is characterized by uniformly low gamma radiation levels comparable to those in the Nedrow and Clarence limestones. Below the Falkirk, a large increase in gamma radiation marks the top of the Camillus Formation at all locations. The relatively low gamma zone at 99 feet in Figure 2-1, and at 77 feet in Figure 2-2, also appears in all the logs at roughly the same depth (10 ± feet) below the top of the Camillus. The moderate to high variability of gamma radiation with depth in the Camillus illustrates the effect of changing proportions of shale and dolomite. The gamma signature at the top of the Syracuse Formation is less pronounced than that at the top of the overlying Camillus (Figure 2-1).

The gamma logs recorded at borings DC-1, DC-4, DC-7, DC-8, DC-11, and DC-12 were each correlated with the respective bedrock core. After establishing the gamma/lithological correlations, the stratigraphy at nine of the non-cored borings was interpreted from the gamma logs recorded at those locations. In this manner, a working knowledge of the stratigraphic framework of the Study Area was developed. The interpreted stratigraphy is annotated on the geophysical logs for borings DC-2, DC-3, DC-5, DC-6, DC-7R, DC-9, DC-10, DC-13, and DC-14. All annotated geophysical logs (except DC-1 and DC-8) are shown in Appendix I.

## Caliper Logs

The caliper log for boring DC-1 is plotted on the right side of Figure 2-1. This type of log provides a continuous record of borehole diameter with depth. The average borehole diameter of 5.6 inches is apparent in the upper 108 feet of the log. The spikes ("breaks") on the log (for example, at 11, 21, and 34 feet) indicate borehole enlargement at those depths. Such an enlargement typically indicates that the boring has intercepted one or more fractures, either dipping or horizontal, in the bedrock. Analysis of all of the caliper logs suggests that many of the caliper breaks in the Onondaga and Bertie Formations may be correlated from hole to hole. The regional occurrence implies that the correlative breaks represent bedding plane fractures.

Although a spike on a caliper log does not imply that a fracture is transmissive, the general competence and relative hydraulic permeability of the bedrock can often be quickly assessed by visual examination of the log. For example, in Figure 2-1, the 20-foot interval from 59 feet to 79 feet (Falkirk member) appears to be unfractured, and is likely to be less permeable than other intervals in the same borehole. The caliper response is dramatically different in the interval between 108 feet and 154 feet (middle to lower Camillus). The log indicates that this interval is heavily fractured/broken, and is likely to have very high secondary permeability. The aquifer (hydraulic conductivity) test results (Section 2.7) generally confirm the usefulness of caliper logs for assessing the relative permeability of stratigraphic intervals in a borehole.

The caliper log shows a marked change in the competence of the borehole at the top of the Syracuse Formation (154 feet). While the Camillus - Syracuse contact had a subdued effect on the gamma log in boring DC-1, the caliper response at the same contact is dramatic. Also note the presence of a void at the base of the Camillus in boring DC-8, as revealed by the caliper log (Figure 2-2).

## Fluid Logs

Fluid logging in boring DC-4 detected a seven-foot-thick layer of warmer, more resistive water overlying colder, more conductive water. The contact between the two water masses was at a depth of 63 feet; static water level was at 56 feet. The geophysical logs through the deeper water mass were essentially invariant, consistent with field parameters measured during subsequent sampling rounds. The anomaly at the contact of the two water masses is coincident with several horizontal and dipping fractures intersected by the boring. These fractures may be conducting water away from the borehole, consistent with the known head relationships at cluster DC-4 (see Section 5.3.2.1). The high resistivity (20 ohm-meters) of the shallow layer is puzzling as it is more than twice the values measured in water samples subsequently collected from wells at the cluster. The electrical properties of the water may have been altered by the drilling process, or by the drilling fluid, and had not yet returned to normal.

The fluid logs from boring DC-8 were nearly featureless. A small positive temperature anomaly was detected in the interval between 120 and 125 feet, in a void in the Camillus. Resistivity throughout the water column was in the range of 12 to 13 ohm-meters, typical of water samples subsequently collected in the upper Camillus. Although water produced by the lower Camillus has a significantly lower resistivity (seven ohm-meters in water samples), there is no evidence of this water "type" on the resistivity log. The absence of low resistivity groundwater may indicate that water entered the uncased boring in the upper Camillus, flowed downward and exited through the void at the base of the boring. Downward flow through an open boring in the Camillus is consistent with the observed head distributions at cluster DC-8 (see Section 5.3.2.2).

Despite the known abundance of fractures penetrated by the two logged borings, only two appear to have created detectable fluid anomalies. Sufficient vertical flow may have occurred in the open borings to result in well-mixed, homogeneous, anomaly-free water columns.

### Video Logs

The video footage was extremely useful in that it provided a permanent visual record of borehole conditions at 15 locations. Observed features included bedding plane fractures, dipping fractures, stratigraphic contacts, perched water inflow, water inflow below the static water level, "rubbleized" bedrock zones, and voids. Examination of the video data was largely performed in "real time" in the field in order to determine well completion zones. More-detailed analysis of the video tapes would almost certainly reveal features of the bedrock that were not noted during the field effort. Such an analysis may be useful during later phases of the project.

Video logging was conducted in smooth-walled coreholes at DC-1, DC-4, and DC-11, and in borings that were drilled with an air hammer at all other clusters. DC-4 and DC-11 were video-logged as coreholes and also as reamed (air-hammered) borings. Subtle features, such as narrow dipping fractures, were commonly seen in coreholes (most often in the Falkirk member), but were less often recognizable in air-hammered borings. It was also possible to identify small-aperture fractures on the video log that produced no response on the caliper logs, regardless of the drilling method. Water clarity in most borings was excellent, even, at a few locations, within hours of the completion of drilling. Turbid water was a persistent problem in only two borings: in the lower Camillus at DC-2, and throughout the water column at DC-8, also Camillus.

Video observations for each logged boring are summarized along the right side of the respective geophysical log. The logs for well clusters DC-1 and DC-8 are shown as Figures 2-1 and 2-2, respectively. The remaining logs are presented in Appendix I. The video logs for borings DC-1 and DC-4 were studied in greater detail in order to prepare Section 4.2.5 of this report. This attention to the subtle features of the borehole walls is reflected in the abundant notation on the video logs for DC-1 (Figure 2-1) and DC-4 (Appendix I). Note the slight depth discrepancy between spikes on the caliper log and fractures identified using the video camera. The video features are offset to a slightly shallower depth compared to the same feature detected by the caliper tool. The offset is more apparent at depths greater than 100 feet. The depth shown on the caliper log is correct.

### 2.5.4 Conclusions

A suite of geophysical and video logs was used to assist in the identification of stratigraphic units and in the delineation of potential water-bearing fractures in the subsurface. While the gamma, caliper, and video logs were extremely useful in characterizing subsurface conditions, the fluid (temperature and resistivity) logs proved to be less useful. Fluid logging, therefore, was terminated early in the logging program. Together with the bedrock coring program and the previous surface geophysical surveys, the logs provided a basis for defining the stratigraphic and structural framework of the Study Area. In addition, the selection of well completion depths was strongly influenced by the geophysical and video information.

## 2.6 MONITORING WELL INSTALLATION AND DEVELOPMENT

### 2.6.1 Introduction

As indicated in Section 2.3, 14 locations were originally identified for the drilling of test borings and the installation of monitoring wells. It was recognized that multiple well completions would probably be necessary at all drilling locations due to geologic and topographic conditions, stratigraphy, variable water quality and contaminant plume locations (both areally as well as vertically), and the expansiveness of the Study Area. For these reasons, it was originally planned to install between two and four wells at each location. As a result of conditions encountered while drilling the deepest test boring at each of the final 18 locations, well clusters eventually consisted of from a single well at locations DC-7, DC-16, up to four wells at locations DC-1 through 6, DC-7R, 8, 10 and 12.

Monitoring well installation depths were determined by reviewing the stratigraphy identified from the core logs and the downhole logging, which consisted of both multi-faceted geophysical logging and borehole video camera logging; real time field analytical results; historical analytical results from nearby contaminated domestic wells; and the desire to monitor a significant portion of the vertical stratigraphic interval, including a potential "clean" zone both above and below the contamination, if present, throughout the Study Area.

### 2.6.2 Monitoring Well Installation

#### 2.6.2.1 Methods

Monitoring well installation was initiated on August 4, 1993 and completed on October 27, 1993. Fifty-five wells were installed at 18 locations, as either open hole wells or using stainless steel (SS) and/or polyvinyl chloride (PVC) well construction materials (well screens and risers).

The shallowest well at each location is an open-hole completion, with the exception of the shallow wells at locations DC-9A, DC-11A, DC-13A, DC-14A and DC-17A. These wells consist of standard screened construction as discussed below. Open-hole completion wells were constructed by installing a four or five inch I.D. steel surface casing into a seven-inch diameter socket advanced five feet into the bedrock. The surface casings have an integral locking cap and serve as protective casings for the wells. A minimum two-foot-thick bentonite seal (pellets or slurry) was emplaced in the annular space around the bottom of the casing. The casing was then grouted to the surface by filling the remaining annular space with cement bentonite grout. The grout was allowed to set a minimum of 24 hours before resuming drilling. Wells DC-1A through DC-8A, DC-10A through DC-12A, and DC-15A were then drilled to a predetermined depth utilizing a four or five-inch diameter downhole hammer. Open holes DC-7 and DC-16 were originally overdrilled, and then backfilled with gravel and sand to within seven feet of the target depth. A five-foot-thick bentonite pellet seal was then emplaced and a two-to five-foot-thick sand pack was installed on top of the seal to complete the well at the desired depth.

During the drilling program, water samples were collected and analyzed as previously discussed in Section 2.4. At locations where analytical results exceeded approximately one part per million (ppm) = 1,000 part per billion (ppb), stainless steel screens and risers were used. This method of construction was selected for these locations in order to avoid possible chemical degradation of the PVC by relatively high concentrations of contaminants.

All of the wells, with the exception of well DC-17A, were installed through a temporary or permanent casing set at least two-feet into rock. The monitoring wells are constructed of 2-inch I.D. Schedule 40, threaded, flush joint, SS and/or PVC riser pipe, and manufactured, No. 20 slot (0.020 inch) well screens. All screened wells were installed in boreholes with a minimum five inch diameter. The screens are twenty feet in length with the exception of DC-7D and DC-13A, where the screen lengths are fourteen and fifteen feet, respectively. All well screens are equipped with threaded bottom plugs and vented caps. Well DC-17A has a 20 foot SS screen and a combination of SS and PVC riser, however, there is no sand pack or bentonite seal to screen a discrete zone. This method of well construction was selected for this location due to the fractured and unstable nature of the borehole wall. Installation of a well screen at this location will preserve access and allow aqueous sampling to be conducted even in the event of formation collapse.

Well screens and risers were stored in factory-supplied plastic wrappers and steam cleaned just prior to installation at each location. The sand pack material was introduced gradually in the annular space between the drill casing and the monitoring well screen. The drill casing was then removed gradually to allow the pack to fill the space between the screen and the borehole wall. The sand packs around each well screen extend from six inches below the screen to approximately two feet above the top of the screen. The sand pack consists of Morie grain size #0 washed, graded, silica sand. In addition, a six inch thick sand "choke" (i.e. finer grade sand), Morie grain size #00, was placed on top of the sand pack. A minimum two-foot-thick bentonite seal was then placed on top of the sand choke.

Due to the highly fractured nature of the Clarence member of the Onondaga Formation, a bentonite slurry was tremied up the surface casing in each open hole well rather than using a cement-bentonite mix. This was done to prevent the cement/bentonite grout from migrating through the fractures and possibly entering the open hole well and raising the pH of the well water.

Well construction was completed by tremie grouting a cement/bentonite mixture up to ground surface. Well construction details are presented on Table 2-4A (open hole wells) and 2-4B (screened wells). Well completion logs are presented in Appendix J.

Additionally, at location DC-lD and at well cluster DC-12, steel protective pipes were installed to prevent possible damage by motor vehicles. This was accomplished by installing five foot lengths of 4-inch O.D. steel pipe two feet into the ground and filling the annulus and the pipes with concrete.

### 2.6.3 Monitoring Well Development

#### 2.6.3.1 Introduction

Monitoring wells are generally developed following their installation, in order to remove residual drilling fluids and sediment; to clean and stabilize the packing material; to improve the hydraulic properties of, and the communication between, the pack and the natural formation material; and to reduce the well water turbidity for sampling purposes. Well development methods can include simply bailing, surging and bailing, pumping and air-lift methods, or a combination of any of these methods.

The monitoring wells for this project consisted of two general types; open hole, and screened with a sand pack. The open hole wells extended through strata containing extensive fractures, mud or clay seams, and zones of different rock types and competence. Some of thse features were located both above and below the water table. These wells were developed to remove residual drilling fluids and sediment, to remove small fractured pieces of rock and the mud/clay that could easily be disloged from the borehole wall, and to reduce the turbidity of the water to 50 Nephelometric Turbidity Units (NTU) or less, where reasonably possible. The screened/packed wells were developed to remove residual drilling fluids and sediment, to clean and stabilize the packing material, and to reduce the turbidity of the water to 50 NTU or less. Because these wells were screened in rock, very little could be done to the borehole walls to enhance the hydraulic communication with the pack other than to remove loose mud or clay from fractures or seams in the rock.

#### 2.6.3.2 Methods

Well development was performed from October 26 to October 29, 1993. Development was performed by raising and lowering an operating Grundfos submersible pump through thescreened interval of constructed wells and throughout the water column in open hole wells. Field parameters including temperature, pH, specific conductivity, and turbidity were measured and recorded for every well volume removed from each well. Field parameters measured during development are presented in Appendix K.

Based on the GC field screening results, development water from wells DC-1A, DC-1B, DC-1C, DC-1D, DC-5A, DC-5B, DC-6A, DC-6B, DC-9C, DC-17A and DC-17B was containerized in 55 gallon drums. Drums containing development water from clusters DC-1 and DC-17 were labeled and transported to the fenced drum storage area. Drums from the other five wells were transported to the spill site and discharged onto the ground surface in accordance with NYSDEC's direction. All equipment utilized for well development was steam cleaned prior to use at each well and prior to leaving the Site.

#### 2.6.3.3 Results

Thirty-six wells were fully developed, nine partially developed (wells went dry before 50 NTU or the five well volume threshold was attained) and ten wells were dry during the development period. The target turbidity of less than 50 NTUs was reached at 33 of the 36 fully developed wells. The turbidity at DC-3B, DC-3C and DC-13A remained above 200 NTUs through the development process. Wells DC-2B, DC-2C, DC-4A, DC-4B, DC-5A, DC-6B, DC-7, DC-8C and DC-15A were all pumped dry before 50 NTUs or five well volumes was reached. Wells DC-1A, DC-3A, DC-6A, DC-7RA, DC-8A, DC-8B, DC-9A, DC-10A, DC-12A and DC-16 were dry during the period of development.

#### 2.6.3.4 Conclusions

The prime COC at the Site are VOCs and cyanide. It has been demonstrated that analytical results for VOCs are not adversely affected by elevated turbidity values in a sample. The analytical method for cyanide, the only target compound that is not a VOC, is also not adversely affected by elevated turbidity values. As such, the analytical results for samples collected from wells in which the turbidity values remained greater than 50 NTU have not been affected with respect to data quality and usability. Therefore, the well development process was performed in a manner that would not compromise the quality of the analytical results.

## 2.7 AQUIFER TESTING

### 2.7.1 Introduction

Aquifer [hydraulic conductivity or (K)] tests were conducted on all monitoring wells to evaluate the hydraulic properties of the various bedrock units and zones penetrated by the test borings and screened by the monitoring wells. The aquifer tests were performed by a DUNN hydrogeologist from December 13 to December 17, 1993, and April 4 to April 5, 1994. The April testing was confined to those shallow wells that were either dry in December or had too little water to provide reliable results.

The objective of the aquifer tests was to provide estimates of in-situ permeability values. These data were used to assess, in relative terms, the capacity of various stratigraphic units to effectively transmit groundwater (and contaminants) across the Study Area.

### 2.7.2 Methods

The hydraulic conductivity tests were conducted by injecting each well with a "slug" of one or more gallons of distilled water and observing the recovery of the water level to static conditions. Water level recovery was measured using a 10 psi pressure transducer set three to four feet below the static water level. The water level data were recorded with an In-Situ Inc. Hermit Model SE 1000 C data logger. Interpretation of water level versus time data from the hydraulic conductivity tests was performed using the Hvorslev method (Hvorslev, 1951), and the Bouwer and Rice method (Bouwer and Rice, 1976). The Hvorslev method assumes that a plot of recovery data (H-h) follows an exponential decline in recovery rate with time. If normalized to H-Ho, recovery data follows a straight line on semi-log paper. The horizontal hydraulic conductivity is then calculated as follows:

$$K = r^2 \ln(L/R/2LT_0)$$

where:

$r$ = radius of well riser
$L$ = well screen length
$R$ = radius of well screen
$T_0$ = basic time lag

The basic time lag ($T_0$) is found from the straight-line fit to recovery data and is the time at which $H\text{-}h/H\text{-}H_0 = 0.37$ (37%). The computer program used to calculate hydraulic conductivity by this method utilizes linear regression techniques applied to the recovery data after logarithmic transformation:

$$\ln (H\text{-}h/H\text{-}H_0) = b_0+b_1t$$

where:

$H$ = head at equilibrium
$h$ = head at a some time (t)
$H_0$ = head at t=O
$b_0$ = y intercept
$b_1$ = slope
$t$ = time

This methodology results in a calculation of a "best fit" straight line to the recovery data. The slope ($b_1$) and y-intercept ($b_0$) can be used to find $T_0$ and K. The accuracy of fit can be assessed using the R-squared (coefficient of determination) and residuals.

The Hvorslev method assumes that the aquifer tested is unconfined, homogeneous and isotropic. This method is most appropriate for shallow wells cased in clean sands below the water table, but also provides reasonable results for semi-confined bedrock aquifers.

Hydraulic conductivity was also calculated using the Bouwer and Rice Method. The Bouwer and Rice method is based on Thiems' equation of steady state flow to a well. The technique is applicable to fully or partially penetrating wells in unconfined aquifers, but it can also be used for semi-confined bedrock aquifers.

The method of K-test analysis developed by Bouwer and Rice utilizes the following equation for estimating hydraulic conductivity.

$$K=[r_c+2\ \ln(R_e/r_w)/2L][1/t][\ln(y_o/y_t)]$$

where:

| | |
|---|---|
| $r_c$ | inside radius of the casing |
| $R_e$ | the effective radius over which y is dissipated |
| $r_w$ | the horizontal distance from well center to undisturbed aquifer |
| $L$ | length of well screen or saturated open hole |
| $t$ | time since $h_o$ |
| $y_o$ | head at $t=O$ |
| $y_t$ | head at some time (t) |

The Bouwer and Rice method also assumes a straight line relationship between a plot of recovery data ($\ln y_t$) versus time (t). The computer program used to calculate horizontal hydraulic conductivity by this method utilizes linear regression techniques applied to the recovery data after logarithmic transformation as described above.

### 2.7.3 Results

A summary of hydraulic conductivity test results is presented in Table 2-5. Data entry forms with water level response graphs are presented in Appendix L. Complete test results for each well are available to the Department upon request. The results indicate that the average horizontal hydraulic conductivity for all bedrock units ranged over four orders of magnitude, from $1.6 \times 10^{-6}$ cm/sec in well DC-4A to $4.8 \times 10^{-2}$ cm/sec in well DC-13B. Refer to Section 5.4 for discussions of the K-test results as they relate to the hydrogeology of the Study Area.

### 2.7.4 Conclusions

The aquifer tests provided useful estimates of in-situ hydraulic conductivity across the Study Area. The results were utilized to evaluate the potential and relative permeability of various bedrock strata or intervals, and to identify potential preferential groundwater flow zones and contaminant migration pathways in the bedrock. The data were also considered during the identification of potential remedial technologies and preliminary screening of alternatives performed during the Feasibility Study portion of the project.

# 3.0 ENVIRONMENTAL MONITORING

## 3.1 ROUTINE MONITORING

### 3.1.1 Introduction

DUNN implemented a comprehensive environmental monitoring program during Phase C of the Remedial Investigation, which was conducted over a 12-month period from July 1993 to July 1994. This program was designed to monitor certain environmental conditions at the spill site and over the entire Study Area in order to gather information and data on the location and behavior of the compounds of concern (COC), under current conditions, on a date-specific basis, and a long term, seasonal basis. The program consisted of establishing and sampling various monitoring points that would provide information relevant to:

- the nature and behavior of the hydrogeologic system,
- the transport and fate of the COC within the system,
- a Habitat Based Assessment (Fish and Wildlife Impact Analysis),
- a Health Risk Assessment (Human Health Evaluation), and
- the performance of the Feasibility Study.

The program included water level monitoring points (wells and staff gages), rain gages and sampling points (monitoring wells, domestic wells, and environmental locations such as streams, springs and ponds). The program drew upon the results of the previous RI investigations, and expanded the initial scope to establish a monitoring network that would allow the investigators (the Department and DUNN) to monitor current conditions at the spill site and within the Study Area. Refer to Plate 2 (in pocket) for the locations of all monitoring points included in the program.

To initiate the program, additional baseline sampling was performed in July 1993. This sampling event was designated as Round 1 of Phase C of the RI, and involved the collection of samples (water, sediment) from environmental sampling locations such as streams, springs and ponds. No domestic wells were sampled at this time since many wells had recently (June 1993) been sampled under the Lehigh Valley RR O&M Project, and such information was available to both the Department and DUNN. In addition, since the drilling and monitoring well installation program did not commence until later in the month, there were no monitoring wells in place from which to obtain samples for chemical analysis during Round 1.

Rounds 2 through 5 of the monitoring program were conducted in November 1993, and January, April, and July 1994. These rounds consisted of the collection of water level data from staff gages and monitoring wells, and collection of samples from the 55 newly installed monitoring wells, as well as from domestic wells and environmental locations. Each round included the complete set of monitoring wells (unless the well was dry), selected domestic wells and a variety of environmental locations. Not all of the same domestic wells or environmental sampling locations were sampled during each round; however, certain locations were repeated to monitor baseline and changing conditions, over time, throughout the Study Area. The variable locations were selected on the basis of and to confirm previous results, to expand the investigators' knowledge and understanding of the environmental conditions within the Study Area, to monitor seasonal conditions and changes, to fill data gaps, and to take advantage of newly discovered monitoring points. Examples of new monitoring points included the clay seam at the horizon of the apparent unconformity between rocks of Silurian and Devonian age (SED-3, sampled during Round 5 - July 1994) and two short-lived seasonal springs sampled during Round 4 - April 1994 (SPR-21 and 26). The clay seam is located in the rock cliff beneath the falls in Mud Creek, and the seasonal springs are in the flat area between the two east-west Genesee and Wyoming railroad lines [one active (southern) and one abandoned (northern)] that cross Spring Street just to the north of MacKay Park in the Village of Caledonia (see Plate 2).

The following subsections describe the routine monitoring program conducted at each of the three types of monitoring locations (monitoring well clusters, domestic wells and environmental locations) during the period from July 1993 to July 1994 (Rounds 1 through 5).

### 3.1.2 Well Cluster Sampling

A monitoring well sampling plan was developed in conjunction with environmental and domestic well sampling, to investigate the areal and vertical extent of DNAPL (if present) and the dissolved phase contaminant plume. Wells were installed at 18 locations: one to establish "background" conditions; seven to investigate the possible presence of DNAPL; and nine to investigate the dissolved phase plume. Refer to Plate 2 (in pocket) for a map of all well cluster sampling locations. At 16 of the 18 locations, multiple wells (two to four), or a well cluster, was installed. At the remaining two locations (DC-7 and DC-16), an individual well was installed. These wells monitor different strata to help define migration pathways, vertical hydraulic gradients within and between well clusters, and to determine the areal and vertical distribution and extent of contamination. The seasonal variability of water levels and contaminant concentrations were also assessed by conducting sampling on a quarterly basis during a period of eight months commencing in November 1993 and ending in July 1994.

#### 3.1.2.1 Sampling Locations and Methods

During the period from November 1993 to July 1994, a total of 55 monitoring wells were sampled up to four times each. Since some of the "A" (generally open-hole) and "B" wells were dry during some sampling rounds, not all of the monitoring wells could be sampled four times. While most wells were sampled for VOCs only, some locations, primarily in the vicinity of Mud Creek, were also sampled for cyanide.

Prior to sampling the monitoring wells during each round, a complete set of water level readings was obtained across the entire monitoring well network in as short a time period as possible. An additional set of water levels was taken upon arrival at each cluster prior to purging the wells for sampling. The volume of water in each well was then calculated and each well was evacuated a minimum of three well volumes or until dry. Field parameters, including temperature, pH, specific conductivity and turbidity, were recorded at the end of purging during Round 2 (November 1993).

At the request of the NYSDEC, field parameters were recorded for each well volume removed during purging for all subsequent sampling rounds. Field parameters for each round are presented in Appendix M.

All purging was performed using well-dedicated WaTerra polyethylene tubing equipped with one-way check valves. All sampling for cyanide was performed through the WaTerra tubing. VOC sampling was performed with well-dedicated PVC bottom filling bailers and/or WaTerra tubing. Round 2 (November 1993) VOC samples were collected with PVC bailers only. Round 3 (January 1994) VOC samples were collected with PVC bailers at all locations, while duplicate samples were collected with WaTerra tubing at selected locations to test the comparability of results using the two sampling devices. Refer to Appendix N for details of the WaTerra/bailer sampling study and the results of the study. On the basis of the analytical results from Round 3, and with NYSDEC's concurrence, either PVC bailers or WaTerra tubing were used to collect VOC samples at selected locations during Rounds 4 and 5. The decision as to whether to sample a well with the WaTerra system or the bailer was based on a threshold of 20 ppb of TCE, with those wells previously exhibiting levels of TCE above the threshold to be sampled by the WaTerra method and those below to be sampled by bailer. All samples were labeled and handled in accordance with the protocol outlined in the QAPjP.

Based on field GC screening and laboratory analytical results, the purge water from some wells was temporarily stored in drums and then transported to location DC-1 for storage or discharge on the ground surface, per NYSDEC direction. For each sampling round, the following summary identifies the wells that could not be sampled because they were dry, the wells for which the purge water was drummed, and the well clusters at which cyanide sampling was performed.

**Round 2 - November 1993**

- Dry wells: DC-6A, DC-7RA, DC-8B and DC-10A.
- Purge water drummed at wells: DC-5A, DC-5B, DC-6A, DC-6B, DC-9C, DC-17A and DC-17B.
- Cyanide sampling at well clusters: DC-1, DC-2, DC-3, DC-4, DC-5, DC-6 (except DC-6A due to dry well), DC-15, DC-16 and DC-17.

**Round 3 - January 1994**

- Dry well: DC-8B.
- Purge water drummed at wells: DC-6A, DC-6B, DC-7RA, DC-7RB, DC-7RC, DC-17A and DC-17B.
- Cyanide sampling at wells: DC-1A, DC-1B, DC-2A, DC-2B, DC-5A through 5D, DC-6A, DC-6B and DC-15A.

Round 4 - April 1994

- No dry wells.
- Purge water drummed at wells: DC-3B, DC-6A, DC-6B, DC-7RA, DC-7RB, DC-7RC, DC-17A and DC-17B.
- Cyanide sampling at wells: DC-1A, DC-1B, DC-2A, DC-5A, DC-5B, DC-6A, DC-6B, DC-15A, and DC-16A.

Round 5 - July 1994

- Dry wells: DC-8B and DC-10A.
- Purge water drummed at wells: DC-2B, DC-2D, DC-3C, DC-6A, DC-6B, DC-7RA, DC-7RB, DC-7RC, DC-8C, DC-17A and DC-17B.
- Cyanide sampling at wells: DC-1A, DC-4A, DC-5A, DC-5B, DC-15A, and DC-15B.

### 3.1.3 Environmental Sampling

A comprehensive environmental sampling program was implemented as part of the RI. An initial abbreviated "round" of environmental sampling was conducted in December 1992. Refer to DUNN's report entitled Domestic Well and Initial Environmental Sampling Report dated May 1993 for the results of this round of sampling. Subsequent sampling rounds, as reported herein, further investigated and expanded upon those earlier results. An additional abbreviated round of sampling was performed in July 1993 (Round 1). Following completion of the installation of the monitoring wells in October 1993, more complete rounds of environmental sampling were performed in November 1993 (Round 2), and in January, April, and July 1994 (Rounds 3, 4 and 5). The environmental sampling locations are indicated on Plate 2. Many of the proposed surface water and spring locations were sampled only once (in April 1994), because of dry conditions during the other four sampling rounds.

Surface water and sediment samples were collected from streams, springs, and ponds in the Study Area. Much of the sampling was concentrated in the vicinity of Mud and Spring Creeks, but several locations were sampled in the region between the two creeks. Samples from the Mud Creek area were analyzed either for VOCs alone or for VOCs and cyanide; all other samples were analyzed for VOCs only. The surface water and spring samples were collected to determine existing surface water quality at selected locations within the Study Area, to locate possible discharge points for contaminated groundwater, and to establish, if possible, a pattern of groundwater/surface water flow and contaminant migration pathways. A few additional sediment samples were collected to confirm specific analytical results from the December 1992 environmental sampling round.

### 3.1.3.1 Sampling Locations and Methods

A total of 11 surface water locations were sampled within the Study Area [SWFH-1, SW-2, SW-6B and SW-6C, SW-14, SW-15, SW-16, SW-17 and SW-23, and SPR-22 and SPR-25 (see below)]. Many of these samples were collected in the vicinity of Mud Creek and Spring Creek. SW-17 was collected from a pipe from the Dolomite Products Co. quarry and does not represent natural surface water flow. The sample is, however, representative of natural surface water and groundwater that has seeped into the quarry. Two other samples that were designated as SPR-22 and SPR-25 are actually surface water samples collected from a sinking stream south of Route 5 and a drainage channel near the Caledonia Fairgrounds, respectively. In some instances, these and others were "samples of opportunity" since many of the planned locations were dry most of the year and other unplanned locations (SPR-21 and SPR-26) were discovered in the spring of the year (April 1994).

A total of 13 springs were sampled during the sampling program (SPR-3, SPR-4, SPR-7, SPR-11, SPR-12, SPR-18, SPR-19, SPR-19A, SPR-20, SPR-20A, SPR-21, SPR-L23S, SPR-24 and SPR-26). Although two additional samples were labeled as springs (SPR-22 and SPR-25), these samples were actually collected from flowing surface water locations and have been included in the previous discussion of surface water samples. Samples SPR-3, SPR-4, and SPR-7, SPR-20, and SPR-20A were collected from springs located in the Mud Creek valley at and north of Mud Creek falls. Samples SPR-11, SPR-12, SPR-18, SPR-21, SPR-26 and SPR-L23S were collected at springs that discharge either directly or indirectly to Spring Creek. Sample SPR-13 was collected from a bedding plane spring (seep) in the quarry face north of the Site. Samples SPR-19 and SPR-19A, and SPR-20 and SPR-20A, were collected at locations very close to each other, due to changing water conditions on a seasonal basis. Samples SPR-19 and SPR-19A are considered to represent water from the same source, whereas samples SPR-20 and SPR-20A are suspected of representing two different sources.

A total of nine sediment samples were collected during the sampling program (SED-2, SED-3, SED-6A, SED-6B, SED-14A, SED-14B, SED-14C, SED-14D, and SED-15). SED-2 was collected from the "swallet" or pond located in the valley of Mud Creek north of the Lehigh Valley Railroad mainline railroad bed. SED-3 was collected from a mud seam in the rock face located beneath the Mud Creek falls. The SED-6A and SED-6B samples were collected from two different locations in the pond in the Mud Creek valley below (north of) the falls. Four sediment samples (SED-14A, B, C and D) were collected from a pond near the north end of Spring Creek, behind (north of) the Genesee Country Inn.

Sampling was performed in accordance with the QAPjP. Water samples were collected with a dipper and transferred to the sample bottles, or by direct submersion of the sample bottles. Water samples collected in November 1993 were measured for temperature, pH, and specific conductance at the time of collection. Field parameters were not measured during subsequent sampling rounds.

The sediment samples were obtained with stainless-steel hand auger, from depths of zero to six inches and 12 to 18 inches into the sediment. The sediment was transferred from the auger into a stainless-steel mixing bowl, briefly composited with a hand trowel, and placed in appropriate sample jars.

All samples were preserved, as necessary, and shipped to the analytical laboratory in chilled coolers with trip blanks, if appropriate, via overnight courier under appropriate chain-of-custody procedures.

### 3.1.4 Domestic Well Sampling

In order to provide a more complete picture of the present distribution of contaminated groundwater in the Study Area, selected residential and commercial wells (collectively referred to as domestic wells) were sampled during the RI. Refer to Figure 3-1 for a map of all domestic well sampling locations, and to Appendix B for the NYSDOH well designation and reported depths of the sampled wells. The sampling dates and analytical results for each well, and the presence or absence of a point-of-entry (GAC) system, are also indicated on the tables in Appendix B.

Each selected well is close to one of the monitoring well clusters installed during the field investigation. The monitoring wells and the nearby domestic wells were intentionally sampled at the same time or within a few days of each other. This allowed an assessment to be made as to which strata may be conveying contaminated groundwater, if any, in the vicinity of a domestic well, and also provided an indication of the variability of contaminant concentrations across relatively small geographic areas. The seasonal variability of contaminant levels was also assessed at many of the domestic well locations.

#### 3.1.4.1 Sampling Locations and Methods

During the period from November 1993 through July 1994, a total of 24 domestic wells in Genesee, Livingston and Monroe County were sampled up to four times each. An assessment of locations, past results, seasonal variations, NYSDOH sampling schedule and project needs, resulted in sampling of a slightly different group of domestic wells during each round. As such, not all wells were sampled during each round, but were sampled anywhere from one to four times during the sampling program. While most wells were sampled for VOCs only, a few wells were sampled for VOCs and cyanide.

Sampling was performed in accordance with the QAPjP. At homes equipped with GAC systems, samples were generally withdrawn from a port before the prefilter. If there was no port before the prefilter, the port between the prefilter and the GAC unit was used for sampling. At homes without water treatment systems, samples were generally collected at points prior to line filter, or prior to entry into pressure and/or hot water tanks. Occasionally, cold water samples were drawn from a faucet because more desirable sampling locations were inaccessible. The samples were collected after purging five gallons of water at the sampling point. Purging was not performed on occasions when a shower, washing machine or dishwasher was in use at the time of sampling. All samples were preserved, as necessary, and shipped with trip blanks to the analytical laboratory in chilled coolers via overnight courier under appropriate chain-of-custody procedures.

## 3.2 WATER LEVEL MONITORING

### 3.2.1 Introduction

Water levels were measured in all of the newly installed monitoring wells during the period from November 1993 to September 1994. The water level monitoring was performed to provide an indication of groundwater flow direction and to calculate vertical hydraulic gradients between wells, i.e. within the hydrogeologic system. A complete round of water levels was initially collected during the first comprehensive quarterly sampling event (November 1993). However, a review of water levels collected during hydraulic conductivity testing in December 1993 indicated the need to collect data on a more frequent basis. This need was based on the apparent rapidly changing water level elevations and the need to monitor regional and local seasonal and diurnal climatic events.

The frequency of water level monitoring was then increased to include monthly data collection. Data were collected more frequently during some months due to ongoing activity at the Site and periodic site visits by NYSDEC's project manager. A continuous water level monitoring program was also implemented for a limited time period in the spring (April 5 through June 6) 1994. The objectives of continuous monitoring were to record data at short time intervals to assess water level changes during the spring thaw, normal rainfall events and after a storm event, if it occurred during the monitoring period. Commencing on April 15, daily rain gage readings were collected by Mr. Alan Mack at the Caledonia State Fish hatchery. These data were evaluated in conjunction with the water levels in the monitoring wells and at the staff gages in Mud and Spring Creek to interpret the hydrologic system within the Study Area. Refer to Appendix O for a tabulation of these readings.

### 3.2.2 Methods

#### 3.2.2.1 Routine Monitoring

Routine water level measurements were obtained from the monitoring wells and the surveyed staff gages in the Mud and Spring Creek valleys prior to each round of sampling, and on a monthly basis beginning in March 1994. Each well and staff gage was marked with a surveyed measuring point from which the depth-to-water measurements were collected. Measurements were obtained with an electric water level indicator, which responds when the probe contacts the water surface. The probe and tape were rinsed with deionized water prior to each measurement to eliminate the potential for cross-contamination.

The depth to water was recorded to within 0.01 foot for each measurement. The depth-to-water information was converted to water level elevations with respect to mean sea level using the surveyed elevations of the measuring points. Tabulated results of all routine monitoring well and staff gage water level measurements are contained in Appendix P. Graphic plots of water levels at each well cluster during the period from November 1993 to September 1994 are contained in Appendix Q.

### 3.2.2.2 Continuous Monitoring

Telog 2100 data loggers equipped with either 5 or 20 psi pressure transducers were installed in wells DC-3A, DC-5A, DC-6A, DC-6B, DC-13A, DC-13B, DC-14A, and DC-17A in April 1994. An In-Situ Hermit 1000C data logger, also equipped with pressure transducers, was installed in wells DC-7RA and DC-7RB. Upon arrival at each well in which data loggers were to be installed, a depth-to-water measurement was obtained. A length of the transducer cable was then measured and marked so that the transducer would be immersed into water to approximately 27% of its useful range (i.e., 3 feet below water for a 5 psi unit). The cable length, and time and date of installation were all recorded in a field book for reference. Continuous water level readings were then recorded at regular fifteen minute intervals during the period from April 5, 1994 to May 3, 1994.

During the Round 4 (April 1994) sampling event, the transducers were briefly removed from the wells to accommodate purging and sampling. The time of removal and re-installation of the units was noted in the field book. Additional Telog 2100 recorders were installed in wells DC-3B, DC-5B and DC-17B on May 3, 1994. The existing Hermit data loggers and transducers in wells DC-7RA and DC-7RB were also replaced with Telog equipment on May 3rd. The remaining Hermit equipment was removed from the wells on May 12th and the Telog units were removed on June 6, 1994. Graphic plots of the continuous water level measurements are contained in Appendix R.

# 4.0 GEOLOGIC CONDITIONS

## 4.1 REGIONAL GEOLOGY

### 4.1.1 Physiographic Setting

The Site and Study Area are situated within the glaciated Allegheny Plateau Physiographic Province of western New York (refer to Figure 4-1). The area is underlain by gently dipping (to the south) sedimentary rocks (primarily carbonate rocks and shales) of Paleozoic age. Erosion of these rocks has produced gentle slopes except where the more resistant rocks have been eroded to produce cuestas or escarpments, and where the surface drainage has been incised into the landscape. Glaciation during the Pleistocene period of geologic history has modified the plateau through both erosion as well as deposition. More recent erosion (last 10,000 years ±), primarily by water, has further modified the landscape to produce, for the most part, a somewhat smoother terrain.

The four 7 1/2 minute geologic quadrangles that cover the area around and including the Study Area demonstrate a range of physiographic or geomorphological features reflective of ancient as well as glacial and recent processes. The northwest quadrangle (Churchville) exhibits a modified glacial terrain consisting of eroded drumlins, meandering glacial meltwater channels, a till plain and glacial lake (glacio-lacustrine) sediments. Minor perennial and intermittent streams occupy the glacial meltwater channels but are of relatively little consequence with respect to modifying the terrain. The northeast quadrangle (Clifton) is dominated by a northeast-southwest oriented drumlin field set amidst a till plain. Existing streams in this area also have little impact on modifying the current topography. The southeast quadrangle (Caledonia) exhibits two significant physiographic features, a large delta built into the ancestral valley of the Genesee River (the site of a former glacial lake), and the current Genesee Valley. Superimposed on the surface of the delta is a series of glacial meltwater stream channels that transported the last vestiges of the melting ice across the surface of the delta. These channels are now occupied by streams and/or local wetlands. The sections of these three quadrangles located adjacent to the Study Area are underlain by relatively weak rock formations or are covered by thick unconsolidated deposits overlying the rock. As such, bedrock outcrops are scarce or non-existent over much of the region. The southwest quadrangle (LeRoy), in which the Site and Study Area are located, is topographically quite different from the three previously discussed. The topography in this quadrangle predominantly reflects characteristics of the underlying bedrock formations. This quadrangle, from the east-west valley of Oatka Creek to the low hills south of Route 5, is underlain by gently dipping sedimentary bedrock formations that crop out on, or are very close to, the ground surface. As such, the topography is quite flat with the exception of the Oatka Creek valley and, to a lesser extent, the valleys of Mud and Spring Creeks. Glacial processes have affected and left a visible mark on this area. In general, the entire area has been washed over by glacial meltwater such that the high land has been eroded leaving a scoured till and bedrock surface and relict glacial meltwater channels on the land surface. Oatka Creek, from the area north of Buttermilk Falls to the east of the Village of Mumford, flows in the most evident meltwater channel in the entire area. Recent processes have modified these features only slightly, as the soil is slowly eroded from the high land and deposited at lower elevations and in the creek valleys. The result of all of these processes is a variable surface topography that is characterized by rolling plains, hills (drumlins), ridges and basins, an escarpment, zig-zag drainage channels, waterfalls and flood plains. Refer to Plate 2 for details of these features.

### 4.1.2 Depositional and Tectonic History

The bedrock geology of western New York is represented by a sequence of Paleozoic strata resting upon Precambrian metasedimentary rocks. The Paleozoic section is composed of Upper Cambrian through Upper Devonian sedimentary rocks, which regionally attain a composite thickness of approximately 5,500 feet. Early Paleozoic time was dominated by the accumulation of several thousands of feet of sediments that formed the region's limestone, dolomite, sandstone and shale bedrock formations. Some of these bedrock units contain evaporite deposits, such as anhydrite, gypsum and salt. The sediments that formed these bedrock units were deposited in shallow seas of relatively long duration. Much of the Early Paleozoic geologic section was removed by erosion during the Middle Ordovician, when uplift to the north caused a temporary southward retreat of the sea. Marine readvance was followed by the Taconic Orogeny, a continental collision between the North American and African plates, which resulted in the formation of a highland area to the southeast of the Study Area. Deltaic and alluvial deposition of clastic materials (rock fragments), derived from the newly formed highland source area, began to fill the subsiding basin. These sediments are represented by the Upper Ordovician and Lower Silurian shales and sandstones that lie at depth beneath the region.

A return of shallow marine waters led to the deposition of the Lockport Group of primarily carbonate rocks. The Lockport Formation, itself, is dolomitic in western New York and represents the maximum marine transgression during Silurian time. Another pulse of energy from the Taconic Orogeny reestablished the supply of clastic sediments to the basin. Development of a vast delta to the southeast, and a minor clastic source area to the north, led to deposition of the shales of the lower Vernon Formation. Vernon deposition represents the beginning of restricted seas and ensuing evaporite deposition, which is represented by dolomite stringers, anhydrite (anhydrous gypsum) and bedded halite (salt). Deposition of evaporites, dolomite stringers, and gray-green shale continued during the accumulation of the sediments that comprise the Syracuse Formation. [The Syracuse Formation was the deepest (and oldest) geologic unit penetrated by the borings during the remedial investigation.] The overlying Camillus Formation consists of a green to grey soft shale, is occasionally dolomitic and sometimes contains anhydrite stringers. This unit represents a shoaling-upward sequence. Above the Camillus lies the Bertie Formation, a relatively thin dolomite unit that represents intertidal shallow water deposition with a return to near-normal salinity. Deposition of the Lower Devonian Helderberg Group limestones and the Oriskany sandstone was characterized by depositional thinning in western New York. Subsequent to their deposition, these Lower Devonian units were completely removed by erosion over much of western New York. This period of erosion also removed some of the underlying Silurian deposits, such as those comprising the Akron Formation and the Williamsville and the upper portion of the Scajaquada members of the Bertie Formation. Refer to the geologic cross-sections (Figures 4-3 through 4-5 and Plate 3) for evidence of the unconformity.

This erosional event was followed by Middle Devonian deposition of the Bois Blanc and Onondaga limestones, which directly overlie the Bertie Formation in an unconformable relationship. The Onondaga sea was not as restricted as the Early Devonian sea and extended beyond western New York. The carbonates of the Onondaga Formation include platform and shelf coral reefs that apparently grew rapidly enough to keep pace with continued deepening of the sea and deposition of other marine sediments.

Continued deepening of the basin, resulting from tectonic uplift in the southeast, was the first indication of the Acadian Orogeny, another collision between the North American and African plates. This orogenic episode resulted in the deposition of the Hamilton Group over the Onondaga. This group consists of shale and siltstone with thin calcareous zones, thin limestones and occasional sandstone stringers. These rock units do not occur within the Study Area but are present south of Harris Road. Deposition of presumably thousands of feet of similar materials, mostly shales and siltstones, continued into the Upper Devonian period as the Appalachian basin became infilled with sediment. The Acadian Orogeny extended in time from at least the middle Devonian through the remainder of the period. (There appears to be no evidence of deformation, due to the folding of the basin, within the Study Area; however, evidence of the orogeny is more noticeable to the north.) Refer to Table 4-1 for a generalized geologic column of the bedrock stratigraphic units within the region. Refer to Section 4.2.4 for a description of the bedrock units encountered within the Study Area during the Remedial Investigation.

### 4.1.3 Structural Geology

The regional structural geology of western New York State is relatively simplistic when compared to that of eastern New York. The major structural feature of the region is a homocline; that is, the bedrock dips generally in one direction. The tectonic history of the region since the beginning of the Paleozoic was one of slow subsidence from the late Cambrian to late Devonian time. During this time period, the Appalachian Basin was slowly developing to the south and receiving shallow water marine sediments over the entire basin. Also, during this time period, sporadic uplifts occurred, creating depositional and/or erosional unconformities within the stratigraphic section.

Subsidence, occurring simultaneously with deposition of sediments in the basin, left its mark on the region by imposing a gentle homoclinal dip to the south of approximately 45 feet per mile (one half degree). Local modifications to the gentle dip occur in areas of subsidence due to the dissolution of underlying Silurian evaporate deposits (Fairchild, 1909), lying at depths ranging from 200 to 700 feet below the ground surface. Refer to Figures 4-3 through 4-5, and to Plate 3 for graphic depictions of the dipping strata across the Study Area.

Large-scale low-amplitude folds, trending north-northeast, occur in the Paleozoic rocks of western New York. These folds are too subtle to map north of the Pennsylvania-New York border. The folds may be the result of rock movement overlying the Salina salt and shale beds, along a decollement (overturned fold or thrust fault) zone (Fakundiny et al, 1978). Small- scale folding has not been documented in the Study Area. Observations of rock exposed in outcrops and in the nearby stone quarries support this position.

Faults are not a common structural feature in western New York. However, one large fault system of regional significance is present west of the Study Area. This system is the Clarendon-Linden Fault System, which trends north-northeast from western Allegany County through eastern Orleans County and across Lake Ontario into Canada. The system is composed of a series of faults with a total vertical displacement of up to 165 feet. Many minor faults have been identified in western New York, with displacements of less than three feet, although none of these minor faults have been noted within the Study Area itself. However, some local small scale faults may be associated with the ridge and basin topography discussed later in the report.

Joints are common physical features evident in bedrock outcrops within the western New York region and the Study Area. Joints appear to be locally common in the Akron/Bertie dolomites, as seen in outcrops along Buttermilk Falls and Mud Creek falls. Rock faces within the quarries indicate an apparent scarcity of joints in the Clarence member of the Onondaga, with joints increasing in abundance or visibility in the overlying Nedrow and Moorehouse members. The joints in the Akron/Bertie appear to be widely divergent and oblique to bedding, whereas the joints in the Onondaga are close to vertical and perpendicular to the bedding. Specific joint observations made during the field work are discussed throughout the text.

### 4.1.4 Glacial History

The regional physiography or geomorphology, including that of the Study Area, shows the profound affect of recent (Wisconsin) periods of glaciation and the final episodes of deglaciation. Although the region has been subjected to several such glacial cycles, the more recent and final episodes have created the landforms that are readily evident on topographic maps, aerial photographs, and in the field. Features such as the till covered uplands to the south of the Study Area, the drumlinized till plain to the northeast, and the morainal deposits to the west, southwest and southeast of the Study Area reflect both ice advances and ice stagnation events. Superimposed on much of this glaciated area, and on the landscape as a whole, are scoured till and bedrock surface features, a complex network of glacial meltwater channels, a drumlin field and deltaic deposits where the meltwaters entered the ponded waters of local glacial lakes.

Within the Study Area, and of significance relative to the hydrogeologic regime of the area, is the network of glacial meltwater channels that cross the area in an east-west direction. These channels are postulated to have been created during one or several periods of drainage to the east and ultimately to a Mohawk drainage outlet near Syracuse (Fairchild, 1909; Muller, 1988; Wilson, 1981). It is unclear if these channels were created in a proglacial position (adjacent to) or beneath the ice mass or both. The channels transmitted a vast quantity of water across the Study Area. As the ice front retreated to the north of the Onondaga cuesta between Batavia and Caledonia, and the ground thawed, much of the surface water was free to find its way into the bedrock fracture system. Once in the subsurface, the water naturally moved in a direction from high head to low head, which, in this case, was from west to east. The flow direction was consistent with the direction of the surface drainage which found its outlet through the north-south channels known as the Taylor Channel and the White Creek Channel.

Both prior to and subsequent to this sequence of events, several significant glacial lakes occupied areas south of the ice front. Lake Warren I and Lake Wayne probably covered the Study Area, whereas Lake Warren III does not appear to have achieved an elevation such that it occupied the Study Area south of the Onondaga cuesta. This is evidenced by the preserved scour surfaces and channel features on the ground surface, and the absence of glacial lake deposits over most of the Study Area.

The deep channels in which Oatka Creek, White Creek, Dugan Creek and Blue Pond are located, as well as some local deltaic deposits, were likely created as eastward drainage continued through lower outlets to the east, causing a decline in base level. This is probably the time period in which the falls in Mud Creek were initiated. These channels were later filled with marl and capped by organic material in restricted-flow areas. Recent alluvium has been deposited in the more prominent valleys, such as along Oatka Creek.

## 4.2 STUDY AREA GEOLOGY

### 4.2.1 Physiography

The Study Area exhibits a variety of landforms related to the depositional and tectonic history of the area (bedrock geology and structure), to periods of glaciation and deglaciation and to recent events. The nature and composition of the bedrock strata and their attitude, i.e. their dips and folds, reflect both very old and very recent activities, as discussed below.

The Study Area is contained primarily within the LeRoy 7 1/2 minute quadrangle, as identified and discussed in Section 4.1.1. This area is underlain by gentle, southerly dipping bedrock strata of Devonian and Silurian age. The ground surface generally reflects this fact, with exposures of the bedrock type and structure evident in the many quarries that are present in the area, and in Buttermilk Falls and the falls of Mud Creek. Superimposed upon the gently dipping bedrock strata is a complex series of smaller scale structures of unknown origin. As discussed in other sections of this report, these features may be related to subsurface dissolution of evaporite-bearing rocks, to isostatic adjustment and/or glacial rebound, and to catastrophic glacial meltwater drainage. These features are particularly noticeable in the area between Mud Creek and Flint Hill (Livingston County)/Lime Rock Road.

Ground penetrating radar (GPR) data were collected in areas of ridge and basin topography along portions of Church and Flint Hill Roads, in June 1992. These data suggest that structural basins are associated with these physiographic features. Drilling location DC-11 was sited to explore one of these structures.

The Study Area and its immediate surroundings exhibit a wide variety of landforms that reflect the effects of both glaciation and deglaciation during the Pleistocene period. More recent modification of the ground surface within the Study Area has resulted from both surface and subsurface erosion. Surface streams have been incised into the rock by erosion and have deposited the eroded material further downstream in the broader portions of their valleys. Subsurface dissolution of evaporite (anhydrite, gypsum) - bearing rocks is known to affect some of the bedrock formations (Camillus and Syracuse) that underlie the Study Area. This process is reportedly a possible cause of the very irregular ridge and basin topography found within the Study Area from Mud Creek to just east of Flint Hill (Livingston County)/Lime Rock Road.

Surface drainage in the Study Area follows a dendritic pattern. The major surface drainage feature of the area is Oatka Creek, which flows northward along the western border of the Study Area, over Buttermilk Falls, and then eastward along the northern border of the Study Area. Mud Creek drains a good portion of the western end of the Study Area, including the Site, as it flows to the northeast over the Mud Creek falls to join Oatka Creek approximately 2.6 miles west of the Village of Mumford. Spring Creek appears to be the major outlet for both surface and subsurface drainage within much of the Study Area. This creek forms the eastern boundary of the Study Area as it flows north from Caledonia to join Oatka Creek at the Village of Mumford.

### 4.2.2 Depositional and Tectonic History

The depositional and tectonic history of the region, as discussed in Section 4.1.2, is applicable to the Study Area. One feature that is significant with respect to the Study Area, including the spill site, is the presence of the unconformity that represents the erosion of the lower Devonian strata and some of the Silurian strata. As such, a small portion of the upper Silurian rock formations are not represented in some parts of the Study Area whereas, in other parts, the sequence appears to be present almost in its entirety. For example, borings in the vicinity of Mud Creek, southeastward to DC-7 and DC-7R, did not encounter any of the Akron or Williamsville stratigraphic units and only about one to two feet of the Scajaquada. However, at locations DC-8 and DC-12, all of the Scajaquada and Williamsville appear to be present and most, if not all, of the Akron is present. This amounts to approximately 20 additional feet of bedrock strata at these latter drilling locations. Although the deep borings at DC-9 and DC-10 were not cored, the geophysical logs imply that all of the Scajaquada and Williamsville are present at these locations and probably most of the Akron as well. Refer to the geologic cross-sections (Figures 4-3 through 4-5, and Plate 3) for graphic depictions of the geologic strata across the Study Area.

### 4.2.3 Unconsolidated Deposits and Soil

#### Spill Site

The unconsolidated overburden material at the spill site consists primarily of fill, glacial till and weathered bedrock. The fill consists of a gray-brown, coarse to fine gravel and a little coarse to fine sand, with frequent large angular rock fragments and occasional cinders. The glacial till consists of a hard, dry, poorly sorted matrix (15-20% of unit) of a little coarse to fine gravel and coarse to fine silt, with a trace of clayey silt. The weathered bedrock consists of light brown to dark gray cherty limestone. North of Gulf Road, near the ruins of the former Knickerbocker Hotel, a one to two-foot-thick layer of sandy silt was encountered in the test pits (refer to the Spill Site Soil Investigation Report dated April 1993). In addition, a 1.5-foot-thick zone of rubbish was noted in a test pit north of Gulf Road, and copper wire/conduit, pipe and wood debris were noted in the vicinity of the railroad bed south of Gulf Road.

The results of the test pitting performed during Phase B of the RI indicate that the overburden at and in the vicinity of the spill site consists of a variety of fill and natural materials. The buried rubbish and other man-made materials are indicative of historical filling and/or regrading of the area. Some of this material may be related to the former operation of the Knickerbocker Hotel. Overburden within the railroad grade consists primarily of crushed stone railroad ballast overlying native soil, glacial till and bedrock at relatively shallow (generally less than 5 foot) depths. Bedrock outcrops in the vicinity of the spill site consist of the Nedrow member of the Onondaga Formation.

It is reasonable to assume that a combination of fill and native materials (till and weathered bedrock) underlie Gulf Road. It is also reasonable to assume that the thickness of this material, and the depth to bedrock beneath Gulf Road, is similar to that adjacent to the road, or between two and five feet thick.

## Study Area

The Study Area was overridden by ice during the Wisconsin glacial stage of the Pleistocene geological epoch. The final two substages of this stage are primarily responsible for the content and deposition of the unconsolidated deposits in the Study Area. These substages are represented by the Hamburg-Marilla and the Valley Heads drift sheets, respectively.

The Hamburg-Marilla drift sheet consists of glacial till deposited as ground moraine and drumlins, and lacustrine sediments deposited in proglacial lakes. This drift sheet includes the drumlin fields located north and northeast of the Study Area.

The till of the Hamburg-Marilla drift sheet is composed of materials derived from the glacial scouring of high-carbonate shales and dolostones of the Lockport, Salina, and Bertie Formations. This till, typically, has a distinctive red color and does not appear to have been encountered in any of the borings performed during the investigation.

The Valley Heads drift sheet consists of glacial till deposited as ground moraine and in proglacial lake (lacustrine) deposits. Although similar in texture and origin to the Hamburg-Marilla drift sheet, the Valley Heads till is generally brown, brownish grey or grey in color. This drift sheet correlates with the soil encountered in the Study Area. The distribution of surficial soils in the Study Area has been mapped by the United States Department of Agriculture and presented in soil survey reports for Genesee (1969), Livingston (1956), and Monroe (1973) counties. Generally, the reports describe three soil types in the vicinity of the Site: Benson Channery loam (BCB); Farmington loam (Fa), or Farmington cherty loam (Fh) or stony loam (Fs); and Honoeye silt loam (Hob). All of these soil types are described as dark brown to grayish brown, well drained, silty soils with an average thickness of 20 to 40 inches found on glacial till or bedrock. Carbonate bedrock is generally encountered directly below these soils. These descriptions coincide with on-site soil classifications performed during the drilling phase of the investigation. Soil thickness ranged from 0.9 to 12.9 feet with the average thickness or depth to bedrock being 3.3 feet. Coarse gravelly fill was encountered at borings DC-1, DC-2, DC-4, DC-5, DC-12 and DC-15. The fill at these locations consists of railroad ballast, quarry rubble, and/or road base materials.

### 4.2.4 Bedrock Geology

Techniques utilized to investigate the bedrock geology of the spill site and Study Area included a literature review, a field reconnaissance, visual observation of bedrock exposures in natural outcrops and in local quarries, bedrock drilling and coring, and geophysical and video camera logging of selected boreholes.

Results of the literature review are discussed or incorporated within various sections of the report. The results of the field reconnaissance and additional visual observations have been described in previous reports and are also interspersed throughout the discussions contained in this report. As such, they are not specifically discussed in this subsection. Details of the drilling program and the geophysical and video camera logging are presented in Section 2.0 of this report. A generalized geologic column for the Site and Study Area is presented in Table 4-1. Figure 4-2 presents a graphic description of the bedrock geology of the Study Area, the locations of four geologic cross-sections, and the boring used to generate the cross-sections. The cross-sections are presented as Figures 4-3 through 4-5 and Plate 3.

As a result of these investigations, the following description of the bedrock units underlying the Study Area has been developed. The rock units are described from the bottom up, i.e. from the deepest (oldest) to the shallowest (youngest).

#### Silurian System

#### Syracuse Formation

The upper portion of the Syracuse Formation consists predominantly of dolomites and evaporite (anhydrite, gypsum, salt) deposits. Several mining companies have produced gypsum in Erie, Genesee, and Monroe Counties. The mined gypsum beds lie 150 to 225 feet below the base of the Onondaga Formation, which indicates that they lie within the uppermost unit (Unit F) of the Syracuse Formation. The interpreted thickness of Unit F at the MacDonald 1 well in Livingston County is roughly 80 feet (Rickard, 1969).

Evaporite-bearing dolomite, which comprises the uppermost portion of Unit F in the Study Area, was cored at three locations (DC-1, DC-7, DC-8) during the field investigation. The maximum core penetration into the yellowish-gray to dark gray unit was 22 feet at boring DC-8. The maximum penetration of the Syracuse Formation during the drilling program was 33 feet at one of the non-cored locations (DC-9). The strata are thin-bedded to very thin-bedded and fine-grained, with gypsum veinlets and/or interbeds. The veinlets were less than 1 mm thick, whereas the interbeds were up to 0.3 foot thick. A void was detected in the Syracuse at borings DC-4 and DC-7.

## Camillus Formation

This formation conformably overlies the Syracuse Formation. Regionally, the Camillus consists of green shales, anhydrites, and occasional dolomites. Increasing amounts of dolomite are generally found throughout the formation in western New York and Ontario, Canada. Anhydrite and gypsum are commonly associated with the shale and have been mined from underground mines along the Silurian outcrop belt. Examples of such mines occur northeast of the Study Area at Wheatland Center and Garbutt in Monroe County. Outcrops of the Camillus Formation were not observed within the Study Area. However, field and drilling evidence indicate that the Oatka Creek valley north of the Onondaga escarpment is underlain by the Camillus. The northern portions of both the Mud and Spring Creek valleys are also assumed to be underlain by the Camillus Formation. The interpreted thickness of the Camillus at the MacDonald 1 well in Livingston County is roughly 60 feet (Rickard, 1969).

The entire thickness (approximately 65 feet in the Study Area) of the Camillus Formation was cored at three locations (DC-1, DC-7, DC-8), and at least half of the formation was cored at three other locations (DC-4, DC-11, DC-12). In the Study Area, the unit consists of a medium light gray to dark gray, fine-grained, crystalline argillaceous dolomite. Rare, thin dolomite beds occur in the middle and lower portions of the unit. The lower two-thirds of the formation are extremely vuggy and porous. Many of the boreholes were prone to blockage or collapse in this interval. Voids were detected in the Camillus at borings DC-4, 7, and 8.

## Bertie Formation

Overlying the Camillus is the Bertie Formation, a 45-foot thick sequence of argillaceous dolomites. The Bertie formation is subdivided into three members, in ascending order -- the Falkirk, Scajaquada, and Williamsville dolomites. In western New York, the Bertie Formation conformably overlies the Camillus, and is overlain, where complete sections are found, by the Akron Formation (Silurian). Owing to the relief of a pre-Bois Blanc unconformity, exposures are found where the Bois Blanc Formation (Devonian) directly overlies the Williamsville member of the Bertie, or some lower member (Rickard, 1966). Rickard's descriptions are applicable to the geology of the Study Area, where the Scajaquada member of the Bertie is commonly in unconformable contact with the overlying Bois Blanc Formation, such as at location DC-11 and at the drilling locations west of Church Road. The thickness of the complete Bertie section in the Study Area is 45 feet at DC-12, where it is conformably overlain by the Akron Formation.

Oatka Creek and Mud Creek have downcut their valleys to expose the Bertie at Buttermilk Falls and the Mud Creek falls, respectively. While the cap rock of both falls is the Clarence member of the Onondaga Formation, the major portion of the bedrock exposed beneath the falls and in the walls of the gorges immediately below (north of ) the falls is the Bertie Formation.

Although evidence of dissolution was absent in the Bertie exposures examined, the formation is reported to be prone to dissolution. Specific observations of the Bertie were made at the Mud Creek falls north of Gulf Road. Seepage was evident below the Onondaga - Akron/Bertie contact and from diagonal joints in the Bertie. Joints were measured in the ledge onto which the falls cascade. These joints were oriented from N35° to 40°E and dipped from 60° to 70° to the southeast. These joints did not extend into the overlying buff colored laminated dolomite. Vertical joints oriented N4°W were noted in the underlying member of the Bertie, which also exhibited conchoidal features. These joints extended downward into the underlying unit, which did not exhibit evidence of conchoidal fracturing. Other exposures of the Bertie were examined at the top of the escarpment on Woody Acres' property. Numerous joints with widely divergent strikes and dips were measured at this location. The orientation of the joints did not correlate with the joints measured in the Onondaga Formation, as discussed later.

### Falkirk Member

The Falkirk member ranged from 27 to 32 feet in thickness at the six coring locations. The appearance of the Falkirk in core samples suggests that the unit be divided into two to four zones. The divisions reflect color changes (typically among various hues of gray), as well as changes in bedding characteristics and in proportions of argillaceous material. This member of the Bertie ranges from a fine-grained to microcrystalline, thin-bedded to massive, dolomite. Single dipping fractures of narrow aperture commonly occur throughout the Falkirk member. Heavily fractured intervals are rare in the unit.

### Scajaquada Member

This member of the Bertie constitutes the top of the dolomitic section at four of the six coring locations (DC-1, DC-4, DC-7, DC-11). The thickness of the member, as cored, varies from one foot (DC-1) to eight feet (DC-8, DC-11, DC-12). The Scajaquada appears to have been eroded to a fraction of its depositional thickness at the drilling locations west of Church Road. The thin remnant at DC-1 features a silicified paleosoil(?) in the upper one centimeter. The original thickness of the Scajaquada member in the Study Area appears to be preserved at DC-8 and DC-12, where the eight-foot-thick unit is conformably overlain by the Williamsville member. At DC-11, the Scajaquada is unconformably overlain by Devonian strata. The Scajaquada consists of medium dark gray to pale yellowish-brown dolomite layers, with dark gray argillaceous seams and partings. The member is thin-bedded, fine-grained, and occasionally has a laminated appearance.

### Williamsville Member

This uppermost member of the Bertie Formation appears to have been completely eroded away at all but two coring locations (DC-8, DC-12). This member is a medium light gray to light gray, laminated, crystalline dolomite with a massive appearance. The presence of the Akron Formation at these two coring locations suggests that the six- to eight-foot thickness of the Williamsville is its original depositional thickness in this area.

### Akron Formation

The uppermost rock unit of the (complete) Silurian section was identified at only two coring locations (DC-8, DC-12). The presence of the Akron Formation is also inferred from the geophysical (gamma) logs at borings DC-9 and DC-10. The thickness of this unit at the four locations ranges between five and eight feet. The Akron has apparently been removed by erosion in the western portion of the Study Area. The formation is described as a medium-gray to yellowish gray, fine-grained crystalline dolomite. This geologic unit is thin-bedded and has a slightly mottled appearance. The upper contact with Devonian strata is sharp and unconformable, while the lower contact with the Williamsville member of the Bertie is gradational. The unconformable nature of the Silurian-Devonian contact is most apparent in core DC-8, where soft-sediment deformation is preserved immediately above a highly irregular Akron surface.

## Devonian System

### Bois Blanc Formation

This thin, discontinuous formation is the only remaining record of Early Devonian sedimentation in western New York. The Bois Blanc Formation thickens rapidly to the west of Buffalo, but thins and disappears just east of the Genesee River Valley (Oliver, 1966). The formation is less than three feet thick at cored locations in the Study Area, and disconformably overlies either the Akron Formation or, more commonly, the Scajaquada member of the Bertie Formation. The unit is heterogeneous across the Study Area, and is variously described as cherty limestone with a limy sandstone base (DC-1, DC-4, DC-7); as limestone (DC-8); as cherty limestone (DC-11); and as sandy limestone (DC-12). The limestone is generally medium gray to medium light gray, fine-grained to coarse-grained crystalline rock, with 0 to 80 percent by volume chert. The basal sand is commonly considered to have been formed by reworking of the Oriskany sandstone that presumably covered the entire area at one time (Oliver, 1966). The thin sandy base, when present, includes rounded quartz grains (DC-1, DC-4, DC-7) and clasts of glauconite and blue chert (DC-7) in a calcareous matrix. At DC-8 and DC-12, the limestone includes angular (finer-grained) limestone fragments or fossil pieces. The core at DC-12 also includes clasts of glauconite and sandstone.

### Onondaga Formation

The uppermost (youngest) bedrock formation exposed at the Site and within the Study Area is the Middle Devonian Onondaga Formation. The complete Onondaga section is reported to be approximately 140 feet thick and is composed of five members. In ascending order, the members are the Edgecliff, Clarence, Nedrow, Moorehouse, and Seneca limestones. The Moorehouse and Seneca members are separated by a 2 to 4 inch thick ash bed known as the Tioga Bentonite. The Moorehouse member, Tioga Bentonite and Seneca member of the Onondaga Formation were not encountered at any of the 18 drilling locations. Aggregate quarries in the area generally mine the Onondaga limestone from the top down to the middle of the Clarence member. Evidence in the former quarries of the General Crushed Stone Company, north of the spill site indicate that the rock was quarried to the base of the Edgecliff and/or Bois Blanc geologic units. A brief description of each member in ascending order is as follows:

Edgecliff Member

This geologic unit, in unconformable contact with the Bois Blanc, consists of medium dark gray to medium light gray fossiliferous limestone. The bedding varies from thin to massive in this medium to coarse-grained limestone. The base of the limestone often contains detrital quartz which rapidly decreases in abundance up section. Light colored chert nodules are scattered throughout the Edgecliff, but are more common at the top of the member as it grades into the Clarence member. The thickness of the Edgecliff at cored locations ranges from 3 to 11 feet.

Clarence Member

Except at DC-8, where it is the uppermost bedrock unit, the entire thickness of this member was cored at all six coring locations. The Clarence member is typically a light gray to medium dark gray, medium-grained to microcrystalline, medium to thin-bedded limestone containing up to 70% chert. The Clarence is approximately 31 feet thick and, reportedly, can generally be subdivided into three units based on chert content and color. The lowest unit contains approximately 50% chert and 50% limestone. The chert is dark gray and mottled, often occurring in beds and lenses. The middle unit is composed of 70% chert and 30% limestone, where the chert is medium gray in color and bedded. The uppermost unit is approximately 50% chert and 50% limestone. The chert is very light gray to white and forms a mottled appearance with the limestone. Joints are not well developed in the Clarence, as evidenced by observations of outcrops and quarry exposures, but have been noted near the Mud Creek falls and in the borehole video tape of boring DC-1 (see Sections 2.5.3 and 4.2.5).

Nedrow Member

The Nedrow member, the uppermost bedrock unit at the spill site, was cored at four locations (DC-1, DC-7, DC-11, DC-12) and possibly a fifth location (DC-4). The member is a medium gray to medium light gray, very fine grained to coarse grained crystalline limestone. The core volume is comprised of up to 20% of medium dark gray to black chert. Although rare in the core, fossils in the Nedrow reportedly include corals, gastropods and brachiopods, and decrease in abundance up-section with increasing shale content. The maximum cored thickness of the Nedrow was 43 feet at location DC-11.

Moorehouse Member

The Moorehouse member is a medium gray, finely crystalline argillaceous limestone approximately 25 feet thick. The increased clay content represents an increasing water depth during the time of deposition. Chert is found throughout the member but is most abundant at the top of the section.

Although not penetrated by any of the borings at the 18 drilling locations, the Moorehouse member is projected to be present in the Study Area, south of Route 5 and north of Harris Road/Cider Street.

### 4.2.5 Spill-Site Bedrock Fracture Characteristics

This subsection describes the physical condition of the bedrock, and the vertical distribution of bedrock fractures at the two coring locations closest to the spill site (DC-1, DC-4). DC-1 is located at the spill site, whereas DC-4 is located approximately 900 feet to the west-northwest of the spill site. The following is a summary of observations made of the bedrock core, as well as observations made of the corehole wall using a downhole video camera. The observations are presented in descending stratigraphic order, i.e., from the ground surface downward. Detailed core fracture descriptions for all six coring locations across the Study Area are included on the core logs in Appendix E. The caliper logs and accompanying video notations (Figures 2-1 and 2-2, and Appendix I) offer a concise presentation of fracture distribution at cored and non-cored locations across the Study Area.

#### Drilling Location DC-1

Approximately 11 feet of Nedrow underlie three feet of fill at the spill site. This rock unit is severely broken up by vertical and horizontal fractures. Water was observed entering the corehole in a zone of multiple fractures approximately seven feet below grade. A larger amount of water inflow was noted at a major broken zone in the Nedrow at a depth of 11.9 feet. The Rock Quality Designations (RQDs) for the core runs in this member averaged about 10%. (The RQD roughly quantifies the competence of cored rock. Refer to Section 2.3.2.1 for a discussion of how the RQD is calculated.)

The 31-foot Clarence section at location DC-1 featured a multitude of dipping and vertical fractures, as well as several horizontal fractures. Prominent bedding-plane fractures were noted at roughly 22 and 34 feet below grade. The RQDs averaged 65%. Water could be observed sheeting down along the walls of the corehole from depths between roughly 15 feet and the water table at 56 feet. Specific water entry points (below the highest such point) were difficult to identify, but most fractures probably convey water.

The 10-foot thickness of the Edgecliff member, located between 45 and 55 feet below grade at the spill site, was very competent. Two horizontal clayey-silt-filled fractures were identified in the Edgecliff segment of the core from DC-1. The RQDs were greater than 90% in the Edgecliff.

The Bois Blanc Formation and the Scajaquada member of the Bertie Formation are apparently unfractured at the spill site. The total thickness of the two units at the spill site is less than three feet. An RQD was not calculated for this thin interval.

Throughout the Study Area, the Falkirk member of the Bertie appears to be the most competent in the stratigraphic section. RQDs at DC-1 exceeded 90%. Eight dipping fractures and three horizontal fractures were identified in 32 feet of core/corehole. The dipping fractures were well developed but narrow. Video observations of the corehole wall showed no evidence that the fractures had been enlarged by solutioning. However, a solution-enlarged vertical fracture was identified at the top of the member and represents the most prominent break in the Falkirk at the spill site.

The Camillus Formation is roughly 65 feet thick beneath the spill site. It can be divided into two zones. The upper 18 feet of the Camillus features occasional thin (less than one foot) broken zones, and two horizontal silty-clay-filled fractures. The lower 47 feet consists primarily of vuggy, porous, and friable rock, with occasional competent zones one to five feet thick. The borehole camera revealed that, below 105 feet, the corehole has a pitted, "corroded", or weathered look, rather than a fractured appearance. The upper zone of the Camillus had RQDs greater than 80%, with 100% core recovery. The deeper zone had RQDs of 0% for most core runs, with core recoveries in the 55-70% range for nearly all core runs.

A sharp contrast in rock quality marks the top of the Syracuse Formation. Below the Camillus-Syracuse contact, the corehole appears smooth-walled and is marred only by a single dipping fracture three feet below this contact. One core run was taken in the formation, with an RQD of 65%, and a core recovery of 100%. The total depth of boring DC-1 was 160 feet.

## Drilling Location DC-4

The overall condition of the cored bedrock at this location is comparable to that described for DC-1, located approximately 900 feet to the east-southeast. There are three major differences at DC-4: 1) the Bois Blanc and Scajaquada are highly fractured; 2) a 1 1/2-foot-thick bedding plane fracture occurs in the Falkirk, and 3) a void is present in the Syracuse.

Three feet of unconsolidated deposits (quarry rubble) overlie the Clarence member at DC-4. This cherty limestone unit is generally permeated with vuggy, calcite-coated, open fractures to a depth of 17 feet. At depths between 17 and 31 feet, the fractures follow irregular surfaces at the contact between the chert nodules and the surrounding limestone. Vertical fractures were rare at this location. Two of the major bedding plane fractures in the Clarence (15 and 29 feet) occur at the same stratigraphic level at both DC-1 and DC-4. RQDs averaged 65%, similar to those at DC-1.

The Edgecliff member is less competent at DC-4 than at DC-1. A 1 1/2-foot-thick zone of vertical fractures occurs in the upper half of the unit. A 4 1/2-foot-thick broken zone of dipping and horizontal fractures begins just above the contact with the underlying Bois Blanc Formation, extends through those strata, and terminates in the underlying Scajaquada member of the Bertie Formation. Core recovery was 74% in the fractured interval of the Scajaquada, with an RQD of 0%.

In addition to the major bedding-plane fracture mentioned above, a dozen steeply dipping fractures were identified in the Falkirk member. These fractures were noted in the core and on the video log of DC-4. The narrow aperture of nearly all of these fractures is demonstrated by the lack of caliper response as the probe passed by the features. RQDs in the Falkirk exceeded 90% at this location.

The upper (competent) section of the Camillus Formation is about 20 feet thick at DC-4, and features four clay seams and two dipping fractures. Severely broken zones extend from a depth of 106 feet to 113 feet, and from 124 feet to the base of the formation at 152 feet. Thin layers of competent rock occur in the broken zones. With respect to DC-1, RQD values are comparable, while core recoveries were lower at DC-4. Coring was terminated in the Camillus at a depth of 130.5 feet after a five-foot core run resulted in no sample recovery. Video and geophysical logging tools subsequently lowered into the corehole were obstructed by a collapsed zone at a depth of 107 feet, and retrieved to the surface. The corehole was then enlarged with a five-inch diameter air hammer and deepened to 174 feet. The video and geophysical logging were repeated the next day, but the bottom seven feet of the hole had collapsed overnight. The collapse was in the Syracuse Formation, 15 feet below the base of the Camillus. The caliper log and the video camera revealed that the smooth-walled boring in the Syracuse led to a 2 1/2-foot-thick void. The pre-collapse thickness of the void is unknown.

# 5.0 HYDROGEOLOGIC CONDITIONS

## 5.1 HYDROLOGY

### 5.1.1 Surface Drainage

The Study Area is in the watershed of the Genesee River, which is located to the southeast of the Village of Caledonia and flows northward and enters Lake Ontario at the City of Rochester, New York. The surface of the Study Area is characterized by sinking streams, wide areas with virtually no overland flow, and voluminous springs along Spring Creek in the Village of Caledonia. Oatka Creek, which lies to the west and to the north of the Study Area, is the major drainage feature within the area. Spring Creek, a spring-fed tributary to Oatka Creek, is quite significant in terms of the local hydrogeology. The creek flows to the north along the eastern edge of the Study Area, and enters Oatka Creek in the Village of Mumford. Several intermittent (seasonal) streams also drain portions of the Study Area and its nearby surroundings. These streams are notable in that each sinks into the subsurface through cracks and fissures in the bedrock. The most important of the sinking streams is Mud Creek. When the water table is high, however, Mud Creek flows along its entire length, and discharges into Oatka Creek 5,000 feet northeast of the spill site. Refer to Plate 2 for the locations of the major drainage features within and bordering the Study Area.

These surface drainage features (sinking streams, limited runoff, voluminous springs) reflect the underdrained nature of the exposed bedrock surface. This underdrained condition further indicates that secondary porosity must be well developed in the shallow bedrock, thereby permitting rapid infiltration of precipitation and runoff, and access to significant subsurface groundwater migration pathways.

**Oatka Creek**

Oatka Creek flows north through the Town of LeRoy, over the Onondaga cuesta at Buttermilk Falls, and into an east-west oriented ice-marginal drainage channel to which it is confined until its confluence with the Genesee River. The confluence of the two streams is located near Scottsville, approximately 11 miles east-northeast of the spill site. It is possible that Oatka Creek loses water to the subsurface west of the Study Area, in the south to north stretch from the Village of LeRoy to Buttermilk Falls, where it flows across surface exposures of the Onondaga limestone.

**Mud Creek**

Mud Creek is the most significant of the sinking (or losing) streams within the Study Area. The creek rises on till-covered uplands in the Town of Pavilion in Genesee County and flows northward through the Town of LeRoy toward Oatka Creek. Surface water runoff is sufficiently high for a few weeks each year such that Mud Creek flows all the way to its confluence with Oatka Creek. The losing reach of Mud Creek north of the LeRoy Airport is either dry, or draining into the subsurface, primarily in one or two seasonally ponded areas. The upstream pond is located approximately 1,500 feet north of Route 5, on Dolomite Products Company property, at an approximate elevation of 770