Final
Supplemental Remedial Investigation Report for the Former Frontier Chemical Waste Process, Inc., Site Niagara Falls, New York

Site Number 9-32-110

Volume I

November 2002

Prepared for:

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
625 Broadway
Albany, New York 12233

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List of Abbreviations and Acronyms

%RSD	percent relative standard deviation
%D	percent difference
AMSL	above mean sea level
ASC	Ecology and Environment Analytical Services Center
ASP	Analytical Services Protocols
BBL	Blasland, Bouck, and Lee, Inc.
BGS	below ground surface
CA	Environment Canada
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
Chemworld	Chemworld Environmental, Inc.
COPC	chemicals of potential concern
CRA	Conestoga-Rovers and Associates
CRDL	contract required detection limit
DCB	dichlorobenzene
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
DUSR	Data Usability Summary Report
E & E	Ecology and Environment Engineering, P.C.
Empire	Empire Soils Investigations, Inc.

List of Abbreviations and Acronyms (cont.)

ERCS	Emergency Response Cleanup Service
ESA	Environmental Services Associates, Inc.
EVE	Eagle Vision Environmental
FR	area use factor
Frontier Chemical	Frontier Chemical Waste Process, Inc.
FS	feasibility study
FSP	field sampling plan
ft/min	feet per minute
GC/MS	gas chromatograph/mass spectrometry
HASP	Site-specific Health and Safety Plan
ICP	inductively coupled argon spectroscopy
ID	internal diameter
IDL	instrument detection limit
IDW	investigation-derived waste
ISCO	ISCO Chemical Company
LCS	laboratory control sample
LEL	low-effect level
µg/L	micrograms per liter
McIntosh	McIntosh and McIntosh, P.C.
MCT	monochlorotoluene
MDL	method detection limit
mL	milliliter
MOE	Ontario Ministry of Environment
mS/m	milliSiemens/meter
MSB	matrix spike blank

List of Abbreviations and Acronyms (cont.)

MS/MSD	matrix spike/matrix spike duplicate
ND	non-detect
NOAEL	no observed adverse effect level
NRTMP	Niagara River Toxics Management Plan
NTU	nephelometric turbidity units
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OD	outer diameter
Oda	Odessa silt clay loam series
OVA	organic vapor analyzer
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PRP	potentially responsible party
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
QL	quantitation limit
RCRA	Resource Conservation and Recovery Act
ROE	ROE Consolidated Holdings
RPD	relative percent difference

List of Abbreviations and Acronyms (cont.)

RQD	rock quality designation
SB	site background
SEL	severe-effect level
SOP	standard operating procedure
SRI	supplemental remedial investigation
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TAGM	Technical and Administrative Guidance Manual
TAL	target analyte list
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCE	trichloroethene
TCL	target compound list
TCLP	toxicity characteristic leaching procedures
TEF	Toxicity Equivalency Factor
TIC	tentatively identified compound
TOC	total organic carbon
TOIC	top of inner casing
USEPA	United States Environmental Protection Agency
VOC	volatile organic compounds
Watts	Watts Engineers, P.C.

Executive Summary

Ecology and Environment Engineering, P.C. (E & E), under contract to the New York State Department of Environmental Conservation (NYSDEC) (Work Assignment No. D003493-30) performed a Supplemental Remedial Investigation (SRI) between October and December 2001 at the former Frontier Chemical Waste Process, Inc., site (Frontier Chemical) on Royal Avenue in Niagara Falls, New York (NYSDEC Site No. 9-32-110). The primary purpose of this investigation was to determine the nature, extent, and potential source areas of the wastes previously identified at the site; and verify the pathways and determine the impact of contaminant migration.

This 9-acre facility is currently abandoned and most of the buildings have been demolished. It is bordered by Royal Avenue to the south and 47th Street to the east, within the city of Niagara Falls. The Niagara River lies within 1 mile south of this site.

The facility treated chemical wastes from 1974 until December 1992, when the facility closed. When in operation, the active waste management units treated or stored approximately 25,140 tons of chemical wastes each year. The waste, which came from businesses located in the eastern United States and southeastern Canada, can be classified as Resource Conservation and Recovery Act (RCRA)-listed wastes, as well as RCRA-characteristic wastes.

SRI Field Activities

In May 2001, an initial site reconnaissance was performed by E & E and NYSDEC. A work plan was developed by E & E and approved by NYSDEC in September 2001. The SRI field work began in October and was completed in December 2001. The fieldwork included the following activities:

- Site reconnaissance;

- Record search;

- Subsurface soil and groundwater investigation;

- Utility investigation to determine potential pathways of contaminant migration; and

- Development of a site base map.

Nature and Extent of Contamination

Results of sample analyses from the various sample media collected during the SRI indicated that there were multiple source areas on site, as well as unidentified off-site sources to the north and northeast of the site. Because the site is inactive and underwent several removal actions, there is no further contribution of contaminants expected at any of the former on-site source areas. No specific sources were identified during E & E's field investigations.

Site soils and groundwater are mainly contaminated by volatile organic compounds (VOCs). Significant semivolatile organic compound (SVOC) contamination (predominantly polycylic aromatic hydrocarbons [PAHs] and phenols) is also present to a lesser degree, along with dioxins, and metals. There are also minor amounts of pesticides in excess of criteria. Groundwater occurs in both the overburden, and underlying Lockport Dolomite bedrock. Three distinct water bearing zones occur in the upper bedrock (A-, B-, and C-fracture zones). Contamination levels in groundwater decreases with depth (i.e., the highest levels of contaminants were detected in overburden groundwater, and concentrations decrease in the underlying A-fracture, B-fracture, and C-fracture bedrock zones). Lateral contaminant migration in the groundwater is generally to the southeast, and vertical migration is downward. Overall contaminant concentrations in both overburden and bedrock groundwater have declined since 1990, except for VOCs in one of the C-fracture bedrock wells (MW-88-5C). In addition, most of the higher areas of groundwater contamination have migrated either vertically deeper into the bedrock, or laterally approximately 100 feet. It appears that the New Road and Falls Street tunnels intercept the majority of the groundwater exiting the site, as well as groundwater from other properties in the vicinity of the tunnels.

Fate and Transport

The primary transport pathways for site contaminants include: surface water flow; infiltration; overburden and bedrock groundwater flow; subsurface utilities and their bedding material; and volatilization.

Based on the persistence and behavioral characteristics of the predominant contaminants detected at the site and the observed presence of chemicals in the various media tested, the potential significant migration pathways include surface water flow, groundwater (including infiltration), and volatilization.

Surface water flow may be a site mechanism that allows lateral migration of contaminants, if present, in surface soils or as residuals on demolition debris, decommissioned tanks, etc. Although no surface soils were collected for analytical testing during this study, the 20% of open ground space is not expected to be significantly contaminated.

The overburden groundwater samples collected at the site include numerous VOCs, as well as select SVOCs (primarily phenols) and inorganic compounds, the result of leaching from site soils. In general, the contaminants are expected to flow at rates less than groundwater. Groundwater migration is expected to spread the contamination in the direction of groundwater flow (southeasterly) and vertically downward to lower water bearing zones. As the contamination migrates, the natural organic carbon in the soil will adsorb many of the detected compounds, thus slowing the advance of the plume. Horizontal migration rates of select VOCs and SVOCs were calculated to be about two to 71 times slower than overburden groundwater (approximately 6 feet per year). VOCs will also be attenuated in response to dispersion, volatilization, and degradation, among other factors.

Analytical test results from the bedrock groundwater monitoring wells indicate the presence of numerous site contaminants, including VOCs, SVOCs (primarily phenols), and inorganic compounds. This, along with groundwater elevation data from the wells indicating a slight downward vertical gradient, indicates a hydraulic connection between the overburden and bedrock groundwater bearing zones and the discharge of overburden groundwater into the bedrock groundwater. The contaminants in the fractured bedrock are expected to flow at rates less than groundwater, which is estimated to be 90 and 290 feet per year for fracture zones A and B, respectively. (Based on the limited number of wells in the C-fracture zone, estimates of groundwater flow velocity in this zone could not be determined.) In addition, the New Road and Falls Street tunnels are expected to intercept the A-zone and B-zone bedrock groundwater. It is anticipated that some portions of the bedrock groundwater flow may be impacting off-site properties prior to entering the tunnels, based on the measured direction of groundwater flow. It is also probable that downward migration of VOCs into the lower bedrock (C-zone fracture system and below) occurs via connected vertical fractures in the bedrock.

VOCs within the site overburden groundwater and soils may also volatilize into the unsaturated soil zone. Soil vapors may discharge into the atmosphere, and into on-site or off-site subsurface structures such as basements, manholes, or sumps. In addition, volatilization of VOCs may occur at groundwater discharge locations, such as sumps, stormwater tunnels, and/or surface water features.

Qualitative Human Health Risk Evaluation

Chemicals of potential concern (COPCs) identified by the preliminary screening in both soil and groundwater were evaluated along with current and potential future exposure pathways with respect to potential human exposure. Since the Frontier Chemical Site is currently an inactive industrial site, current human receptors would include site visitors and possibly trespassers. If the site were redeveloped, site workers could be exposed to soil contaminants by the same pathways that currently exist for visitors, but the magnitude of potential worker exposures would be much greater due to the expected higher intake rates, greater exposure frequency, and longer exposure duration. Comparisons of chemical concentrations in subsurface soils to risk-based concentrations developed for industrial soil, indicate that the risks to future workers from long-term exposure to site soil contamination will not exceed risk levels regarded as acceptable by the United States Environmental Protection Agency (USEPA). Risk to current and future visitors, whose potential exposures are considerably less than workers, are well below levels of concern.

In addition, under existing site conditions, with no groundwater use, there is no pathway for direct contact with contaminated groundwater. However, vapors from volatile groundwater contaminants can migrate upward through the soil and be released to ambient air through sewer manholes, cracks in pavement, or in unpaved areas to ambient air, potentially exposing site visitors via the inhalation route. Site visitors' exposures are not likely to reach levels of concern because the total exposure time from infrequent short-duration visits will be relatively small. If the site were redeveloped for commercial or industrial use, the magnitude of water exposures would be expected to be greater due to higher frequency and longer duration of exposure and possible exposures to higher vapor concentrations in indoor air. Inhalation of vapors from the highest concentrations of vinyl chloride and TCE in groundwater could pose significant cancer risks to future site workers. If groundwater was used in the plant processes, worker exposures from incidental contact and vapor inhalation would be even greater and might reach levels associated with unacceptably high cancer risks and other adverse health effects.

During site redevelopment, construction workers involved in soil excavation and installation of building foundations and subsurface utilities could be exposed via direct contact with contaminated subsurface soils and inhalation of vapors within excavations and manholes at levels that might pose health risks. Appropriate protective measures should be used during construction work to limit potential exposures.

1

Introduction

1.1 Purpose of the Supplemental Remedial Investigation

Ecology and Environment Engineering, P.C. (E & E) performed a Supplemental Remedial Investigation (SRI) at the former Frontier Chemical Waste Process, Inc. (Frontier Chemical) Site (Site No. 9-32-110) located in Niagara Falls, New York. This work was performed under the State Superfund Contract Work Assignment No. D003493-30 issued April 10, 2001, by the New York State Department of Environmental Conservation (NYSDEC), Division of Environmental Remediation.

The purpose of this SRI was to:

- Compare current groundwater quality with data obtained in previous investigations;
- Evaluate the degree and extent of subsurface soil contamination across the site;
- Evaluate the nature, extent, and location of potential source areas of the waste previously identified at the site;
- Further evaluate pathways of contaminant migration; and
- Evaluate the off-site contaminant loading into the adjacent sewer tunnels.

1.2 Site Background

1.2.1 Site Description

The former Frontier Chemical facility occupied approximately 9 acres, bordered by Royal Avenue to the south and 47th Street to the east, in the city of Niagara Falls, New York (see Figure 1-1). The Niagara River lies within 1 mile south of this site.

The facility treated chemical wastes from 1974 until December 1992, when the facility closed. The solid waste management units (SWMUs) at the facility included:

- A treatment and pretreatment system for aqueous waste;
- Synthetic fuel-blending system for waste solvents/oils;
- A solvent recovery system;
- Bulk and drummed material handling, storage, and transfer facilities; and
- A hydrolysis process, tanks, old surface impoundments, an old waste pile, and site trucks.

When in operation, the active waste management units treated or stored approximately 25,140 tons of chemical wastes each year. The waste, which came from businesses located in the eastern United States and southeastern Canada, can be classified as Resource Conservation and Recovery Act (RCRA)-listed wastes, as well as RCRA-characteristic wastes.

There are three fractured bedrock aquifers present beneath this site in the upper bedrock (A-fracture zone, B-fracture zone, and C-fracture zone). Groundwater from both the overburden and upper bedrock aquifers flows generally in a southeasterly direction. Although the flow is toward the Niagara River, it is intersected by two unlined open rock tunnels: the New Road Tunnel (east of the site), and the Falls Street Tunnel (south of the site). Water from the New Road Tunnel empties into the Falls Street Tunnel at the intersection of 47th Street and Royal Avenue, southeast of the site. During periods of no precipitation, water flowing through these tunnels is treated by the city of Niagara Falls Sewage Treatment Plant prior to discharge to the Niagara River. This is accomplished through the diversion of water from the Falls Street Tunnel, by several diversion weirs adjacent to and further downstream of the Frontier Site, to the adjacent lined Southside Interceptor Tunnel. The Southside Interceptor Tunnel conveys the water directly to the treatment plant for treatment. However, during periods of precipitation, the potential exists for water in the Falls Street Tunnel to go over the diversion weirs and continue to flow in an easterly direction in the Falls Street Tunnel toward the South Gorge Interceptor. In order for water to continue down the Falls Street Tunnel past the diversion weirs, the volume of water would have to exceed the holding capacity of the Southside Interceptor Tunnel. The treatment plant uses the Southside Interceptor Tunnel for water storage prior to treatment under high flow conditions. Water that bypasses the diversion weirs and remains in the Falls Street Tunnel eventually travels through the South Gorge Interceptor where it is diverted north to the Gorge Pumping Station. Water from the Gorge Pumping Station is pumped back (in a southeast direction) to the treatment plant. However, under periods of heavy precipitation (high flow in the system) water in the South Gorge Interceptor may also overflow to the South Gorge Interceptor outfall, allowing untreated water to empty into the Niagara River.

The United States Environmental Protection Agency (USEPA) and NYSDEC added Frontier Chemical to the list of sites that contribute a significant amount of contaminants to the Niagara River after extensive groundwater investigation revealed the following chemicals at the site: monochlorotoluene (MCT), methylene chloride, chloroform, dichlorobenzene, tetrachloroethene (PCE) and other organic contaminants. Based on the high concentration detected in groundwater (71% of compound solubility), dense non-aqueous phase liquid (DNAPL) is believed to be present at the northern and southern edge of the facility. During previous investigations at the site, DNAPL was reported to be present in several site monitoring wells (Golder 1986 and 1988; Ecco, Inc. 1990 and 1991).

Beginning in 1999, most of the site's buildings were demolished, the rubble remained on site, and several existing monitoring wells were damaged or destroyed.

1.2.2 Site History

The site, located at 4626 Royal Avenue in Niagara Falls, New York, was originally developed in 1906 by ISCO Chemical Company (ISCO) as a caustic-chlorine plant. During World War II, the International Minerals and Chemicals Corporation bought the site and operated the facility as a caustic soda/potash and chlorine plant. Figure 1-2, dated 1954, illustrates site features prior to Frontier Chemical's operations. In 1974 Frontier Chemical, which provided hazardous and nonhazardous chemical treatment, moved their company to the site from Pendleton, New York. Frontier Chemical expanded its operation, which included wastewater treatment, fuels blending, and bulking chemicals for off-site disposal. Figures 1-3, dated 1979, and 1-4, dated 1984, illustrate site features during Frontier Chemical's operations.

In 1985, Frontier Chemical and a sister company, BLT Services, Inc., became wholly owned subsidiaries of Environmental Services Associates, Inc. (ESA). In February 1990, ROE Consolidated Holdings (ROE) obtained 39% of ESA's stock and assumed operational control of ESA, which had operational control of the site.

Several environmental investigations have been conducted at the site over the past 21 years. Table 1-1 provides a chronological history of activities conducted at the site.

The first environmental investigation was conducted by Wehran Engineering Corp. in 1981 (Wehran Engineering Corp. 1982). The purpose of this investigation was to define the nature of the subsurface geologic materials at the site; determine the existence, direction, and rate of flow through groundwater; and establish a groundwater monitoring system for the Frontier Chemical facility.

In February 1985, Thomsen Associates (Empire Soils Investigations, Inc., [Empire]) conducted a hydrogeologic investigation for Frontier Chemical to comply with the NYSDEC requirements for groundwater monitoring at the facility

(Thomsen Associates 1985a). In June 1985, Empire completed the report that evaluated the Frontier site groundwater quality (Thomsen Associates 1985b). In 1986, Planning Research Corporation completed a preliminary assessment for USEPA to comply with the 1984 RCRA Hazardous and Solid Waste Amendments (PRC 1986). A regional and historic data review was later conducted by Golder Associates for Frontier Chemical as part of a groundwater investigation at the site (Golder 1986). In April 1988, Golder Associates then conducted a Phase I and II hydrogeological investigation as part of the ongoing process of investigation to determine the sources and extent of groundwater contamination at the site (Golder 1988). Ecco, Inc., followed these investigations with a Phase III hydrogeologic investigation for Frontier Chemical in 1990 to evaluate the overburden and bedrock stratigraphy to define potential migration pathways, off-site loading, baseline cancer risk assessment, and potential remediation measures (Ecco, Inc. 1990). Using the data from this investigation, Ecco, Inc., submitted a Final Interim Remedial Measure Report to prevent further expansion of the areal and vertical extent of groundwater contamination while a detailed site remediation program was being developed (Ecco, Inc. 1991).

In August 1991, Eagle Vision Environmental (EVE) became the site's new management. Most of the Frontier Chemical staff was terminated in August 1992 due financial difficulties and the company went bankrupt in 1992. After the layoffs, there were several reported releases of Comprehensive Environmental Response Compensation and Liability Act (CERCLA) hazardous substances from storage drums. On December 4, 1992, NYSDEC closed the site with the execution of a "Modification to Summary Abatement and Notice of Hearing" and issued an Order of Consent requiring the owner to begin cleanup of the site by removing all stored waste from the facility. When the company failed to meet the required deadline for waste removal, the state requested that USEPA secure the site and begin a Superfund Response Action to remove the waste. On December 22, 1992, USEPA began removal activities with an Emergency Response Cleanup Service (ERCS) and 24-hour security at the site. On September 30, 1993, a Phase I removal was initiated by the Potentially Responsible Party (PRP) group to address 4,092 drums and 6,700 pounds of laboratory chemicals on site.

Phase I began in October 1993, after approximately five months of negotiations with 430 PRPs. The PRPs hired a cleanup contractor to remove all laboratory chemicals and drums from the site and send them to multiple disposal facilities. This field work was completed in May 1994 and all wastes were subsequently destroyed at off-site disposal facilities.

In September 1994, Blasland, Bouck and Lee, Inc. (BBL) completed a Removal Action Plan to characterize the contents of the tanks addressed in the Phase I removal. In August 1995, Conestoga-Rovers and Associates (CRA) submitted the Phase I Drum Removal Action Completion Report to USEPA.

A Phase II removal action dealt with enforcement actions for the removal of all wastes from the 45 tanks on site.

Phase II began in July 1994, after approximately three months of negotiations with over 400 PRPs. A consultant hired by the PRPs sampled the tanks and prepared a removal action plan that was approved by USEPA. Removal of the tank wastes was completed in March 1995.

Sometime in 1999, 5335 River Road, Inc., the current site owner, began demolition of the site's buildings. Demolition was completed in September 2001. Figure 1-5, dated 2001, illustrates current site conditions.

1.2.3 Conceptual Site Model

Although operations at the Frontier Chemical site ceased in 1994, residual contamination exists in the underlying overburden and bedrock. The soils were not analytically characterized in previous investigations, however groundwater contamination was identified in both the overburden and underlying bedrock. The investigations conducted to date have identified and characterized four water-bearing zones beneath the site:

- One water-bearing zone in the overburden consists of perched water in the fill, glaciolacustrine deposits, and basal till deposits; and

- Three water-bearing zones in the bedrock consist of the A-fracture zone, B-fracture zone, and C-fracture zone.

The overburden ranges in thickness from approximately 12 to 18 feet. It is composed of up to 8 feet of fill (topsoil, clayey silt, silt, sand, and gravel with some cinder blocks, glass, wood, slag, bricks, crushed stone, concrete, asphalt, and white lime residue) followed by 5 to 10 feet of glaciolacustrine deposits (interbedded clays, silts, and sands) and a basal glacial till (gravel, sand, silt, and clay mix) overlying the top of bedrock. The bedrock is Lockport Dolostone, which consists of several hydraulic zones. The first zone (Zone 1) is a 2- to 5-foot-thick weathered zone with a 1.5- to 2-foot-thick high-permeability zone near the top. This zone is commonly referred to as the A-fracture zone. This zone is followed by an 8- to 10-foot unweathered thick bedded zone of lower permeability (Zone 2). At the base of Zone 2 is a 1-to 2-foot-thick high-permeability marker bed referred to as the B-fracture zone. The B-fracture zone varies in thickness from 1 to 4 feet. Beneath this zone is Zone 3, which is a medium- to thick-bedded fossiliferous zone. Within this zone, the C-fracture zone was identified through in situ aquifer testing (i.e., packer tests) (Ecco, Inc. 1990). The C-fracture zone is approximately 20 feet below the B-fracture zone and is not as distinct and permeable as the A- and B-fracture zones.

Groundwater beneath the site generally flows from northwest to southeast. Vertical hydraulic gradient is slightly downward between the overburden and the A-and B-fracture zones; however, a slight upward gradient between the C and B-fracture zones was reported in Ecco, Inc. 1990. In addition, the site is bordered on the east and south by large-diameter unlined open rock storm sewer tunnels (New Road and Falls Street tunnels, respectively) that intersect the B-fracture zone. In previous investigations it was determined that groundwater from this zone enters the sewer tunnels. Groundwater from the overburden and A-fracture zone is also believed to enter the sewer tunnels through fractures created from blasting during tunnel construction. During periods of no precipitation, water flowing through these tunnels is treated by the city of Niagara Falls Sewage Treatment Plant prior to discharge to the Niagara River. This is accomplished through the diversion of water from the Falls Street Tunnel, by several diversion weirs adjacent to and further downstream of the Frontier Site, to the adjacent lined Southside Interceptor Tunnel. The Southside Interceptor Tunnel conveys the water directly to the treatment plant for treatment. However, during periods of precipitation, the potential exists for water in the Falls Street Tunnel to go over the diversion weirs and continue to flow in an easterly direction in the Falls Street Tunnel toward the South Gorge Interceptor. In order for water to continue down the Falls Street Tunnel past the diversion weirs, the volume of water would have to exceed the holding capacity of the Southside Interceptor Tunnel. The treatment plant uses the Southside Interceptor Tunnel for water storage prior to treatment under high flow conditions. Water that bypasses the diversion weirs and remains in the Falls Street Tunnel eventually travels through the South Gorge Interceptor where it is diverted north to the Gorge Pumping Station. Water from the Gorge Pumping Station is pumped back (in a southeast direction) to the treatment plant. However, under periods of heavy precipitation (high flow in the system) water in the South Gorge Interceptor may also overflow to the South Gorge Interceptor outfall, allowing untreated water to empty into the Niagara River.

2 Supplemental Remedial Investigation Activities

2.1 Introduction

The SRI at the Frontier Chemical site consisted of several activities conducted to identify the physical characteristics of the study area. These activities included: a site reconnaissance; records search; subsurface soil and groundwater investigations and sampling; and development of a site base map. Field activities were conducted between October 15 and December 5, 2001. During this effort, 11 Geoprobe piezometers, nine Geoprobe boreholes, and 11 monitoring wells were drilled, installed, and sampled, and 46 existing wells were sampled. Four test pits were also excavated along utility lines to investigate potential pathways of contaminant migration from the site.

Drilling, Geoprobing, and excavation activities were conducted by SJB Services, Inc., under the supervision of an E & E and Watts Engineers, P.C. (Watts) field team. The team consisted of one geologist and one environmental scientist, respectively. In accordance with the Site-specific Health and Safety Plan (HASP), a health and safety officer was on site throughout the field program to ensure that personnel were protected from site hazards. Appropriate protective clothing was worn by site workers while performing intrusive activities for protection against contamination and to prevent cross-contamination between sample locations. An organic vapor analyzer (OVA) was used to assess the concentration of volatile organic compounds (VOCs) in the workers' breathing zone, excavation trenches, boreholes, and soil and water samples. VOC concentrations above background levels were screened for methane content using a carbon filter (e.g., methane passes through the carbon while most other hazardous VOCs are adsorbed). In addition to these instruments, an oxygen/explosimeter was used during intrusive activities to monitor potential explosive conditions.

The methodologies and specific goals of each of the aforementioned activities are described below in Sections 2.2 through 2.6.

2.2 Site Reconnaissance

Prior to work plan development, a site reconnaissance was conducted at the Frontier Chemical site on May 29, 2001, which included representatives from NYSDEC, New York State Department of Health (NYSDOH), and E & E. It was noted during the visit that 80 to 90% of the site structures (buildings and tanks) had been demolished and that the rubble was stockpiled across the entire central portion of the site. Some of the remaining features included the truck scale and associated building in the northeast corner of the site, tanks in the central portion of the site, buildings on the west and southern portions of the site, and less than 10 drums containing solid materials were noted in the rubble of former Drum Storage DS-3. Demolition began sometime in 1999. In June 2000, NYSDEC Region 9 performed a well inventory at the site. Of the 76 wells installed on site, five were abandoned under previous investigations, one was reported as destroyed in 1985, 54 were found, and 15 were missing. Of the 54 wells that were found, six were damaged, probably from demolition activities. The remaining 15 missing wells are believed to have been destroyed by the demolition activities. Three of the missing wells (MW-88-9OB, -9A, and -9B) were found on May 29, 2001, but the casings were sheared off at ground surface. Appendix A contains photographs of the site from the May 29th reconnaissance.

During a subsequent site visit on September 7, 2001, the rubble had been moved and stockpiled in the southeast corner of the site. All of the on-site roads were cleared of debris allowing vehicle access, and 11 of the damaged well casings were repaired. The debris removal and well repair was conducted by Ontario Specialty. Figures 1-3 and 1-4 illustrate site conditions during Frontier Chemical's operation, and Figure 1-5 illustrates current site conditions.

Prior to initiation of field activities, a final site inspection was conducted. The purpose of this inspection was to record depth to groundwater and total well depths in all wells, and replace all well locks. Based on these activities, it was determined that of the 76 original site wells, 17 have been decommissioned or destroyed, 11 were repaired, and 13 remain unusable (which includes five of the repaired wells). Based on this information, the final determination was to replace nine wells in key areas of the site. The key areas were chosen based on contaminants detected in the 1990 Ecco, Inc., investigation.

2.3 Record Search

E & E met with the NYSDEC Region 9 site representative on May 4, 2001. Pertinent historical site investigation reports were briefly reviewed and sent out to be copied on that day. The copies were received by E & E on May 10, 2001. E & E then performed a comprehensive review of the reports prior to developing the work plan. A summary of historical events and available reports is presented in Table 1-1.

In addition to reviewing NYSDEC files, the City of Niagara Falls Department of Wastewater Facilities was contacted for utility drawings and Environmental Data Resources, Inc., was contacted for a Sanborn map report. The following drawings were obtained from the city of Niagara Falls:

- 1934: Diversion Sewer Drawings;

- 1972: CDM Contract 3, Sheet 25.5;
- 1978: CDM-SSI Contract 3, Sheet 5 As-Built;
- 1982: CDM Figure A (FST Plant Profile);
- 1989: DeLeuw Cather Utility Sheet; and
- 1997: FST Obstruction Investigation Map.

The Sanborn map report included six insurance maps from 1950, 1955, 1958, 1965, 1979, and 1985. A copy of the Sanborn map report is provided in Appendix B.

2.4 Subsurface Soil Investigation

Subsurface soil sampling was conducted during three investigative activities at the site: drilling for monitoring well installations; geoprobing for piezometer installations; and test pit excavations. Each activity is described below.

2.4.1 Monitoring Well Drilling

Eleven monitoring wells were drilled and installed between October 15 and 25, 2001 (see Figure 2-1 [back pocket]). A truck-mounted CME-75 drill rig was used to install six overburden, four shallow bedrock (A-fracture zone), and one intermediate bedrock (B-fracture zone) wells on site.

The six overburden well boreholes were advanced through the overburden using 4.25-inch hollow stem augers with continuous split-spoon sampling in accordance with the E & E July 2001 work plan. The five shallow bedrock well boreholes were advanced through the overburden using 6.25-inch hollow stem augers. Continuous split-spoon sampling in the shallow bedrock boreholes only occurred at MW-01-9A, in accordance with the July 2001 work plan. The 11 monitoring well boring logs are presented in Appendix C. Table 2-1 summarizes the standard penetration test data recorded during split-spoon sampling activities. At least one subsurface soil sample was collected from each split-spooned borehole. However, due to the extensive nature of contamination on site, two soil samples were collected from two well locations [MW-01-1OB and BH87-4B(R)]. Table 2-2 provides a summary of the samples collected, including the sample number, date, depth, instrument reading, analyses, and soil description.

In addition to the field samples, quality assurance/quality control (QA/QC) samples, including duplicate samples, trip blanks, and matrix spike/matrix spike duplicates (MS/MSDs), were also collected. All samples were submitted to E & E's Analytical Services Center (ASC) for analysis. Results of QA/QC samples are discussed in Section 4, and subsurface soils results are discussed in Section 5.

2.4.2 Geoprobe Survey

Twenty Geoprobe boreholes were drilled and 11 piezometers were installed between October 26 and 30, 2001 (see Figure 2-1). The boreholes were advanced through the overburden using a truck-mounted Simco Geoprobe rig with continuous subsurface soil sampling in accordance with the July 2001 work plan. Geoprobe boring logs are presented in Appendix C. One subsurface soil sample was collected from the most contaminated interval in each borehole. Table 2-2 provides a summary of the samples collected, including the sample number, date, depth, instrument reading, analyses, and soil description.

2.4.3 Test Pit Excavations

Four test pits (TP-01-1 through TP-01-4) were excavated and backfilled on November 8, 2001 (see Figure 2-1). The purpose of the test pit excavations was to determine if off-site contaminant is migrating along the bedding material surrounding buried utilities. Test pit locations were selected based on physical site features and the maps received from the Town of Niagara Falls Water and Sewer Department. Test pits were excavated with a JCB 215 backhoe per the methodology described in the work plan (E & E 2001). No soil samples were collected from the test pits because no unusual soil conditions were encountered. Table 2-3 provides a summary of test pit excavation data including the date of excavation, depth, length, air monitoring readings, and soil description.

2.5 Groundwater Investigation

2.5.1 Monitoring Well Installation and Development

As stated in Section 2.4.3, one groundwater monitoring well was installed in each of the 11 boreholes drilled at the site (see Figure 2-1). All drill cuttings were visually inspected for signs of contamination and screened with an OVA. Drill cuttings suspected of containing contamination were placed in 55-gallon drums. The drums were labeled and staged on site. All decontamination water and well-development purge water was containerized in one of the two 1,500-gallon polyethylene tanks. An inventory of all investigation-derived waste (IDW) is presented in Appendix D.

2.5.1.1 Overburden Monitoring Well Installation

One groundwater monitoring well was installed in each of the six overburden monitoring well boreholes. As per the work plan (E & E 2001), all overburden wells were constructed of 2-inch internal diameter (ID) polyvinyl chloride (PVC) casing and 10-foot segments of 0.010-inch machine-slotted screen. A sand filter pack was placed around each well screen from the bottom of the borehole to 2 feet above the top of the screen. The sand filter pack was followed by a 2-foot thick bentonite chip seal. Following a minimum one half-hour wait that allowed the chips to hydrate, bentonite/cement grout was installed from the top of the seal to the ground surface. Tables 2-4 and 2-5 summarize the monitoring well drilling and construction data, respectively, and the well borelogs are presented in Appendix C. Table 2-6 summarizes well construction data for existing site wells. Note that some of the wells have been decommissioned, destroyed, damaged, and repaired. Nine of the 11 wells installed during this investigation replaced damaged, destroyed, or unusable wells. The other two wells were installed to fill data gaps. Only wells deemed critical in determining the nature and extent of contamination (based on results of previous investigations) were replaced.

2.5.1.2 Shallow Bedrock Monitoring Well Installation

Four shallow bedrock (A-fracture zone) groundwater monitoring wells were installed using 4-inch carbon steel set into the top of bedrock to prevent cross-contamination between the overburden and shallow bedrock aquifers. The overburden was drilled using 6.25-inch hollow stem augers. Continuous split-spoon sampling was only performed in MW-01-9A to fill soil data gaps because the other A-fracture wells were installed adjacent to newly installed overburden wells which underwent continuous split-spoon sampling. The overburden was sealed off with 4-inch outer diameter (OD) carbon steel casing set 1 to 2 feet below the top of rock. The rock socket was drilled with a 5⅞-inch roller bit. Bedrock drilling continued no sooner than 24 hours after the steel casing was grouted in place. Bedrock drilling was performed using HQ rock coring (3-15/16 inch OD) methods 5 feet into the bedrock as per the work plan (E & E 2001). All bedrock wells were completed as open-hole wells. Each of the four shallow bedrock wells lost 50 to 110 gallons of drill water during the rock core drilling. A summary of drilling parameters including well number, date started and completed, total depth, number of split-spoon samples, drilling type, and well type is presented in Table 2-4; and well boring logs are presented in Appendix C. A summary of the rock quality designation (RQD) from the rock cores is provided in Table 2-7. RQD is a quantitative index developed by Deere in 1963 to log cores. It provides a preliminary estimate of the variation of the in situ rock mass properties from those of the sound portion of the rock core. All rock cores were placed in wooden core boxes and stored in the on-site shed located along the eastern edge of the site at the completion of the investigation.

2.5.1.3 Intermediate Bedrock Monitoring Well Installation

One intermediate bedrock (B-fracture zone) groundwater monitoring well was installed using a telescoping casing (i.e., 6-inch carbon steel and 4-inch carbon steel casings) designed to prevent cross-contamination between the overburden and shallow bedrock (A-fracture zone) aquifers. The overburden was drilled using 8.25-inch hollow stem augers and the overburden was sealed off with 6-inch OD carbon steel casing set 1.5 feet below top of rock. The rock socket was drilled with a 7⅞-inch roller bit. Bedrock drilling continued no sooner than 24 hours after the 6-inch steel casing was grouted in place. A 4-inch inch OD carbon steel casing was set 10 feet below the 6-inch casing after a 5⅞-inch roller bit was drilled to 27 feet below ground surface (BGS). The second round of bedrock drilling continued no sooner than 24 hours after the 4-inch steel casing was grouted in place. Bedrock drilling was performed using HQ rock coring (3-15/16 inch OD) methods 5 feet into the bedrock as per the work plan (E & E 2001) and completed as open-hole bedrock well. Approximately 85 gallons of drill water was lost to the bedrock during the rock core drilling. A summary of drilling parameters including well number, date started and completed, total depth, number of split-spoon samples, drilling type, and well type is presented in Table 2-4; and well boring logs are presented in Appendix C. A summary of the RQD from the HQ cores is provided in Table 2-7. All rock cores were placed in wooden core boxes and stored in the on-site shed located along the eastern edge of the site at the completion of the investigation.

2.5.1.4 Monitoring Well Development

Monitoring well development was performed on all of the newly installed wells between November 1 to 14, 2001 by the E & E and Watts field team. The development was performed no sooner than 24 hours following grout placement using dedicated polyethylene bailers and new nylon bailer cord as described in the work plan (E & E 2001). Temperature, pH, conductivity, and turbidity readings were recorded to monitor the progress of the development process. Appendix C contains the well development records for each well.

2.5.2 Piezometer Installation

Upon completion of the 20 Geoprobe boreholes, 1-inch ID piezometers were installed in 11 of the direct-push boreholes to the top of bedrock. All 11 piezometers were constructed with 5-foot long flush joint Schedule 40, 0.010-inch machine-slotted PVC screens with threaded bottom plugs and flush-threaded PVC riser pipe to approximately 2 feet above ground surface. The formation was initially allowed to naturally collapse around the piezometer screen. However, the collapse did not fully occur, so silica sand was installed to 1 foot BGS and the annulus was sealed with granular bentonite. The piezometers were secured with a locking cap. Piezometer construction is summarized in Table 2-8 and direct-push borelogs are presented in Appendix C.

2.5.3 Groundwater Sampling

Groundwater samples were collected from the 11 newly installed monitoring wells, 46 existing monitoring wells, and 11 piezometers (see Figure 2-1) on November 6 to December 5, 2001, by the E & E and Watts field team.

2.5.3.1 Monitoring Well Sampling

Prior to sampling of the monitoring wells, static water levels were measured in each well. The volume of water in each well was then calculated, and at least three volumes of water standing in the well casing were removed, or the well was purged dry. The same dedicated polyethylene bailers and nylon cord used for the new well development were also used for sampling. Temperature, pH, conductivity, and turbidity measurements were recorded throughout the well purging process, and immediately prior to sampling. As with development water, all purge water was placed in one of the two 1,500-gallon polyethylene tanks located on site. An inventory of all IDW is presented in Appendix D. Table 2-9 presents sample numbers, dates, well descriptions, analyses, and field chemistry readings at the time of sampling.

In addition to the field samples, QA/QC samples including trip blanks were also collected. All samples were submitted to E & E's ASC for analysis. Results of QA/QC samples are discussed in Section 4, and well results are discussed in Section 5.

2.5.3.2 Piezometer Sampling

One-inch dedicated polyethylene bailers and nylon cord were used to sample the 11 piezometers. The piezometers were not developed prior to sampling, however, they were purged at least three well volumes.

In addition to the field samples, QA/QC samples including trip blanks were also collected. All samples were submitted to E & E's ASC for analysis. Results of QA/QC samples are discussed in Section 4, and well results are discussed in Section 5.

2.6 Base Map Development/Site Survey

A detailed topographic base map of the Frontier Chemical site and immediate vicinity was developed by a McIntosh & McIntosh, P.C. (McIntosh) survey crew. The fieldwork for this survey was performed from November 12 to 16, 2001. The base map was prepared by performing a ground survey and using an existing site base map. Horizontal control was established using a local magnetic azimuth, and vertical control was established using a elevation of 581.24 feet assigned to Bench Mark #1 (square cut on northwest corner of concrete footer at northwest leg of transmission tower #LN 32 TWR97) and 572.86 assigned to Bench Mark #2 (cut "X" on north-northeast bonnet bolt of hydrant on west side of 47th Street). All relevant features on site and in adjacent areas (e.g., buildings, power poles, manhole covers, etc.) were plotted on a scale of 1 inch equals 40 feet. Figure 2-1 illustrates the base map generated for this investigation.

3 Physical Characteristics of Study Area

3.1 Physiography and Topography

The study area is located in Niagara County, New York, approximately 1 mile north of the Niagara River within the town of Niagara Falls. Niagara County lies within the eastern part of the Central Lowland Province. The Central Lowland Province in the vicinity of the site is composed of late Ordovician to Silurian rocks formed over 400 million years ago. These rocks were formed in a variety of shallow sea environments covering the area during the Silurian period (Isachsen et al. 1991). These Ordovician and Silurian sequences are comprised of limestone, shale, siltstone, sandstone, and conglomerates formed during the advance and retreat of shallow seas. The Frontier Chemical Site is located within the Huron Plain, in an area dominated by the Lockport Group created from sediments deposited in a shallow shelf to a carbonate flat environment.

3.2 Geology

3.2.1 Regional Geology

Niagara County is almost entirely covered by glacial sediments with minor amounts of alluvial deposits along present day streams. Glacial deposits throughout the county range in composition and morphology from deep layers of glacial till, to outwash plains and lacustrine sediments formed in glacial lakes. Glacial till, which was deposited directly by glacial ice, consists of a mixture of unsorted, compacted boulders, gravel, sand and clay up to 10 feet thick. Lacustrine deposits, which were deposited in glacial lakes that formed along the margins of the ice sheets, consist primarily of clay up to 20 feet thick, with lenses of silt and fine sand. The lacustrine clays and silts that underlay the town of Niagara Falls were the result of the Wisconsin ice sheet that covered the area 13,000 to 20,000 years ago. The retreat of the Wisconsin ice sheet formed the glacial Lake Lundy, which is responsible for most of the reddish sediments and soils in the area. In the Niagara Falls area, overburden thickness ranges from less than 1 foot near the Niagara Escarpment to more than 80 feet along Tonawanda Creek.

Niagara County is covered by parts of the Huron and Ontario Plains, with the Ontario plain extending from the shores of Lake Ontario to the foot of the Niagara Escarpment. The Huron Plain extends from the Niagara Escarpment southward beyond the county line to the Onondaga Escarpment (Onondaga limestone exposure). The Niagara Escarpment consists of a steep northward sloping Lockport dolomite exposure, with the crest elevation slightly more than 600 feet above mean sea level (AMSL). The nearly level Ontario Plain topographically slopes from the escarpment at a rate of 20 feet per mile towards Lake Ontario (8 miles north of the escarpment). The topography is mostly uniform except for a few shallow stream valleys that generally trend northeast-southwest. The nearly level Huron Plain occupies approximately half of the county and gently slopes westward from over 600 feet AMSL in the east (Dysinger) to 570 feet AMSL at the mouth of Tonawanda Creek. The level topography is interrupted by narrow, irregular ridges that trend in a northeast-southwest direction. These ridges demonstrate 20 to 50 feet of relief and range from 1.4 to 2 miles in length (USDA SCS 1972).

Niagara County bedrock consists of Late Ordovician to Silurian age sedimentary rocks including the Richmond, Medina, Clinton, and Lockport Groups (see Figure 3-1). These bedrock units are nearly flat, representing a homoclinal structure with an east-west strike and dip to the south approximately 25 to 30 feet per mile (E & E 1995). The Lockport Group, consisting of shale, dolostone, and limestone deposited during the late Silurian period in shallow shelf environments, is the most common bedrock unit found in and around the city of Niagara Falls. The lower Lockport (Gasport Formation) is comprised of limestone and dolostone formed in a shallow, warm, clear, shelf environment containing a variety of fossil life, which is in stark contrast with the underlying lifeless limestone. The middle Lockport (several formations) is comprised mostly of dolostone with some chert and few fossils (mostly snails and clams) formed in a very shallow shelf to a carbonate flat environment (Isachsen et al. 1991). The Lockport Dolomite is the uppermost bedrock unit and is defined as a coarse crystalline, thin to massive, bedded dolomite, limestone, and shaly dolomite, with vugs containing primarily gypsum and calcite (Tesmer 1981). The Lockport Dolomite is approximately 150 feet thick and is characterized by fractures caused by successive periods of tectonic activity during the Paleozoic. Regional fracture (joint) orientations trend northeast-southwest as a result of the Taconic Orogeny, and northwest-southeast as a result of the Acadian Orogeny.

3.2.2 Site Geology

Overburden

The site exhibits little relief with elevations around 570 feet AMSL (USGS 1980). The detailed Niagara County soil survey does not extend to the site location, but two general soil types have been classified near the site (approximately 0.5 mile north): Cut and Fill Land and Odessa Silt Clay Loam Series (Oda) (USDA SCS 1972). Cut and Fill Land represents areas where the original soil has been stripped and removed or are covered with more than three feet of material. This land type is a mixture of materials that have little or no profile development and is the result of construction operations including borrow areas, fill areas, dikes, canal spoils, and dredgings (USDA SCS 1972).

The Odessa Silty Clay Loam Series consists of deep, moderately fine textured, poorly drained soils found on nearly level slopes (0 to 2%). These soils are found south of the Niagara Escarpment and were formed in glacial lacustrine environments where calcareous clay is dominant. Glacial till is typically within 8 feet of the surface in many areas. The general soil profile is firm brown to light reddish-brown silty clay overlain by a dark grayish-brown silty clay loam surface layer 8 inches thick (USDA SCS 1972).

The nature of the overburden was characterized during this investigation through test pit excavations and split-spoon sampling. The overburden thickness encountered during borehole investigations (split spooning) ranged from 14.7 to 17.1 feet. It consists of up to 2 feet of fill material (topsoil, silt, sand, and gravel with some cinder blocks, glass, wood, slag, bricks, crushed stone, concrete, and asphalt) followed by 12 to 15 feet of silty clays overlying the bedrock (see Figures 3-2 and 3-3). The natural soils encountered generally consisted of brown to red to green silty clays, or fine sand and silt, with trace gravel at most localities. Blow counts recorded during split-spoon sampling indicate a loose to medium relative density soils (see Table 2-1).

Bedrock

Based on this and previous investigations, the bedrock underneath the site is Lockport Dolomite. The upper bedrock contains several hydraulic fracture zones caused by the tectonic activity during the Paleozoic (see Figures 3-2 and 3-3). The first zone (Zone 1) is a 2- to 5-foot-thick weathered zone with an estimated 1-foot-thick high-permeability zone (A-fracture zone). This zone is followed by an 8- to 10-foot unweathered thick-bedded zone of lower permeability (Zone 2). At the base of Zone 2 is a 1-to 2-foot-thick high-permeability marker bed labeled as the B-fracture zone. The B-fracture zone varies in thickness from 1 to 4 feet. Beneath this zone is Zone 3, which is a medium- to thick-bedded fossiliferous zone. Within this zone, the C-fracture zone was identified through in-situ aquifer testing (i.e., packer tests) (Ecco, Inc. 1990). The C-fracture zone is approximately 20 feet below the marker bed and is not as distinct and permeable as the A and B zones.

Rock cores were obtained from the five SRI bedrock monitoring well locations via HQ coring. The shallow bedrock wells were cored 15 to 24 feet BGS and intermediate bedrock well MW-88-7B(R) was cored from 27.5 to 32.5 feet BGS. The cores exhibited a fair to excellent RQD (see Table 2-8), indicating competent, massively bedded dolomite. The rock was medium to hard and ranged from porous to pitted. The rock also exhibited slight to moderate weathering and very close to moderately close spaced horizontal fractures, with some vertical fractures near the top of rock.

3.3 Hydrology

3.3.1 Regional Hydrology

Niagara County is surrounded on three sides by fresh water sources that include Lake Ontario to the north, Niagara River to the west, and Tonawanda Creek to the south. Drainage of the Ontario Plain, located north of the Niagara Escarpment (Lockport dolomite exposure approximately 8 miles south of the lake), is northward into Lake Ontario. Streams on the Ontario Plain are predominantly narrow, crooked channels 10 to 30 feet deep that travel through narrow flood plains (USDA SCS 1972). There are also several broad, basin-like areas with poorly drained outlets. The Huron Plain, which includes the site, is located south of the Niagara Escarpment. Streams on the Huron Plain drain southward into Tonawanda Creek and eventually empty into the Niagara River (USDA SCS 1972).

Based on previous groundwater investigations in the Niagara Falls area, groundwater is transmitted in both overburden and bedrock aquifers. Due to the poor water quality and availability of municipal water from the Niagara River, groundwater is not extensively utilized as a potable water source in the Niagara Falls area (Woodward-Clyde 1992). In the overburden, groundwater flows through fill, glacial lacustrine, and basal till material. Groundwater flow direction is variable, with the topography, proximity of discharge/recharge sources, and dip of the bedrock controlling the flow direction. Based on previous studies in the Niagara Falls area, the overburden exhibits low transmissivity in comparison to the bedrock. The low permeability lacustrine and basal till soils reduce vertical infiltration of groundwater and tend to create localized perched water zones. The flat surface slope and the networks of underground utilities in the overburden further impede horizontal groundwater flow (Woodward-Clyde 1992). Wells screened in these lacustrine deposits commonly exhibit hydraulic conductivities on the order of 3×10^{-4} feet per day (ft/day) or less (Woodward-Clyde 1992).

As stated in Section 3.2.1, the Lockport Group (composed of dolostone, shale and limestone) is the most common bedrock unit in the Niagara Falls area. In general, the regional groundwater flow through the Lockport Group is towards the Niagara River and the Niagara Gorge. The hydraulic properties of the Lockport Group are principally governed by secondary porosity caused by fractures and vugs (dissolution cavities) widened by mineral dissolution. Successive periods of tectonic activity during the Paleozoic were responsible for stresses that caused fracturing of the bedrock. The principle water-bearing zone in the Lockport Dolomite is the upper 10 to 25 feet of the bedrock, which contains many closely spaced horizontal fractures interconnected with high-angle (vertical) fractures (E & E 1995). Nine laterally extensive horizontal fracture zones have been identified throughout the formation, two of which are within the upper 25 feet. Each fracture zone is represented by a series of fractures that range in thickness from a few inches to approximately 5 feet in some areas. Aquifer tests performed in these horizontal fracture zones indicate hydraulic conductivities of 0.2 to 200 feet per day, with a median conductivity of 40 feet per day (E & E 1995). Generally, transmissivity decreases with depth due to the weight of the overlying rock and a decrease in interconnection of horizontal and vertical fractures.

Recharge enters the weathered bedrock as infiltration of precipitation from the overlying glacial sediments when vertical and horizontal fractures intersect the bedrock surface. Recharge also enters as infiltration from the Niagara River, New York Power Authority Reservoir, and unlined city storm sewers (E & E 1995). Hydraulic monitoring of well clusters at various sites within the Niagara Falls area have shown both upward and downward vertical gradients throughout the Lockport Group (Woodward-Clyde 1992). Vertical gradients are downward in recharge areas and are upward in discharge areas. Bedrock groundwater discharges to man-made features, such as buried unlined storm sewers (Falls Street Tunnel) and the drain system surrounding the buried twin Power Authority water conduits, as well as the Niagara River.

3.3.2 Site Hydrology

3.3.2.1 Surface Water

The Frontier Chemical site is located in an industrial section of Niagara Falls, where approximately 25% of the surface area at the site is covered by grass/ vegetation and the other 75% of the surface area covered by buildings, building foundations, and pavement. Water on the grassed areas tends to collect in topographic lows before draining into the overburden. Surface drainage on the paved surfaces generally flows southward into storm sewer outfalls and then west either to the city of Niagara Falls sewage treatment facility or, during high-flow conditions, directly into the Niagara River (approximately 1 mile to the west) through the Falls Street Tunnel. Large areas of standing water were noted on the paved areas of the site during the investigation activities between October 2001 and May 2002. It appears that some of the storm sewer outfalls, especially in the central area of the site, are plugged from the demolition activities and are not draining into the Niagara Falls sewer tunnels properly.

3.3.2.2 Overburden Groundwater

The silty-clay material that comprises most of the overburden is saturated, but due to the low permeability, does not tend to yield water. Overburden groundwater generally flows to the southeast, however, there appears to be a groundwater depression in the central portion of the site resulting in flow to the northwest, west, and southwest (see Figure 3-4 [back pocket]). Horizontal gradients were calculated by dividing the difference in head between the upgradient and downgradient wells in a particular zone by the distance between the wells (see Table 3-1). The horizontal gradient in the overburden is approximately 1.95 feet per 100 feet towards the southeast, but ranges between 4.5 to 25 feet per 100 feet around the groundwater depression. Vertical gradients were calculated by dividing the difference in head between well pairs by the vertical distance between the midpoints of the screens of the two wells (see Table 3-1). The vertical gradient between the overburden and A-fracture zone is 1.58 feet/foot towards the bedrock, signifying recharge areas. In previous investigations, the groundwater depression in the central portion of the site was present with a horizontal gradient that ranged from 2.4 to 10 feet per 100 feet, but flow direction was ultimately towards the southeast. The average overburden hydraulic conductivity is approximately 2.1 x 10^{-6} feet per second based on slug and pump-test activities (Ecco, Inc. 1991).

3.3.2.3 Bedrock Groundwater

Previous investigations have identified three laterally extensive horizontal fracture zones in the upper bedrock during drilling activities. The first fracture zone (the A-fracture zone) consists of highly fractured and weathered Lockport dolomite in the upper 3 to 5 feet of the bedrock. Groundwater flow in the A-fracture zone is to the south/southeast, with a horizontal gradient of approximately 1.3 feet per 100 feet (see Figure 3-5 [back pocket] and Table 3-1). The vertical gradient between the A- and B-fracture zones is 1.04 feet per foot towards the B-fracture zone, signifying recharge areas (see Table 3-1). Previous investigations estimated horizontal flow within the A-fracture zone was 2.0 feet per 100 feet in a southerly and easterly direction, with hydraulic conductivity ranging from 5.6 x 10^{-8} ft/sec to 5.2 x 10^{-5} ft/sec based on slug and pump-test activities (Ecco, Inc. 1991). Although this previous data appears to suggest extreme heterogeneity in the A-fracture zone, the low permeability results are from the east and western portion of the site and the higher permeability results are from the central and southern portion of the site, with hydraulic conductivity ranging from 2.5 x 10^{-5} ft/sec to 5.2 x 10^{-5} ft/sec (Ecco, Inc. 1991).

The next fracture zone (the B-fracture zone) consists of a 2-foot-thick fracture zone approximately 8 to 10 feet beneath the A-fracture zone. Groundwater flow in the B-fracture zone is towards the east and the south, with a groundwater "mound" in the west-central area of the site. The horizontal gradient ranges from 2.3 feet per 100 feet from the north to the south and 4.7 feet per 100 feet from the groundwater mound in the west to the east, with an average gradient of 3.5 feet per 100 feet (see Figure 3-6 [back pocket] and Table 3-1). In previous investigations, groundwater flow was primarily in a southerly and easterly direction, similar to the A-fracture zone, and a groundwater mound was present in the west-central area of the site. The estimated average horizontal flow within the B-fracture zone was 2.4 feet per 100 feet and the average hydraulic conductivity was approximately 1.4 x 10^{-5} ft/sec based on pump-test activities (Ecco, Inc. 1991).

The third identified fracture zone (the C-fracture zone) is approximately 20 feet below the B-fracture zone. Groundwater flow direction and rate were not determined during this investigation because the demolition activities destroyed all but two C-fracture zone wells. The vertical gradient between the B- and C-fracture zones is 0.17 foot/foot towards the B-fracture zone, signifying discharge areas (see Table 3-1). In previous investigations, the C-fracture zone flow direction was southerly with a horizontal gradient of 0.7 foot per 100 feet and with an upward vertical flow gradient towards the B-fracture zone (Ecco, Inc. 1991).

The site is bordered on the east by the New Road Tunnel (which is about 6 feet wide by 5 feet high) and on the south by the Falls Street Tunnel (which is about 7 feet wide by 6 feet high). Both of these tunnels intercept the B-fracture zone. In previous investigations, it was determined that groundwater from the B-fracture zone enters the sewer tunnels. As previously stated, during periods of no precipitation, water in the Falls Street Tunnel is diverted to the Southside Interceptor, which discharges to the City of Niagara Falls Sewage Treatment Plant. However, during periods of heavy precipitation, flow can bypass the diversion weirs and flow to the South Gorge Interceptor where it is diverted back to the Sewage Treatment Plant via the Gorge Pumping Station. If flow in the South Gorge Interceptor is high, it may also bypass the weirs to the Gorge Pumping Station and discharge directly to the Niagara River. Table 3-1 summarizes water level measurements recorded prior to drilling and geoprobe activities, and after development of the new wells. Tables 3-2 and 3-3 summarize horizontal and vertical gradients, respectively.

4 Quality Assurance/Quality Control (QA/QC) Procedures

This section describes the sampling procedures utilized for each environmental medium collected and analyzed for this project. The Quality Assurance Project Plan (QAPP) presented in the work plan was followed for all SRI activities. The procedures described in the QAPP are consistent with the current updates of the USEPA sampling procedures as described in SW-846.

4.1 Field QC Samples

Field QC samples provide a means to check ways that sample quality can be compromised in the field or through shipping, and also document overall sampling precision. The following sections describe field QC samples collected during the SRI.

Trip Blanks

Trip blanks check for the possible introduction of VOCs from the time the samples are collected to the time they are analyzed. Trip blanks were prepared in the field trailer by filling 40-milliliter (mL) glass vials with organic-free deionized water. They were handled like field samples; however, they were not opened in the field. One trip blank sample accompanied each shipment containing samples to be analyzed for VOCs. No contaminants were detected in any of the trip blanks. Appendix G contains appropriate trip blank analytical data.

Duplicate Samples

Consistency in both sample collection and sample analysis is checked through analysis of duplicate samples. Duplicate samples consist of aliquots of sample media placed in separate sample containers and labeled as separate samples. Duplicate samples were collected at a rate of approximately one per 20 field samples. Table 4-1 lists the duplicate samples and the original samples which they duplicated. Duplicate sample analytical data are presented in the data summary tables presented in Section 5.

Rinsate Samples

Rinsate samples are collected to check on the effectiveness of the decontamination process on sampling equipment. Since dedicated sampling equipment was used to collect groundwater SRI samples, rinsates were not necessary.

Drill Water Samples

Drill water samples are collected to check whether water added to the borehole during drilling or used for decontamination of drilling equipment contains analytes which can affect the quality of the groundwater or split-spoon soil samples. The drill water samples were collected by pumping the water from the rig tank(s) to the appropriate sample containers. The source of the drill water was a fire hydrant along 47th Street, just east of the site. The results of the drill water sample are presented in Table 4-2.

4.2 Laboratory QC Samples

Laboratory QC samples provide mechanisms to check analytical precision. This is accomplished by routinely performing several internal QC checks. QC procedures used during the SRI sample analyses are detailed below.

Method and Calibration Blanks

Quality checks on the laboratory instrumentation and methods are conducted by analysis of method blanks. Method blanks consist of organic-free deionized water subjected to every step of the analytical process to determine possible points of organic laboratory contaminant introduction.

Similarly, laboratory equipment used to conduct inorganic analyses (usually an inductively coupled plasma unit) is evaluated by analyzing instrument calibration blanks. These blanks analyzing pure reagent matrix are compared to set instrument response baselines.

One method blank per 20 samples was analyzed, while one calibration blank was analyzed every two hours or every 10 samples, whichever was more frequent.

Spike Samples

Spike samples simulate the background effect and interferences found in the actual samples, and the calculated percent recovery of the spike is used as a measure of the accuracy of the total analytical method. Spike samples were prepared by adding to an environmental sample (before extraction or digestion) a known amount of pure analyte to be assayed. The percent recovery of the spike analyte measures the accuracy of the method. Spikes were added at a concentration approximately midpoint on the calibration curve. Spikes (e.g., laboratory control samples) added to a matrix blank were analyzed with each sample batch to assess analytical performance not affected by sample matrix. If matrix spike samples indicated a potential matrix effect, the matrix spike blanks were evaluated to verify the problems were not due to an analytical concern.

Laboratory Duplicate or Matrix Spike Duplicates

In addition to analytical error introduced by machinery and sample handling, error can also occasionally result from analytical process interference by a sample matrix. This can result in the reporting of analytes at concentrations lower than the true concentrations. Laboratory or matrix spike duplicates are aliquots of the same sample that are split prior to analysis and are treated exactly the same throughout the analytical method. The relative percent difference (RPD) between the values of the MS and MSD for organics or between the original and the duplicate for inorganics was taken as a measure of the precision of the analytical method. MS/MSD samples were collected at a rate of one per 20 field samples or batch MS/MSD samples were analyzed at a rate of one per day per matrix. MS/MSD data are evaluated as part of the data validation process.

4.3 Data Validation

Analytical data reports generated by the laboratory were checked to verify that data reported are consistent with the laboratory QA Manual and standard operating procedures (SOPs). The data reports verified by the laboratory are included in Appendix E.

In addition to the laboratory review, an independent data validator reviewed the data. Chemworld Environmental, Inc., (Chemworld) of Rockville, MD, performed the validation. Chemworld validated the data in accordance with the USEPA Region II Data Validation Checklists/Guidance and the appropriate methods from the NYSDEC Analytical Services Protocols (ASP), October 1995. The validation included an evaluation of the following:

- Holding times;
- Initial and continuing calibration;
- Reporting limit check standards;
- Laboratory blanks;
- Field blanks;
- MS/MSD samples;
- Laboratory control samples ([LCS], same as matrix spike blanks);
- Laboratory duplicates;
- Field duplicates;
- Sample result verification; and
- Method-specific QC samples (e.g., gas chromatography/mass spectrometry [GC/ MS] tunes and inductively coupled argon spectroscopy [ICP] serial dilutions).

Any deviations from acceptable QC specifications were discussed in a data validation report. The data validator added appropriate qualifiers to the data to indicate potential concerns with data usability. These qualifiers were transferred to the data presented on summary tables in Section 5.0. For the SRI data, the following qualifiers were added:

J - The qualifier indicates estimated value because the associated QC data indicated a potential laboratory or matrix problem. In addition, J flags indicate the results are below the contract required detection limit (CRDL), but above the instrument detection limit (IDL) or method detection limit (MDL). For inorganic data, a B flag on the laboratory report in Appendix E indicates these results. The J flag also may indicated potential interference. For inorganic data, an E flag on the laboratory report in Appendix E indicates these results.

U - The result is considered non-detect due to blank contamination. If the result is above the CRDL, the CRDL is considered elevated.

The complete data validation reports will be provided to NYSDEC under separate cover.

4.4 Summary of Data Validation Reports

The following summary is based on the results of data reviews as reported in the Data Usability Summary Reports (DUSRs) in Appendix E.

VOCs

The data validation results for the analysis of volatile organics by GC/MS are presented in DUSR Number 1 and DUSR Number 2 dated May 29, 2002. Based on the QC criteria, all of the data are usable. The following deviations from QC specifications were noted:

- **Continuing Calibration:** In a number of cases, where the percent difference (%D) for a chemical was found to have exceeded the specified limit of 25%, the associated sample results were qualified as estimated, either J for positive results or UJ for non-detectable results.

- **Surrogate Recovery:** Based on high surrogate recovery noted for 1,2-dichloroethene-d4 in sample MW-88-8A, the positive VOC results in the sample were qualified as J. Based on low surrogate recovery noted for toluene-d8 in sample FC-88-8A, the sample results were qualified as J for positive results and UJ for non-detectable results.

- **Internal Standards:** Based on low recovery reported for all three internal standard in Sample FC-PZ09-WO, all VOC results in the sample were qualified estimated (J or UJ).

SVOCs

The data validation results for the analysis of semivolatile organics by GC/MS are presented in DUSR Number 3 dated May 31, 2002. TIC results that were found to be less than 5 times the level in the associated method blank were qualified as R, unusable. Low levels of phthalate in eight monitoring well samples were flagged U as non-detect due to background laboratory contamination. Other groundwater samples with low level contamination also should be considered suspect. Otherwise, the data are usable. The following deviations from QC specifications were noted:

- **Holding Times:** Sample MW-88-120BR-RE was extracted two days past the allowable holding time, so the positive results for semivolatile organic compounds (SVOCs) in the sample were J-qualified.

- **Continuing Calibration:** In a number of cases, where %D for a chemical was found to have exceeded the specified limit of 25%, the associated sample results were qualified as estimated, either J for positive results or UJ for non-detectable results.

- **Surrogate Recovery:** Based on high surrogate recovery for all eight surrogate compounds in sample MW-88-120B-R, the positive SVOC results in the sample were J-qualified. In three samples, where low surrogate recovery for base-neutral compounds was reported, all sample results for base-neutral compounds were qualified as estimated (J for positive and UJ for non-detectable results).

- **Matrix Spike Blank (MSB):** Based on high recovery 4-nitrophenol in two MSB samples, the positive results for 4-Nitrophenol in associated samples were qualified as J.

- **Internal Standards:** In samples where low recovery was reported for some internal standards, the results for compounds associated with the affected internal standards were qualified as J for positive results and UJ for non-detectable results. In samples where high internal standard recovery was reported, the associated positive results were qualified as J.

- **Method Blanks:** Method blank SBLKS1 was found to contain phenol at 59 µg/kg, acetophenone at 86 µg/kg, and bis(2-ethylhexyl)phthalate at 47 µg/kg, and method blank SBLKS2 was found to contain acetophenone at 89 µg/kg. Bis(2-ethylhexyl)phthalate was detected in blanks SBLKW1 and SBLKW2 at concentrations of 1 µg/L and 30 µg/L, respectively. In associated samples, bis(2-ethylhexyl)phthalate results that were less than 10 times the blank level and results for the other chemicals that were less than 5 times the blank level were qualified as U, not detected at the sample quantitation limit (QL).

Pesticides/PCBs

The data validation results for the analysis of pesticides and PCBs by GC are presented in DUSR Number 4 dated June 4, 2002. Based on the QC criteria, all data are usable. The following deviations from QC specifications were noted:

- **Surrogate Recovery:** Based on high surrogate recovery for trichloroethene (TCE) and dichlorobenzene (DCB) in some samples, the positive results for pesticides and PCBs in the samples were J-qualified. In samples where low surrogate recovery for TCE and dichloroethene (DCE) was reported, all pesticide and PCB results were qualified as estimated (J for positive and UJ for non-detectable results).

- **MSB**: Based on low spike recovery in for gamma BHC (Lindane) in the MSBs for both water and soil, Lindane results were qualified as estimated (J for positive and UJ for non-detectable results). Based on high spike recovery in for heptachlor, aldrin, and endrin in the MSB sample for soil, the positive results for these compounds in associated samples were J-qualified.

- **%D Between Two GC Columns:** In a number of samples, the %D between two columns was greater than 25% for one or more compounds. If %D was between 25% and 70%, the associated positive result was qualified as J. If %D was greater than 70%, the result was qualified as JN, presumptively present at an approximated quantity.

- **Linearity:** The percent relative standard deviation (%RSD) for methoxychlor exceeded the 20% limit for calibrations on November 16, 2001 and November 27, 2001. Associated results for methoxychlor, all non-detectable results, were qualified as UJ.

- **Calibration Checks:** In a few instances, percent differences greater than 25% were reported for endrin in the performance evaluation mixture and for heptachlor in the individual standard mixture. Associated sample results were qualified as estimated, either J for positive results or UJ for non-detectable results.

Inorganics

The data validation results for the analyses of inorganics are presented in DUSR Number 5 dated June 7, 2002. Based on the QC criteria, all of the data are usable. The following deviations from QC specifications were noted:

- **CRDL Standards:** For several metals high or low recovery were noted for CRDL standards. Associated positive sample results within the affected range were qualified as J.

- **Matrix Spike:** In cases where high spike recoveries were noted metals, associated positive results were J-qualified. Where low spike recoveries were noted for metals, all associated results were qualified as estimated (J for positive and UJ for non-detectable results).

- **ICP Serial Dilution:** Percent differences reported for inductively coupled argon spectroscopy (ICP) serial dilutions for a number of metals exceeded the allowable limit of 10%. Associated positive results that were more than 10 times the instrument detection limit were J-qualified.

- **Laboratory Duplicates:** Where analysis of duplicate samples indicated poor precision, the associated positive results were J-qualified.

- **Holding Times:** Samples MW-88-13A, MW-15, MW-88-3B, and MW-88-6 OB were analyzed for cyanide and mercury one day beyond the allowable holding time. The positive results for cyanide in these samples were J-qualified.

TCLP Volatiles, TCLP Semi-Volatiles, TCLP Metals

The data validation results for these analyses are presented in DUSR Number 6 dated June 14, 2002. All of the data are usable. The semivolatile results did not require qualification.

Results for toxicity characteristic leaching procedure (TCLP) volatiles were qualified as follows:

- Results for samples MW-87-4B1-4 and MW-87-4B4-6 were qualified as estimated (J for positive hits UJ for non-detectable results) due to low surrogate recovery for 4-bromofluorobenzene.

For TCLP metals, the following deviations from QC specifications were noted:

- **Matrix Spike:** Due to low spike recoveries were for barium and selenium, associated results were qualified as estimated (J for positive and UJ for non-detectable results). High spike recovery was noted for silver, but no qualification was required since sample results were all non-detectable.

- **ICP Serial Dilution:** %D reported for ICP serial dilutions for barium, cadmium, chromium, and lead exceeded the allowable limit of 10%. Associated positive results that were more than 10 times the instrument detection limit were J-qualified.

- **Holding Times:** Because samples MW-01-10B4-6, MW-87-4B1-4, and MW-88-20B4-6 were TCLP extracted for mercury eight days beyond the allowable holding time, the non-detectable results for mercury in these samples were qualified as UJ.

Dioxins

The data validation results for the analysis of dioxins are also presented in DUSR Number 6. The following deviations from QC specifications were noted:

- **Holding Times:** Since samples were extracted for Method 1613 13 days beyond the allowable holding time, sample results were qualified as estimated (J or UJ).

- **Results Outside Calibration Limits:** Sample results that were outside the method calibration limits were J-qualified.

5 Nature and Extent of Contamination

5.1 Introduction

This section presents results of the SRI field activities in order to develop an understanding of the nature and extent of contamination at the site. This information was used to assess the fate and transport of contaminants (Section 6) that pose a threat to human health and the environment.

Screening

The analytical results (see Tables 5-1 through 5-13) were screened to identify samples and analyte levels that may represent a possible threat to human health and the environment. For screening purposes, groundwater analytical data were compared to the NYSDEC Class GA ambient water standards and guidance values (June 1998); and soils data were compared to the NYSDEC Technical and Administrative Guidance Manual (TAGM) 4046 soil cleanup objectives (January 1994). In addition, soil samples tested for TCLP parameters were screened against 40 Code of Federal Regulations (CFR) Chapter I Part 261.24 Toxicity Characteristics.

The TAGM 4046 provides recommended soil cleanup objectives that would be protective of groundwater, human health, and the environment. In the case of metals, recommended soil cleanup objectives or site background are provided in the guidance. Unlike the soil screening guidance, the groundwater standards are promulgated standards with which all ambient freshwaters of the State of New York are to comply. Groundwater samples were compared to class NYSDEC GA (drinking water quality) standards.

Organization of VOC Data

During previous investigations the VOC analytical data were organized into five groups based on their chemical similarity and/or constituents in common commercial solvents (Ecco, Inc. 1990). To facilitate comparisons between this and previous investigations, the same VOC groups were used to evaluate the data (Table 5-1). In addition to these five distinct groups of VOCs, total monochlorotoluene (MCT) concentrations and total VOC minus MCT concentrations also were evaluated and compared to previous data. MCTs consist of three isomers: 1-chloro-2-methyl-benzene, 1-chloro-3-methyl-benzene, and 1-chloro-4-methyl-benzene.

Tentatively Identified Compounds

During VOC and SVOC organic analyses, tentatively identified compounds (TICs) were identified qualitatively. TICs are chromatographic peaks in GC/MS analyses for VOCs and SVOCs organics that are not target compounds, system monitoring compounds, or internal standards. TICs were qualitatively identified through a mass spectral library search, and the identifications were estimated by a qualified data reviewer. No standard response factor is used in the quantitation of TIC compounds; therefore, all TIC concentrations are estimated values. This process is used to identify and estimate concentrations of any potential unknown contaminants at the site. A summary of TICs is provided at the end of Appendix F. Although MCTs are not part of the target compound list (TCL) VOC analysis, they were tentatively identified during the TCL VOC and SVOC analyses. Concentrations of all TICs are estimated. MCT isomer concentrations are presented in Tables F-1, F-2, and F-3 in Appendix F.

Dioxins

A number of dioxin or furan congeners have been shown to exert a number of toxic responses similar to those of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), the most toxic dioxin. Under the auspices of the World Health Organization, the dioxin-like congeners have been assigned 2,3,7,8-TCDD Toxicity Equivalency Factors (TEFs), indicating their toxicity relative to 2,3,7,8-TCDD, which itself has been assigned a TEF of 1.0. Then the analytically determined concentration of each congener is multiplied by its respective TEF value and all the products are summed to give a single 2,3,7,8-TCDD equivalent (USEPA 1989). Tables F-4 and F-5 in Appendix F provide a summary of the 2,3,7,8-TCDD equivalent calculations.

Niagara River Toxics Management Plan (NRTMP) Parameters

To determine potential effects of groundwater discharging to the Niagara River via the Falls Street Tunnel, groundwater samples from five wells (MW-9, MW-11, MW-88-6A, MW-88-13A, and MW-01-9A) were also analyzed for Niagara River Toxics Management Plan (NRTMP) Parameters. The NRTMP, which was established in 1987, consists of the Niagara River Declaration of Intent and work plan signed by the USEPA, Environment Canada (CA), NYSDEC, and Ontario Ministry of Environment (MOE). This declaration is a pledge of cooperation to achieve significant reductions of toxic chemical pollutants in the Niagara River. Under the NRTMP, the 18 constituents listed below were identified as persistent toxic chemicals known as the "Priority Toxics."

VOCs:	Tetrachloroethene (also known as per-chloroethene or PCE)
SVOCs:	Benz(a)anthracene
	Benzo(a)pyrene
	Benzo(b)fluoranthene
	Benzo(k)fluoranthene
	Chrysene

	Hexachlorobenzene
	Octachlorostyrene
PCBs	
Dioxins	
Pesticides:	Chlordane (alpha and gamma)
	DDTs (DDD, DDE, and DDT)
	Dieldrin
	Mirex
	Toxaphene
Metals:	Arsenic
	Mercury
	Lead

Of these NRTMP parameters, the only two that are not part of the Target Analyte List (TAL) and TCL parameters are mirex and octachlorostyrene. Therefore, these parameters were added to the TCL list for designated samples of this project.

5.2 Subsurface Soil Investigation

Previous soil sample evaluation for the presence of contamination was limited to field organic vapor headspace sampling. Therefore, subsurface soil sampling during this SRI was conducted via Geoprobe coring and split-spoon sampling during monitoring well installation in order to generate a limited characterization of site soil conditions. All subsurface soil samples were submitted to E & E's ASC for TCL VOCs, TCL SVOCs, TCL Pesticides/ PCB, TAL metals and cyanide analyses. In addition, three samples were submitted for dioxins and full TCLP parameters. A summary of the analytical data is provided below and the frequency of detection and positive hits are presented in Tables 5-2, 5-3, and 5-4. In addition, test pit excavations were performed to determine if utility bedding was functioning as a preferred pathway for contamination. The subsections below present the results of these investigations.

5.2.1 Subsurface Soil Sampling Results from Well/Geoprobe Boreholes

Volatiles

Twenty-one of the 30 VOCs detected in the soil samples were found at concentrations exceeding the screening criteria. The samples collected from the north, northwest, and west portions of the site did not contain VOCs above screening levels. VOCs exhibiting high concentrations include PCE, 1,1,1-TCE, and TCE (Group II); all of the Group III VOCs; and MCT (Group IV).

Figures 5-1 and 5-2 show the distributions of total VOCs (not including MCTs and other TICs), MCTs, and each of the five VOC groups. The highest total subsurface soil VOC concentration detected was 2,089,000 parts per billion (ppb) in

PZ-01-10. MCT concentrations were generally higher than those of the other VOCs. The highest MCT concentration was 7,884,000 ppb (MW-88-2OB[R]).

The high levels of VOCs detected at PZ-01-10 are primarily associated with Group III VOCs. Group III concentrations at the rest of the site were several orders of magnitude lower with only four locations having concentrations higher than 100,000 ppb: GP-01-8 at the south edge of the site with 747,600 ppb, MW-88-7OB (R) with 513,800 ppb, PZ-01-6 with 280,100 ppb, and PZ-01-11 with 195,500 ppb.

Semivolatile Organic Compounds

Ten of the 38 SVOCs detected in the soil samples exceeded the screening criteria. Similar to the VOC concentrations, samples collected from the north and west portions of the site did not contain SVOCs above the screening levels. The SVOCs detected above screening levels included phenols, hexachlorobenzene, and six polynuclear aromatic hydrocarbons (PAHs) (benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and dibenz(a,h)anthracene). Phenols, benzo(a)pyrene, and dibenz(a,h)anthracene concentrations exceeded their screening levels in every sample they were detected in. The highest total PAH concentration detected was 21,100 ppb (PZ-01-10). The highest phenol concentration detected was 8,700 ppb (MW-01-10B) (see Figure 5-1).

Pesticides and PCBs

Twenty pesticides were detected in the soil samples, with aldrin, endrin, and heptachlor epoxide exceeding the screening criteria. No PCBs were detected in the soil samples.

Inorganics

All 23 metals were detected in the soil samples. Eight of these metals exceeded screening levels: iron and zinc in all samples, chromium in 22, nickel in 18, mercury in 11, copper in eight, cadmium in five, and arsenic in one sample. However, for several of the metals, there is no cleanup objective listed other than the site background which is not available for this site. Therefore, concentrations of inorganics at the site cannot be evaluated completely using solely the NYSDEC levels. The highest metals concentrations were found in PZ-01-08, PZ-01-10, and MW-87-4B(R) (see Figure 5-3).

Cyanide was also detected in 25 of the 29 samples at concentrations ranging from 0.059 to 0.72 mg/kg or parts per million (ppm). There is no NYSDEC screening criteria for cyanide in soil.

Dioxins

Dioxins were detected in all three borehole soil samples tested (MW-01-1OB [4 to 6 feet], BH87-4B[R] [1 to 4 feet], and MW-88-2OB[R] [4 to 6 feet]) at concentrations of 0.563, 765, and 2,680 parts per trillion (ppt), respectively (see Table 5-3). There is no NYSDEC screening criteria for dioxins in soils.

Hazardous Characteristics Testing

The same three borehole soil samples tested for dioxins (see above) underwent TCLP analyses. Four VOCs were detected (benzene, chlorobenzene, PCE, and trichloroethene [TCE]), of which TCE exceeded the criteria at a concentration of 2.32 ppm in MW-01-10B. Only one SVOC (1,4-dichlorobenzene), and four metals (barium, cadmium, chromium, and lead) were detected, all below criteria (see Table 5-4).

5.2.2 Test Pit Excavations

As stated in Section 2.4.3, four test pits (TP-1 through TP-4) were excavated in the southern portion of the site. The purpose of these excavations was to determine if contamination was migrating off site through the bedding material of utilities entering or exiting the site. Instrument screening (i.e., organic and explosive vapor monitoring) and visual observations indicated no unusual conditions, therefore, no soil samples were collected from the test pits. Since the utilities investigated were above the water table, and there are no apparent source areas along the southern portion of the site, it is not likely that the utilities are acting as conduits for contaminant transport.

5.3 Groundwater Investigation

Groundwater monitoring well sampling was performed at the site between November 6 and December 5, 2001. Groundwater samples were collected from 11 new monitoring wells and 11 new piezometers, as well as 49 existing monitoring wells.

All the piezometers and wells were sampled for TCL VOCs. Additionally, most locations were also planned to be tested for TCL SVOCs, TCL pesticides/PCBs, TAL metals and cyanide. As agreed upon with NYSDEC, due to limited sample volume caused by low well yields, some of these parameters could not be tested.

The wells tested for these parameters include A-fracture bedrock wells MW-88-6A, MW-88-13A, and MW-01-9A and B-fracture bedrock wells MW-9 and MW-11. These wells were chosen because they were the most downgradient wells sampled (i.e., closest to the Falls Street tunnel), providing data of groundwater that will most likely enter the Falls Street tunnel which may discharge directly to the Niagara River.

A summary of the sample date, analyses, and field chemistry measurements is provided in Table 2-9, frequency of detection and positive analytical results for the groundwater samples are presented in Tables 5-5 through 5-13, and groundwater concentration contours are presented in Figures 5-4 through 5-15. For comparison purposes, Tables 5-6B, 5-8B, 5-10B, and 5-12B present historic groundwater results along with 2001 data for volatile compounds detected over

0.5 ppm. A discussion of the analytical results from analysis of the groundwater samples is presented below.

5.3.1 Overburden Groundwater Results

VOCs

All 28 overburden wells sampled (17 monitoring wells and 11 piezometers) contained VOCs. Twenty-six VOCs were found at concentrations exceeding NYSDEC Class GA groundwater standards (see Tables 5-5 and 5-6A). The highest concentration of total VOCs detected in the overburden is 394,300 ppb in the vicinity of piezometer PZ-01-4. This area of elevated VOCs radiates outward from PZ-01-4 towards the south-southwest (see Figure 5-4). The west-central, central, south-central portions of the site are also characterized by areas of high VOC concentrations with total VOCs of 182,710 ppb (PZ-01-6), 63,800 ppb (MW-01-10B), and 119,460 ppb (MW-88-60B). In previous investigations, the highest concentration of total VOCs exceeded 1,000,000 ppb (MW-88-2OB), radiating outward towards the southeast (Ecco, Inc. 1990). It appears that VOC contamination in the overburden at this location has significantly decreased since the Ecco, Inc., 1990 investigation. The contamination may have moved downgradient to the southeast (MW-88-6OB) and may also have infiltrated downward into the bedrock. The high level at PZ-10-4 may represent a potential source area not identified in the 1990 investigation.

MCTs

Fifteen of the 28 overburden wells contained MCT isomers (see Tables F-2 and F-3). The highest concentration of MCTs detected in the overburden is 264,000 ppb (BH87-4B[R]) (see Figure 5-5). In previous investigations, the highest concentration was approximately 300,000 ppb (MW-88-2OB) (Ecco, Inc. 1990). The concentration at this location has significantly decreased to approximately 414 ppb, and it appears that the majority of the contamination has moved downgradient to the south-southwest and may also be infiltrating downward into the bedrock.

Group I VOCs

Sixteen of the 28 overburden wells contained Group I VOCs. The highest concentration in the overburden is 7,100 ppb (PZ-01-12) (see Figure 5-6). In previous investigations, the highest concentration was approximately 5,000 ppb (MW-88-8OB) (Ecco, Inc. 1990). This high concentration has significantly decreased over time (currently 69 ppb) and appears to have moved to the southwest towards PZ-01-12 and MW01-1OB, and/or may be infiltrating downward into the bedrock.

Group II VOCs

Twenty-one of the 28 overburden wells contained Group II VOCs. The highest concentration in the overburden is 268,000 ppb (PZ-01-4) (see Figure 5-7). In previous investigations, the highest concentration was approximately 100,000 ppb (MW-88-8OB) (Ecco, Inc. 1990). The contamination at this well has significantly decreased to 52 ppb, and it appears that most of the contamination has moved to the southwest towards PZ-01-4. The contamination may have also infiltrated downward into the bedrock.

Group III VOCs

Seventeen of the 28 overburden wells contained Group III VOCs. The highest concentration in the overburden is 172,000 ppb (PZ-01-6), with a second isolated high concentration area of 116,750 ppb at monitoring well MW-88-6OB (see Figure 5-8). In previous investigations, the highest concentration was approximately 650,000 ppm (MW-88-2OB) (Ecco, Inc. 1990). This high concentration has significantly decreased over time (currently at 3,060 ppb), and it appears to have moved to the southeast towards MW-88-6OB and may have also infiltrated downward into the bedrock. The cause of the high level at PZ-01-6 and decreased level at MW-88-2OB is unexplainable, and may be the result of subtle preferential pathways within the overburden.

Group IV VOCs

Nineteen of the 28 overburden wells contained Group IV VOCs. The highest concentration in the overburden is 266,900 ppb (BH87-4B[R]) (see Figure 5-9). In previous investigations, the highest concentration was approximately 300,000 ppb (MW-88-2OB), with elevated VOC concentrations radiating outward to the east (Ecco, Inc. 1990). These concentrations have significantly decreased and appear to have moved downgradient to the southwest towards PZ-01-7 and south towards BH87-4B(R). It may have also infiltrated downward into the bedrock.

Group V VOCs

Thirteen of the 28 overburden wells contained Group V VOCs. The highest concentration in the overburden is 7,110 ppb (MW-7[R]) (see Figure 5-10). In previous investigations, two isolated high concentrations were detected in MW-88-6OB and MW-88-2OB (both approximately 5,000 ppb) (Ecco, Inc. 1990). It appears that the majority of the contamination at MW-88-2OB has moved along downgradient towards MW-7(R). The contamination at MW-88-6OB may have infiltrated into the bedrock.

SVOCs

Ten of the 12 monitoring wells sampled in the overburden contained SVOCs in the groundwater. Six SVOCs exceeded NYSDEC Class GA groundwater standards (see Tables 5-5 and 5-6A). The highest concentration of total SVOCs in the overburden is 4,950 ppb (MW-7[R]), which is mainly phenolic compounds (see below). SVOC concentrations exhibit an elongated distribution that is radiating outward from MW-7(R) to the southeast.

Phenols

Seven of the 12 monitoring well locations in the overburden contained phenolic constituents in the groundwater, all of which exceed NYSDEC Class GA groundwater standards (see Tables 5-5 and 5-6A). The highest concentration in the

the overburden is 4,600 ppm (MW-7[R]). In previous investigations, the highest concentration was 88,000 ppb (MW-88-2OB) (Ecco, Inc. 1990). It appears the phenolic contamination has moved downgradient to the southeast and southwest. It may have also infiltrated downward into the bedrock.

Pesticides and PCBs

Nine of the 12 overburden monitoring wells contained pesticides, and the concentrations in six of the wells exceeded NYSDEC Class GA groundwater standards (see Tables 5-5 and 5-6A). The highest concentration in the overburden is 0.54 ppb (MW-01-1OB). No PCBs were detected in overburden groundwater.

Inorganics

All 12 of the overburden monitoring wells contained inorganic constituents. The concentrations of 13 inorganics exceeded NYSDEC Class GA groundwater standards (see Tables 5-5 and 5-6A). Concentrations of four inorganics (aluminum, arsenic, cyanide, and lead) were plotted in order to facilitate evaluation of inorganic contamination. The highest concentrations are: aluminum at 12,800 ppb (MW-88-7OB); arsenic at 193 ppb (MW-7[R]); lead at 35.5 ppb (MW-88-6OB); and cyanide at 522 ppb (MW01-1OB).

5.3.2 A-Fracture Zone Bedrock Groundwater Results

VOCs

All 21 A-fracture zone wells contained VOCs. Twenty-five VOCs exceeded NYSDEC Class GA groundwater standards (see Tables 5-7 and 5-8A). The highest concentration of total VOCs in the A-fracture zone is 354,064 ppb (MW-88-8A), with the concentrations decreasing radially and towards the south/southeast (see Figure 5-4). In previous investigations, the highest concentration was 450,000 ppb (MW-88-3A), with VOC concentrations decreasing radial to the east and southeast (Ecco, Inc. 1990). The contamination at this location may have moved deeper into bedrock. The high concentration in MW-88-8A appears to be the result of downward migration from the overburden.

MCTs

Sixteen of the 21 A-fracture zone wells contained MCT isomers (see Tables F-2 and F-3). The highest concentration in the A-fracture zone is 42,900 ppb (MW-88-3A[R]) (see Figure 5-5). In previous investigations, the highest concentrations were approximately 90,000 ppb (MW-17); 80,000 ppb (MW-14); and 50,000 ppb (MW-88-1A) (Ecco, Inc. 1990). It appears that the contamination in these zones have moved deeper into the bedrock. Contamination at MW-17 may have also moved downgradient to the southeast, and is possibly being intercepted by the tunnels.

Group I VOCs

Sixteen of the 21 A-fracture zone wells contained Group I VOCs (see Tables 5-7 and 5-8A). The highest concentration in the A-fracture zone is 4,300 ppb (MW-

88-3A[R]) (see Figure 5-6). In previous investigations, the highest concentration was approximately 8,000 ppb (MW-88-3A) (Ecco, Inc. 1990). Although the highest Group I concentration is still found in MW-88-3A, the contamination has decreased by half and has probably moved downgradient to the south-southeast and is possibly being intercepted by the tunnels. The contamination may have also moved deeper into the bedrock.

Group II VOCs

Nineteen of the 21 A-fracture zone wells contained Group II VOCs (see Tables 5-7 and 5-8A). The highest concentration in the A-fracture zone is 69,510 ppb (MW-88-8A) (see Figure 5-7). In previous investigations, the highest concentration was approximately 300,000 ppb (MW-88-3A) (Ecco, Inc. 1990). It appears that most of the Group II contamination in this zone has moved deeper into the bedrock or downgradient to the south-southeast and is possibly being intercepted by the tunnels. Concentrations at monitoring well MW-88-8A did not show a significant decrease in Group II VOC concentrations, which indicates that this well is situated outside the preferred A-fracture zone flow paths, and/or overburden contamination may be moving downward at a rate equal to horizontal migration.

Group III VOCs

Eighteen of the 21 A-fracture zone wells contained Group III VOCs (see Tables 5-7 and 5-8A). The highest concentration in the A-fracture zone is 97,470 ppb (MW-88-6A) (see Figure 5-8). In previous investigations, the highest concentration was approximately 100,000 ppb (MW-88-2A) (Ecco, Inc. 1990). Similar to Group I and II VOCs, it appears that the Group III contamination in this zone has moved deeper into the bedrock and/or downgradient to the south-southeast and is possibly being intercepted by the tunnels. Contamination from the overburden may also be moving downward into this bedrock zone at the MW-88-2A and MW-88-6A locations.

Group IV VOCs

Seventeen of the 21 A-fracture zone wells contained Group IV VOCs (see Tables 5-7 and 5-8A). The highest concentration in the A-fracture zone is 47,040 ppb (MW-88-3A[R]) (see Figure 5-9). In previous investigations, the highest concentration was approximately 80,000 ppb (MW-17) (Ecco, Inc. 1990). Again, it appears the contamination in this zone has moved deeper into the bedrock and/or downgradient to the south-southeast and is possibly being intercepted by the tunnels. Contamination from the overburden may also be moving downward at these areas of high concentrations.

Group V VOCs

Ten of the 21 A-fracture zone wells contained Group V VOCs (see Tables 5-7 and 5-8A). The highest concentration in the A-fracture zone is 4,510 ppb (MW-2) (see Figure 5-10). In previous investigations, two isolated high concentrations of Group V VOCs were detected in the vicinity of monitoring wells MW-88-7A and MW-88-12A (both approximately 20,000 ppb) (Ecco, Inc. 1990). Contamination in this zone has probably moved deeper into the bedrock and/or downgradient to the southwest and is possibly being intercepted by the tunnels. Contamination from the overburden in the vicinity of MW-2 may also be moving downward into this bedrock zone.

Semivolatiles

Fourteen of the 15 wells in the A-fracture zone contained SVOCs. The concentrations of nine SVOCs exceeded NYSDEC Class GA groundwater standards (see Tables 5-7 and 5-8A). The highest concentration of total SVOCs in the A-fracture zone is 5,375 ppb (MW-88-2A[R]), with SVOC concentrations decreasing outward towards the southwest. Most of these SVOC concentrations are phenolics (see below).

Phenols

Twelve of the 16 monitoring wells in the A-fracture zone contained phenols at concentrations exceeding NYSDEC Class GA groundwater standards (see Tables 5-7 and 5-8A). The highest concentration of total phenols in the A-fracture zone is 4,400 ppb (MW-88-2A[R]) (see Figure 5-11). In previous investigations, the highest concentration of phenols was 32,000 ppb (BH87-4A) (Ecco, Inc. 1990). It appears that SVOC contamination in this zone has moved deeper into the bedrock and/or along flow paths toward the south, and is possibly being intercepted by the tunnels. Contamination from the overburden may also be moving downward into this bedrock zone.

Pesticides and PCBs

Fifteen of the 16 monitoring well locations in the A-fracture zone contained pesticides and PCBs in the groundwater. Of the 19 pesticides and one PCB that were detected, eight of the pesticides and the one PCB exceeded NYSDEC Class GA groundwater standards (see Table 5-7 and 5-8A). The highest concentration of pesticides was in MW-88-6A at 0.998 ppb, and the highest concentration of PCBs was detected in MW-01-9A at 1.3 ppb.

Inorganics

All 16 of the wells in the A-fracture zone contained inorganics. The concentrations of 11 inorganics exceeded NYSDEC Class GA groundwater standards (see Tables 5-7 and 5-8A). The distributions of aluminum, arsenic, lead, and cyanide are presented on Figures 5-12 through 5-15. The highest concentrations are: aluminum at 2,640 ppb (MW-17); arsenic at 1,040 ppb (MW-88-3A[R]); lead at 157 ppb (MW-88-12A); and cyanide at 936 ppb (MW-88-3A[R]).

5.3.3 B-fracture Zone Bedrock Groundwater Results

VOCs

All 17 monitoring wells in the B-fracture zone contained VOCs. The concentration of 23 VOCs exceeded NYSDEC Class GA groundwater standards (see Tables 5-9 and 5-10A). The highest concentration of total VOCs in the B-fracture zone is 93,271 ppb (MW-11) (see Figure 5-4). In previous investigations, the highest concentration was found in the vicinity of monitoring well MW-88-3B (exceeding 200,000 ppb), with concentrations decreasing towards the south (Ecco, Inc. 1990).

A majority of the VOC contamination in the B-fracture zone appears to have moved deeper into the bedrock and/or downgradient to the south-southeast, and is possibly being intercepted by the tunnels. Contamination from the A-fracture zone also may have moved downward into this bedrock zone.

MCTs

Fifteen of the 17 B-fracture zone wells contained MCTs (see Tables F-2 and F-3). The highest concentration in the B-fracture zone is 47,400 ppb (MW-11) (see Figure 5-5). In previous investigations, the highest concentration was approximately 40,000 ppb (MW-88-3B) (Ecco, Inc. 1990). It appears the contamination in this zone has moved downgradient to the south-southeast and is possibly being intercepted by the tunnels.

Group I VOCs

Fourteen of the 17 B-fracture zone wells contained Group I VOCs (see Tables 5-9 and 5-10A). The highest concentration in the B-fracture zone is 2,800 ppb (MW-11) (see Figure 5-6). In previous investigations, the highest concentration was approximately 4,000 ppb (MW-88-6B) (Ecco, Inc. 1990). It appears that Group I contamination in this zone has moved deeper into the bedrock and/or downgradient to the south-southeast towards monitoring well MW-11 and is possibly being intercepted by the tunnels. Contamination from the A-fracture zone may also be moving downward into this bedrock zone.

Group II VOCs

Thirteen of the 17 B-fracture zone wells contained Group II VOCs (see Tables 5-9 and 5-10A). The highest concentration in the B-fracture zone is 31,500 ppb (MW-11) (see Figure 5-7). In previous investigations, the highest concentration was approximately 120,000 ppb (MW-88-3B) (Ecco, Inc. 1990). The contamination at MW-88-3B has significantly decreased to 427 ppb, indicating that the majority of the contamination in this zone has moved downgradient to the south-southeast and is possibly being intercepted by the tunnels.

Group III VOCs

Fourteen of the 17 B-fracture zone wells contained Group III VOCs (see Tables 5-9 and 5-10A). The highest concentration in the B-fracture zone is 48,100 ppb (MW-11) (see Figure 5-8). In previous investigations, the highest concentration of Group III VOCs was approximately 30,000 ppb (MW-88-5B) (Ecco, Inc. 1990). Although the contamination at MW-88-5B is relatively the same, it appears the contamination in this zone has moved downgradient to the south-

southeast and is possibly being intercepted by the tunnels. Contamination from the A-fracture zone may be moving downward into this bedrock zone.

Group IV VOCs

Fifteen of the 17 B-fracture zone wells contained Group IV VOCs (see Tables 5-9 and 5-10A). The highest concentration in the B-fracture zone is 50,220 ppb (MW-11) (see Figure 5-9). In previous investigations, the highest concentration was approximately 40,000 ppb (MW-88-3B) (Ecco, Inc. 1990). It appears the contamination in this zone has moved downgradient to the south-southeast and is possibly being intercepted by the tunnels. Contamination from the A-fracture zone may also be sinking into this bedrock zone.

Group V VOCs

Eight of the 17 B-fracture zone wells contained Group V VOCs (see Tables 5-9 and 5-10A). The highest concentration in the B-fracture zone is 10,040 ppb (MW-88-5B) (see Figure 5-9). In previous investigations, two isolated high concentrations of Group V VOCs were detected in the vicinity of monitoring wells MW-88-3B and MW-88-6B (both approximately 10,000 ppb) (Ecco, Inc. 1990). It appears the contamination in this zone has moved along flow paths towards the southwest, and is possibly being intercepted by the tunnels.

Semivolatiles

Twelve of the 13 monitoring well locations in the B-fracture zone contained SVOC constituents in the groundwater. The concentrations of five SVOCs exceeded NYSDEC Class GA groundwater standards (see Table 5-9 and 5-10A). The highest concentration of SVOCs in the B-fracture zone is 11,869 ppb (MW-88-5B), radiating outward towards the southwest. Most of these SVOCs are phenols (see below).

Phenols

Eight of the 13 monitoring wells in the B-fracture zone contained phenol constituents in the groundwater, and the concentrations of eight constituents exceeded NYSDEC Class GA groundwater standards (see Tables 5-9 and 5-10A). The highest concentration of phenols in the B-fracture zone is 11,000 ppb (MW-88-5B) (see Figure 5-11). In previous investigations, the highest concentration of phenols was 34,000 ppb (MW-88-3B) (Ecco, Inc. 1990). It appears that the contamination in this zone has moved deeper into the bedrock and/or downgradient to the south-southwest and is possibly being intercepted by the tunnels. Contamination from the A-fracture zone may also be moving downward into this bedrock zone.

Pesticides and PCBs

Five of the 13 monitoring wells in the B-fracture zone contained pesticides, and one well (BH87-2A) contained one PCB (Aroclor 1254). The concentrations of four of the pesticides (aldrin, alpha-chlordane, dieldrin, and endrin) and the one PCB exceeded NYSDEC Class GA groundwater standards (see Tables 5-9 and

5-10A). The highest concentration of pesticides is 0.55 ppb (MW-88-1OB), and Aroclor 1254 at 0.18 J ppb (BH87-2A).

Inorganics

All 13 of the wells tested in the B-fracture zone contained inorganic constituents, and the concentrations of 12 constituents exceed NYSDEC Class GA groundwater standards (see Tables 5-9 and 5-10A). The distributions of concentrations of aluminum, arsenic, cyanide, and lead are shown on Figures 5-12 through 5-15. The highest concentrations are: aluminum at 1,230 ppb (MW-90-1B); arsenic at 339 ppb (MW-88-5B); cyanide at 1,230 ppb in MW-88-5B; and lead at 655 ppb (MW-88-8B).

5.3.4 C-Fracture Zone Groundwater Results

VOCs

Both monitoring wells sampled in the C-fracture zone contained VOCs. The concentrations of 13 VOCs exceed NYSDEC Class GA groundwater standards (see Tables 5-11 and 5-12A). The highest concentration of total VOCs in the C-fracture zone is 8,000 ppb (MW-88-5C). The other well (MW-88-4C) contained only 4 ppb of total VOCs. In previous investigations, the highest concentration of total VOCs was approximately 6,100 ppb (MW-88-5C) (Ecco, Inc. 1990). The increase at this location is due to downward migration of contaminants from the B-fracture zone.

MCTs

Only one of the two C-fracture zone wells (MW-88-5C) contained MCTs, at a concentration of 4,410 ppb (see Tables F-2 and F-3).

Group I VOCs

Only one of the two C-fracture zone wells (MW-88-5C) contained Group I VOCs, at a concentration of 77 ppb (see Tables 5-11 and 5-12A).

Group II VOCs

Only one of the two C-fracture wells (MW-88-5C) contained Group II VOCs, at a concentration of 1,525 ppb (see Tables 5-11 and 5-12A).

Group III VOCs

Both C-fracture wells contained Group III VOCs: MW-88-5C contained 1,750 ppb, and MWE-88-4C contained 4 ppb (see Tables 5-11 and 5-12A).

Group IV VOCs

Similar to Groups I, II, and III, only one of the two C-fracture zone wells (MW-88-5C) contained Group IV VOCs, at a concentration of 4,580 ppb (see Tables 5-11 and 5-12A).

Group V VOCs

Neither of the two C-fracture wells contained Group V VOCs.

Semivolatiles

Only monitoring well MW-88-5C was sampled for SVOCs. The concentrations of two SVOCs (bis [2-ethylhexyl]phthalate and phenol) exceeded NYSDEC Class GA groundwater standards (see Tables 5-11 and 5-12A). Monitoring well MW-88-5C contained 149 ppb of total SVOCs.

Phenols

Only monitoring well MW-88-5C was sampled for phenols. It contained 31 ppb total phenols, which exceeds NYSDEC Class GA groundwater standards (see Tables 5-11 and 5-12A). In previous investigations, the highest concentration of phenols was approximately 80 ppb (MW-88-5C).

Pesticides and PCBs

Only monitoring well MW-88-5C was sampled for pesticides and PCBs. Of the four pesticides detected (4,4-DDE, beta-BHC, dieldrin, and endosulfan sulfate), only the concentration of dieldrin exceeded NYSDEC Class GA groundwater standards (see Tables 5-11 and 5-12A). Monitoring well MW-88-5C contained 0.0432 ppb of pesticides.

Inorganics

Only monitoring well MW-88-5C was sampled for inorganics, with a total of 15 detected, two of which (copper and sodium) exceeded NYSDEC Class GA groundwater standards (see Tables 5-11 and 5-12A).

5.3.5 Niagara River Toxics Management Plan Parameters

VOCs

PCE was detected in four of the five samples tested, all at concentrations above the screening criteria of 5 ppb. The concentrations were 12,000 ppb (MW-88-13A) and 120 J ppb (MW-88-6A) (both A-fracture bedrock wells); and 6,000 ppb (MW-11) and 170 J ppb (MW-9) (both B-fracture bedrock wells) (see Table 5-13).

SVOCs

There were no NRTMP SVOCs detected in any of the samples (see Table 5-13).

PCBs

One PCB (Aroclor 1254) was detected in only one of the wells (MW-01-9A, an A-fracture bedrock well), at a concentration (1.3 ppb) above the screening criteria of 0.09 ppb for total PCBs (see Table 5-13).

Pesticides

Five NRTMP pesticides were detected (see Table 5-13). Three exceeded screening criteria: 4,4-DDT and alpha-chlordane in MW-88-6A at concentrations of 0.24 J ppb and 0.14 ppb, respectively; and dieldrin in MW-01-9A at a concentration of 0.014 JN ppb. The "J" qualifier indicates that the value is estimated, and the "JN" qualifier indicates that the compound is presumably present at an approximated concentration.

Dioxins

Dioxins were present in all five samples at concentrations ranging from 0.0024 ppt to 1.68 ppt (see Table 5-13). There is no NYSDEC criteria for dioxins in groundwater.

Metals

Arsenic was detected in all five samples at concentrations (123 ppb to 327 ppb) exceeding the screening criteria of 25 ppb; lead was detected in three samples (MW-11, MW-88-13A, and MW-88-6A) below the criteria of 25 ppb at concentrations of 3.3 ppb, 2.3 J ppb, and 2.4 J ppb, respectively; and mercury was detected in one sample (MW-11) below the criteria of 0.7 ppb at a concentration of 0.28 ppb (see Table 5-13).

6

Fate and Transport

6.1 Introduction

This section discusses the natural mechanisms that may result in and affect migration of contaminant compounds and elements at the Frontier Chemical Site and the chemical persistence and behavioral characteristics of those compounds and elements. This information is combined with site-specific data and observations to assess the extent of migration that has occurred. The following discussion is based on the understanding that the current site conditions are related to the identified source areas and chemical compounds and elements at the site.

As discussed in Section 5.0, a variety of organic and inorganic contaminants are present above screening levels in the soil and groundwater at the site. The contaminants discussed in this section represent those present above the established screening levels. The contaminants and associated contaminated media requiring possible remediation will be evaluated in the feasibility study. However, several compounds/elements that may drive such remedial measures are selected here for evaluation of their typical migration behavior. Specifically, this section evaluates fate and transport of VOCs, SVOCs (including phenols and PAHs); and select inorganic compounds (aluminum, arsenic, chromium, cyanide, iron, lead, mercury, nickel, and zinc). It should be noted that additional SVOCs and inorganics, as well as PCBs, pesticides and dioxins, were detected at relatively low concentrations and/or at sporadic locations throughout the site; and are, therefore, generally not pertinent to this study.

6.2 Potential Sources of Contamination and Routes of Migration

6.2.1 Source Areas

Source areas may be associated with site features such as former surface impoundments (e.g., ponds), former drum storage areas, former tank farms, and residuals from past site activities including chemical spills. These source areas may include contaminated soil and groundwater.

The site property reportedly was used as a caustic chlorine (mercury cell) production plant, and later as a chemical waste treatment facility. Former sludge ponds were used for liquid sludge disposal from caustic soda production, and tanks that stored TCE, PCE, benzochloride, dichloro-/trichloro-/tetrachlorobenzene and other products (Woodward Clyde et. al. 1992). Also, the site history (see Section 1) indicates that historical operational changes at the site resulted in modification, addition, or removal of numerous facilities and features throughout the site property, which may have resulted in the movement of contaminated soils. These changes include building construction and demolition, tank decommissioning, process equipment demolition, sludge pond removal, and associated earthwork activities. In addition, based on the use of the site, building foundations, pilings, and on-site utilities may have disturbed the confining layer of cohesive soil overlying the bedrock, such that vertical chemical migration pathways may have been formed.

The site has been inactive for several years and underwent several source removal actions in the 1990s; therefore, no additional contaminant contributions to the existing source areas are expected. Based on the numerous and varying uses of the site areas over time, as well as the current state of the property (i.e., abandoned with most buildings demolished), the identification of existing and remaining source areas is best described in terms of high concentrations of detected contaminants. The apparent unsaturated soil contaminant sources at the site include the general areas proximate to the following (refer to Figures 1-2, 1-3, and 1-4).

- Between former buildings 12, 22, and 50 and buildings 18, 24, 51, and 55:
  - PZ-01-05
  - PZ-01-08
  - MW-01-1OB

- In the vicinity of the former sludge settling basin and spray pond:
  - MW-88-2OB
  - MW-7(R)
  - BH87-4B(R)

- In the vicinity of former buildings 14, 16, and 25:
  - PZ-01-12
  - GP-01-08

- Between former buildings 8, 9, and 12:
  - PZ-01-10
  - MW-88-7OB(R)

- Northeastern portion of site:
  - PZ-01-01
  - GP-01-05
  - MW-88-12OB(R)

In addition, given the location of the site (in an area of known impacted soil and groundwater from other industrial facilities) and the historical industrial nature of surrounding areas, unidentified off-site sources of contamination were detected.

Specifically, groundwater contamination in upgradient on-site wells to the north and northwest of the site (e.g., MW-17, MW-88-10A, MW-88-1A and –1B; MW-88-4A, MW-14; MW-90-1A and –1B) are indicative of some contributing off-site sources to groundwater contamination.

6.2.2 Routes of Migration

Natural and other mechanisms that can result in the migration of contaminants from their source areas include: surface water flow, infiltration, groundwater flow, subsurface tunnels and utilities, and volatilization. Other migration of contaminants at the site may be associated with the physical movement of soils and associated contaminants during the numerous facility modifications. Also, test results indicate DNAPL may be present at the site. DNAPL movement is a potential route of migration. The impact of these mechanisms will vary by source area and the specific site conditions.

Surface Water Flow

Surface water flow may be a site mechanism that allows lateral migration of contaminants. Surface water flow at the site occurs primarily during precipitation events as sheet flow over the ground surface. Water was observed to enter site drainage structures (catch basins) that connect to the storm sewers located adjacent to the site; accumulate in the topographic low areas on site; or infiltrate the ground. In addition, historical surface spills at the site may have exited the site by sheet flow. Based on recent site observations, a majority of site surface areas (approximately 80%) have a relatively impermeable barrier (e.g., pavement, concrete slabs) and the remaining 20% of the site areas are unpaved (e.g., grass, gravel).

Erosion results in the entrainment of soil particles within the surface water flow, whereby particles remain suspended in turbulent flows and subsequently settle in more quiescent waters. Thus, erosion via surface water flow is expected to be significant during and immediately following heavy precipitation events. Based on field observations of site topography and current surface conditions at the facility, it is not believed that erosion is historically a significant migration pathway at the site.

Infiltration

Infiltration of precipitation would be expected in areas not covered by a relatively impermeable barrier. Since a majority of the site surface areas have such a relatively impermeable barrier, it is expected that migration of contaminants in subsurface soils would be limited due to infiltration. However, it is expected that infiltration would act to cause water soluble compounds present in the unsaturated zone to migrate vertically downward to the groundwater table in areas where infiltration can occur. In addition, infiltration recharges the groundwater, which may increase groundwater gradients, potentially enhancing migration via groundwater flow.

Groundwater Flow

Overburden groundwater flow would be expected to allow both vertical and lateral migration of contaminants located within the saturated zone, as well as contaminants that migrate into the saturated zone from the overlying unsaturated zone due to infiltration. Bedrock groundwater flow (in fracture zones A, B, and C) is also expected to allow for both vertical and lateral migration of contaminants, as groundwater movement is largely controlled by the horizontal and vertical fracture patterning indicative of the Lockport Dolomite. Groundwater flow would be considered a significant transport mechanism for contaminants that are water soluble and that have lesser sorbing characteristics. Migration via groundwater flow can allow contaminants to travel significant distances from their source area.

Based on current site conditions, groundwater flow at the site is generally toward the Niagara River, as overburden groundwater was found to generally flow horizontally to the southeast; groundwater in the A-fracture zone to the south/southeast; and groundwater in the B-fracture zone to the south/southeast/east. Also, the downward vertical gradient in groundwater between the overburden and bedrock fracture zones A and B allows contaminants to migrate into the bedrock. A slight upward vertical gradient was reported between the C- and B-fracture zones (Ecco, Inc. 1990). In addition, based on the horizontal flow directions measured in the water-bearing zones at the site (e.g., eastern groundwater flow in the B-fracture zone), portions of both overburden and bedrock groundwater flow are expected to migrate to off-site areas.

As described below, subsurface utilities and tunnels affect the direction of groundwater flow off site.

Subsurface Utilities and Tunnels

Contaminants in groundwater and infiltration flow also have the potential to migrate into and through the bedding of subsurface utilities. These subsurface features likely act as preferential pathways for subsurface flow at the site.

The high-capacity, gravity storm water sewer tunnels (i.e., New Road and Falls Street tunnels) located to the east and south of the site, respectively, are also receptors for subsurface flow. According to drawings provided by the City of Niagara Falls Department of Wastewater Facilities and the Niagara Falls Regional Groundwater Assessment Report (Woodward-Clyde et. al. 1992), the main bodies of the tunnels are unlined and are expected to intersect the B-fracture zone adjacent to the site. According to the 1992 report, the Falls Street tunnel was constructed in the early 1900s using drill and blast techniques (i.e., drilled charges were set and exploded, followed by mechanical removal of loosened rock and soil). The New Road Tunnel is also reportedly a drill and blast tunnel (Ecco, Inc. 1991). Based on the reported construction technique used to create the tunnels, the bedrock surrounding the tunnels were likely influenced (additional fractures created and expansion of existing fractures) by the blasting such that localized preferential pathways were formed. Therefore, bedrock groundwater is expected to enter the tunnels directly (fracture zone B), or travel through fractures above and adjacent to the tunnel for subsequent infiltration to the tunnel either adjacent to the site or at a downstream location. According to the 1992 report, groundwater has been observed to infiltrate along the ceiling of the tunnel, which confirmed that groundwater is infiltrating the tunnel.

This is supported by historical regional groundwater maps, based on measurements in the late 1980s and early 1990s (Woodward-Clyde et. al. 1992), that depict the Falls Street tunnel as being a primary regional influence on Upper Dolomite groundwater (i.e., upper 45 +/- feet of bedrock, including fracture zones A, B, and C). (The New York Power Authority conduits located west of the site, which are located deeper in bedrock but intersect the Falls Street tunnel in plan view, are also a significant regional influence on the bedrock groundwater.) The maps show that the tunnel is a receptor (sink) of the groundwater flow from areas located both north and south of the tunnel, and has significantly altered the natural pattern of bedrock groundwater flow such that the areal extent of site groundwater is limited from migrating further downgradient.

A portion of the overburden groundwater flow is also expected to enter the tunnels due a downward gradient imposed proximately by the tunnels. However, remaining portions of the overburden flow may migrate horizontally, beyond the tunnel to the southeast, and vertically as described above.

As depicted on Figure 2-1, the New Road Tunnel discharges to the Falls Street Tunnel at the confluence of 47th Street and Royal Avenue. As further described in Section 3.0, diversion weirs were installed in the Falls Street Tunnel to divert a portion of the flow to the Southside Interceptor, a lined sewer that discharges to the Niagara Falls Sewage Treatment Plant. Reportedly during dry weather conditions, the flow in the Falls Street Tunnel is diverted to the Southside Interceptor adjacent to the site (Woodward Clyde et. al. 1992). During wet weather conditions, a smaller portion of the tunnel flow is diverted, with the remaining flow being subsequently discharged to areas downstream (e.g., Niagara River). Therefore, it can be inferred that site groundwater, under normal weather conditions, is likely transmitted by the Falls Street Tunnel to the city's treatment plant (via the Southside Interceptor). However, during heavy precipitation events, some of the site groundwater entering the Falls Street Tunnel may discharge directly to the Niagara River.

Volatilization

VOC contamination in soil and groundwater is expected to migrate in the form of soil gas to utility beddings above the groundwater table, and ultimately to the ambient air at the ground surface. Migration of VOCs is less predictable than groundwater migration due to subsurface heterogeneities and subsurface structures (e.g., utilities, building foundations, pavement, etc.).

DNAPL

Based on analytical test results (high concentrations in soil and groundwater concentrations greater than 1% of the compounds solubility), DNAPL may be present at the site. However, there is no additional information (e.g., product noted in monitoring wells) identified during this study to confirm the presence of or suggest significant migration. A DNAPL study was not completed as part of the RI. Migration of DNAPL through overburden soils is dependent on several factors, primarily the surface tension of the DNAPL (resulting in capillary forces retarding its migration), the relative density of the DNAPL, and the soil porosity. Generally, DNAPL will migrate downward, provided a sufficient weight of DNAPL is available to overcome capillary forces. If the DNAPL encounters a soil with lower porosity that it cannot penetrate, it will tend to pool, then flow along the slope of the top of finer soils. If sufficient weight of DNAPL is not available to continue migration, the DNAPL becomes trapped in the soil matrix where it slowly dissolves in groundwater. Due to the nature of DNAPL, it is often difficult to locate.

DNAPL transport in fractured media (e.g., bedrock) is complicated, although the same general principles apply. DNAPL will enter a fracture if gravitational forces exceed capillary forces. Since the continuity and orientation of rock fractures is often difficult to assess, so is the migration of DNAPL. The presence of vertical fractures will allow the downward migration of DNAPL.

6.3 Contaminant Persistence and Behavioral Characteristics

Numerous classes of chemical compounds/elements were detected in the various environmental media at the site. However, predominantly VOCs, along with select SVOCs (phenols and PAHs) and inorganic compounds (aluminum, arsenic, chromium, cyanide, iron, lead, mercury, nickel, and zinc) are the contaminants that occurred with the most significance based on their detected concentrations above screening values. Other detected contaminants at relatively low concentrations and/or at sporadic locations throughout the site was reviewed, but was considered less significant to the overall evaluation of the site. Therefore, the analysis and discussion of those chemical classes are not included below.

In general, chemical compounds within a given chemical class will behave similarly in the environment. However, significant differences in behavior of chemical compounds may be observed within a chemical class. Their behavior is dependent on their physical and chemical properties as well as environmental conditions, such as the presence of bacteria, pH variations, and Eh conditions. Water solubility is a critical property affecting the environmental transport of a chemical: highly soluble chemicals can be rapidly leached from soil and are generally mobile in groundwater. For inorganic contaminants, the solubility will depend on the valence state of the element and on the chemistry of the surrounding medium. A compound’s volatilization rate from water depends on its vapor pressure and water solubility: highly water-soluble compounds generally have lower volatilization rates from water than compounds with a low water solubility. Vapor pressure and Henry's Law constants are measures of volatilization behavior.

The following discussion is based on published information on the chemical classes and specific chemicals at the site. Relevant physical and chemical properties are summarized in Table 6-1.

6.3.1 Volatile and Semivolatile Organic Compounds

VOCs

The VOCs detected at the site have been historically grouped into five categories (Groups I through V) (see Table 5-1), which correspond to the following four general VOC groups.

- **Halogenated Aliphatic Hydrocarbons.** This group of VOCs corresponds to site VOC Groups I and II, and is a major class of chemicals detected in site media. TCE, PCE, and 1,1-TCA are examples of halogenated aliphatic hydrocarbons. Due to their moderate to poor water solubility and moderate sorption characteristics, these compounds may leach from soils and enter groundwater in dissolved phase. These compounds also have a high potential for volatilization to the atmosphere. Since they also have densities greater than water, they may form a separate phase within an aquifer if present in sufficient volume (i.e., DNAPL). Degradation of several compounds results in numerous byproducts which may not have been originally placed in the environment (e.g., PCE degrades to TCE, 1,2-DCE, and eventually to vinyl chloride). The rate and extent of degradation are highly dependent on site specific factors such as nutrient availability and microbial composition in soil and groundwater. Halogenated aliphatic hydrocarbons are not significantly bioaccumulated.

- **Aromatic Hydrocarbons.** This group of VOCs corresponds to site VOC Groups III and IV, excluding MCT, found in both soil and groundwater across the site. Aromatic hydrocarbons (e.g., benzene, toluene, xylenes) do not typically degrade into other compounds unless site-specific factors (e.g., pH, temperature, microbial activity) in soil are met; nor are they especially persistent in the environment. This group includes many of the VOCs associated with petroleum products. Based on their high vapor pressures and relatively low water solubilities, volatilization is a significant transport mechanism in media exposed to the atmosphere (e.g., surface soils). These chemicals have moderate sorption tendencies, and may leach from soil to groundwater.

- **Halogenated Aromatic Hydrocarbons.** This group of compounds includes MCT (also called chloromethylbenzene), a major site contaminant in both soil and groundwater. These compounds volatilize readily in oxygenated environments and have a strong tendency to sorb onto soil particles. They are generally moderately soluble in water, likely undergo very limited biodegradation, and may also bioaccumulate in the environment.

- **Ketones.** This group of VOCs corresponds to site VOC Group V (e.g., 2-butanone, acetone). Ketones are solvents that are widely used in industry and environmental laboratories. Due to a high vapor pressure, these compounds volatilize quickly and are not generally found in unsaturated soil environments. Many of these compounds are very soluble in water and have a relatively low tendency to sorb to soils. This suggests that some ketones may move quickly through groundwater. These chemicals were detected in many site groundwater samples, and a lesser amount of soil samples.

SVOCs

Phenols and PAHs were the most prevalent types of SVOCs detected in the site soil and groundwater samples.

- **Phenols.** These compounds do not readily volatilize and generally do not significantly sorb onto soil particles or bioaccumulate. As a group they are characterized also by high solubility. Therefore, these compounds would be expected to move readily in the environment via infiltration and groundwater flow. Phenols were found in both soil and groundwater samples at the site.

- **PAHs.** PAHs are rather large, hydrophobic organic molecules that have low water solubilities, low volatilization rates, and a strong tendency to sorb to soil and other organic media with higher organic content. This results in little movement in water media. Typically due to their molecular size, they are not easily degraded or biodegraded; and, are subject mainly to the erosional transport mechanism. PAHs are not transported by leaching into groundwater or surface water to an appreciable degree. At the site, select PAHs (benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and dibenz(a,h)anthracene) were primarily present in subsurface soil at significant concentrations, being detected in fewer than 10 collected samples. PAHs are often associated with combustion.

6.3.2 Groundwater Transport of VOCs and SVOCs

The transport of aqueous phase organic contaminants in the overburden groundwater is dependent on physical features of the aquifer (i.e., groundwater velocity) and chemical properties of the contaminant. Based on a simplified form of the advection dispersion equation (that describes the spread of a contaminant as it moves through groundwater), the following methodology accounts for contaminant movement in a homogeneous porous medium in one direction not accounting for degradation or transformation (Walton 1984). This method accounts for sorption (i.e., the process whereby dissolved matter is removed or immobilized in or onto the soil matrix of a porous medium).

- **Groundwater seepage velocity**: $v = \frac{ki}{n}$

This equation is based on Darcy's Law and is based on the physical properties of the aquifer whereby:

k = hydraulic conductivity
i = hydraulic gradient
n = effective porosity

- **Retardation factor**: $R = 1 + \frac{\rho_b}{n} K_d$

  This equation is based on the advection dispersion equation whereby:

  ρ_b = bulk dry density of porous media
  K_d = distribution coefficient

  This factor accounts for the fact that sorption results in a reduction in advection (i.e., when contaminants travel at the same rate as the average velocity of groundwater) by R times. Therefore, if dispersion is neglected, the center of mass of a groundwater plume travels slower than the groundwater velocity by R times.

- **Distribution coefficient**: $K_d = K_{oc} f_{oc}$

  This coefficient is generally site specific and depends on the structure and chemical composition of the soil whereby:

  K_{oc} = octanol-carbon partition coefficient (chemical specific values available in literature); the ratio of a chemical's concentration in the octanol phase to its concentration in the water phase
  f_{oc} = mass fraction of organic carbon

Estimates of the transport velocities for select significant site contaminants are presented in Section 6.4.

The transport of organic contaminants in fractured bedrock groundwater is primarily controlled by the fracture pattern and geochemistry present in the rock. At this site, the hydraulic communication that exists between the upper dolomite bedrock groundwater and the adjacent tunnels governs the transport of contaminants in bedrock groundwater near the downgradient property line.

6.3.3 Inorganics

Inorganics (including metals and cyanide) as a class are highly variable in their general properties and their behavior in the environment, and are naturally occurring in the various environmental media. The fate of inorganics in the environment is largely determined by their water solubility and tendency to bind to soil that contain minor to moderate amounts of silt and clay. The migration of inorganics is dependant on many factors, including the metal's valence and speciation, and qualities of the subsurface environment (e.g., pH, Eh, the level of organics, the presence of potential anions [such as sulfate, chloride, and others]).

Inorganics can be transported via erosion (if found in surface soil) due to surface water flow. Inorganic concentrations in groundwater are influenced by the composition of aquifer materials, such that they may dissolve or weather (i.e., partial dissolution process in which certain elements leach, leaving other elements behind). Inorganics are soluble to a limited degree in water, with their actual solubilities influenced by pH. Solubilities themselves, however, do not describe the extent of migration through leaching and surface water/groundwater transport. Rather, it is the degree of partition between the soil matrix and the leaching water. In most cases, these inorganics would strongly adsorb to the soil matrix and not preferentially partition into surface and groundwater. Thus, inorganics can range from highly immobile to very soluble.

This study did not include identification of processes that effect the transport of individual inorganics. However, the transport behaviors described are borne out in the groundwater samples that show little presence of these inorganics above screening values, as compared to soil samples, with the exception of a few elements (e.g., aluminum, arsenic, cyanide, lead). (Also, it should be noted that the groundwater samples were collected using bailers. A majority of collected samples had very high turbidity measurements (greater than 50 NTU), indicating the presence of suspended solids with possible inorganics sorbed to the surface. Turbidity in groundwater samples can cause interference with the analysis. Therefore, the actual concentrations of dissolved inorganics may be much lower than those measured.

In addition, since the pH of the groundwater from recent field data suggests that the groundwater is generally neutral to basic ($pH \geq 7$), as shown in Table 2-9, the detected inorganics are less likely to be mobile in groundwater than in an acidic environment (lower pH conditions). It is expected that the inorganic plumes would migrate in a similar, but at a slower rate than the groundwater.

6.4 Observed and Predicted Migration

This section combines potential migration pathways with the site contaminant trends and distribution, as well as an understanding of the persistence and behavioral characteristics of the predominant contaminants detected at the site. As described above, the current and historical, potential significant migration pathways include surface water flow, groundwater (including infiltration), and volatilization.

6.4.1 Surface Water Flow

Surface water flow associated with precipitation events may be a site mechanism that allows lateral migration of contaminants, if present in site surface soils or as residuals on demolition debris, decommissioned tanks, etc. Although no surface soils were collected for analytical testing during this study, the 20% of open ground space is not expected to be significantly contaminated, based on the relatively clean nature of most of the subsurface soils tested in these open areas (e.g., former larvicide pond area). However, due to the historical use of the site, site activities (e.g., chemical spills to the ground) may have resulted in surface soil contamination at various, sporadic locations throughout the site. Contaminated stormwater that does not pond for evaporation and infiltration, may discharge to the off-site municipal storm sewer system via site drainage structures. Since stormwater samples in the on-site and off-site sewer systems were not collected, this contaminant migration has not been confirmed.

6.4.2 Groundwater

Overburden Groundwater

Overburden groundwater at the site is recharged by the infiltration of precipitation and associated with the migration of groundwater from off-site areas. Analytical test results from the overburden monitoring wells indicate the presence of numerous VOCs, as well as select SVOCs (primarily phenols) and inorganic compounds (aluminum, arsenic, lead and cyanide). This would indicate the leaching of these compounds from site soils occurs; and, in the case of the inorganic compounds, is likely partially a result of the high turbidity of the collected samples and the natural occurrence of inorganics in soil.

As with the subsurface soils, most of the very high levels of total VOCs (not including MCT) in the overburden groundwater were detected in the central and south-central portion of the site, either coincident with or slightly offset from soil hot spots. Halogenated aliphatic compounds (Groups I and II VOCs) were generally detected in a greater number of samples and locations than aromatic hydrocarbons (Groups III and IV VOCs without MCTs). This is consistent with the anticipated behavior as the halogenated aliphatics typically have lower partitioning coefficients and thus, are less likely to sorb on to the soils and instead are likely to leach to groundwater. The highest levels of MCTs and ketones (Group V VOCs) in groundwater also correspond well with high concentrations of subsurface soils.

The highest level of phenols was detected in the south-central portion of the site, corresponding well with high levels in subsurface soils. Inorganic compounds were detected in overburden groundwater throughout the site.

As expected, based on overburden groundwater flow directions, the lateral migration of contamination is generally to the southeast, and vertical migration is downward. In general, the VOCs, SVOCs and inorganics are expected to flow at rates less than groundwater. Based on the methodology presented in Section 6.3.1 above, the following provides estimates of contaminant migration rates for significant VOCs and SVOCs in overburden groundwater based on the retardation factor.

- **Groundwater seepage velocity**: As further discussed in Section 3.0, the horizontal gradient in the overburden groundwater is approximately 3.6 feet per 100 feet (i = 0.036). Based on the results of slug tests in overburden wells, the average horizontal hydraulic conductivity (k) is approximately 5.6 x 10^{-5} centimeters per second (or 0.16 feet per day). Assuming an average effective porosity (n) for the primary water-bearing soils (including silty sands, weathered rock, and sands) is approximately 0.35 (Holtz et. al. 1981), the average seepage velocity within the overburden is estimated to be about 0.016 foot per day, or about 6 feet per year.

- **Retardation factor**: Based on the types of primary water-bearing soils above bedrock, the estimated soil bulk dry density is 1.75 megagrams/cubic meter or about 110 pounds/cubic feet (Holtz et. al. 1981). TAGM 4046 assumes a mass fraction of organic carbon (f_{oc}) for primary water-bearing soils is assumed to be 1%. The octanol-carbon partition coefficients (K_{oc}) and distribution coefficients (K_d) for various detected VOCs and SVOCs are presented in Table 6-1. Therefore, estimates of contaminant velocities for select site contaminants in overburden groundwater are summarized in Table 6-2.

Groundwater migration is expected to spread the contamination in the direction of groundwater flow (southeasterly) and vertically downward to lower water bearing zones. As the contamination migrates, the natural organic carbon in the soil will adsorb the organic compounds, thus slowing the advance of the VOC plume. Additionally, VOCs will be attenuated in the direction of groundwater flow in response to dispersion, volatilization, and degradation, among other factors. Overall contaminant concentrations in the overburden groundwater have declined since earlier rounds of groundwater sampling, as contaminants have migrated horizontally and vertically and attenuated.

The metals migration rate in groundwater is not well understood and is difficult to predict. In general the pH of the groundwater is approximately greater than or equal to 7.0, which will not enhance mobility rates of the detected inorganics. Migration of metals in groundwater is expected to occur, but is less significant than migration of VOCs.

As described in Section 6.2.2, contaminants in overburden groundwater are expected to enter the stormwater tunnels located adjacent to the site. In particular, areas where utility laterals extend to or cross the tunnel (from the site) may provide localized areas for overburden water to migrate directly into utilities and utility bedding material. However, some portions of the overburden flow are expected to migrate horizontally to the southeast, generally towards the Niagara River, and may be impacting off-site properties.

Bedrock Groundwater

Analytical test results from the bedrock groundwater monitoring wells indicate the presence of numerous site contaminants. This, along with groundwater elevation data from the wells indicating a downward vertical gradient, indicates a hydraulic connection between the overburden and bedrock groundwater bearing zones and the discharge of overburden groundwater into the bedrock groundwater. In general, contamination in groundwater decreases with depth (i.e., the highest levels of contaminants were detected in overburden groundwater, and concentrations decrease in the underlying bedrock fracture zones A, B, and C).

VOCs, as well as select SVOCs (primarily phenols) and inorganic compounds (aluminum, arsenic, lead, and cyanide) were detected in the wells screened in the three fracture zones (A, B, and C). Also, similar to the overburden groundwater zone described above, most of the high levels of total VOCs in the overburden groundwater were detected in the east-central, central, southeast portion of the site. Similar to the overburden groundwater, halogenated aliphatic compounds (Groups I and II VOCs) were generally detected in a greater number of samples and locations than aromatic hydrocarbons (Groups III and IV VOCs without MCTs), which is consistent with the anticipated behavior as the halogenated aliphatics. The highest levels of MCTs and ketones (Group V VOCs) in groundwater generally correspond with high concentrations in overburden groundwater. The highest level of phenols was detected in the south-central portion of the site, corresponding to high levels in the overburden.

The highest concentrations of most contaminants were detected in groundwater from locations offset to the southeast from the overlying high concentrations in overburden groundwater zone, corresponding with the direction of groundwater flow. However, in some cases (e.g., Groups I, IV, and V VOCs), concentrations in this fracture zone are much higher than the corresponding overburden levels or off-set in a different direction. The cause for this is unknown, although since the migration of contaminants in the A-fracture zone is fracture-driven, contaminant migration occurs along preferential pathways in directions other than overall groundwater gradients.

Inorganic compounds in bedrock groundwater were detected in areas throughout the site. As described for overburden groundwater, in the case of the inorganic compounds, detected concentrations are likely partially a result of the high turbidity of the collected samples and the natural occurrence of inorganics in soil and bedrock.

The VOCs, SVOCs, and inorganics in the fractured bedrock are expected to flow at rates less than groundwater. Based on information presented in Section 3.0, the estimated groundwater velocities in the fractured bedrock zones are as follows.

- **A-Fracture Zone:** Groundwater flow in the A-fracture zone is to the south/southeast, with a horizontal gradient of approximately 1.5 feet per 100 feet (i = 0.015). Based on the results of pump tests, the average horizontal hydraulic conductivity (k) is approximately 5.5 x 10^{-4} centimeters per second (or 1.6 feet per day). Published values of secondary porosity for fractured bedrock with hydraulic conductivity on the order of 10^{-2} to 10^{-4} cm/s ranges between about 5 and 20% (Jumikis 1983); assume average n equal to 0.10. The estimated horizontal velocity is calculated to be approximately 0.24 foot per day, or about 90 feet per year. (Vertical flow beneath the site is predominantly downward between the overburden and the A- and B-fracture zones.)

- **B-Fracture Zone:** Groundwater flow in the B-fracture zone is to the south/southeast/east with a horizontal gradient of approximately 0.5 foot per 100 feet (i = 0.005). Based on the results of pump tests, the average horizontal hydraulic conductivity (k) is approximately 5.6 x 10^{-3} centimeters per second (or 16 feet per day). Assuming that an average porosity of 0.10, the estimated horizontal velocity is approximately 0.8 foot per day, or about 290 feet per year.

- **C-Fracture Zone:** Based on the limited number of wells in this zone, estimates of site-specific bedrock aquifer characteristics and, therefore, groundwater flow velocity could not be determined.

Due to the complex nature of groundwater flow in bedrock, whereby flow is along fractures and bedding planes, an accurate rate of contaminant migration could not able to be determined. However, based on the local and regional flow patterns of upper dolomite bedrock groundwater, the New Road and Falls Street tunnels are expected to intercept the bedrock groundwater. It is anticipated that some portions of the bedrock groundwater flow may be impacting off-site properties prior to entering the tunnels, based on the measured direction of groundwater flow (e.g., groundwater in the B-fracture zone flows from the site to the east, and ultimately flows to the south towards the tunnels based on known regional groundwater flow patterns). In addition, it should be noted that the tunnels are reported to receive impacted groundwater from other contaminated sites in the area, both at upstream and downstream locations.

Therefore, the estimated contaminant loading to the tunnels from the three impacted bedrock fracture zones is as follows.

- **A-Fracture Zone:** Assuming that the fracture zone is approximately 1.5 to 2.0 feet thick (in the vertical direction) with an assumed porosity of 0.10; the general south/southeast groundwater flow direction; the calculated groundwater velocity of 90 feet per year; and the hydraulic connection between this fracture zone and the stormwater tunnels adjacent to the site; the estimated volume of site groundwater entering the Falls Street Tunnel is approximately 67,000 gallons per year.

  Based on the current distribution of VOCs (including MCT), SVOCs, and other contaminants in the A-fracture zone groundwater, assume the average organic contaminant concentration in the A-fracture zone groundwater currently entering the tunnel is 50 mg/L. Therefore, the estimated loading to the tunnel from the A-fracture zone is currently approximately 30 pounds per year. It should be noted that under dry weather conditions, some of this contaminant mass is intercepted by the southside interceptor sewer.

- **B-Fracture Zone:** Assuming that the fracture zone is approximately 1.0 to 2.0 feet thick (in the vertical direction) with an assumed porosity of 0.10; the general south/southeast/eastern groundwater flow direction; the calculated groundwater velocity of 290 feet per year; and the hydraulic connection between this fracture zone and the stormwater tunnels adjacent to the site; the estimated volume of site groundwater entering the Falls Street Tunnel is approximately 217,000 gallons per year.

  Based on the current distribution of VOCs (including MCT), SVOCs, and other contaminants in the B-fracture zone groundwater, assume the average organic contaminant concentration in the B-fracture zone groundwater currently entering the tunnel is 20 mg/L. Therefore, the estimated loading to the tunnel from the B-fracture zone is currently approximately 35 pounds per year. It should be noted that under dry weather conditions, some of this contaminant mass is intercepted by the southside interceptor sewer.

- **C-Fracture Zone:** As stated above, due to the limited well sample data for this zone, an estimate of contaminant loading was not made.

Overall, contaminant concentrations in the A and B bedrock fracture groundwater have declined since earlier rounds of groundwater sampling, as contaminants have migrated horizontally and vertically and attenuated. VOCs in one of the two C-fracture zone wells sampled decreased (MW-88-4C), however, VOCs in the other C-fracture zone well (MW-88-5C) increased, indicating possible downward migration.

6.4.3 Volatilization

VOCs within the site overburden groundwater and soils may volatilize into the unsaturated soil zone (i.e., the zone above the water table). The thickness of the unsaturated soil zone, based on the explorations, is shallow (approximately less than 5-feet thick). Migration of soil vapors (gases) occurs through the void spaces between the soil grains in the overburden. Soil vapors may discharge into the atmosphere, and into on-site or off-site subsurface structures such as basements, manholes, or sumps. In addition, volatilization of VOCs may occur at groundwater discharge locations, such as sumps, the stormwater tunnels, and/or surface water features.

Insert Table 6-1

Table 6-2 Estimated Average Contaminant Velocity

Compound	Retardation Factor	Estimated Average Contaminant Velocities (feet per year)
1,1-Dichloroethane	2	2.6
1,1-Dichloroethene	2	3.7
Total 1,2-DCE	3	1.9
PCE	12	0.48
1,1,1-TCA	7	0.80
TCE	6	0.94
Vinyl chloride	3	1.7
1,2-Dichlorobenzene	71	0.082
1,3-Dichlorobenzene	14	0.42
1,4-Dichlorobenzene	71	0.082
Benzene	4	1.32
Chlorobenzene	15	0.40
Ethylbenzene	47	0.13
Toluene	13	0.43
Total Xylenes	11	0.53
Monochlorotoluene	8 – 65	3.4 – 0.38
Phenol	2	2.8

7

Qualitative Human Health Risk Evaluation

7.1 Introduction

Section 5 summarizes the contaminants that were detected in groundwater and subsurface soil at the site. The data summary tables in Section 5 show that numerous chemicals are present in site soil and groundwater at concentrations that exceed New York State regulatory standards and guidelines. Although those regulatory criteria were developed to be health-protective, the mere presence of environmental contamination at higher concentrations does not necessarily pose a risk to human health.

For contamination to pose a human health risk, both of the following conditions must be true:

- There must be a complete pathway of exposure from the contamination to human receptors; and

- The magnitude of the receptors' exposure to contamination must be sufficient to cause an adverse health effect.

If there is no complete pathway of exposure, there will be no risk associated with the contamination. If a complete pathway exists, but the magnitude of the receptor's exposure is low, the associated risk may not be significant. Both factors need to be considered when evaluating potential human health risks posed by site contamination.

New York State regulatory criteria for soil and groundwater were used as a preliminary screening tool to identify chemicals of potential concern (COPCs). These regulatory values cannot be used directly as indicators of the levels of risk posed by contaminants at the site. In some cases, the concentrations are based on considerations other than health risk (e.g., background levels, analytical limitations, etc.). In other cases, risk-based concentrations were derived using exposure assumptions that are not applicable to this site, either for estimated exposures much greater than would reasonably be expected or for an exposure pathway that does not exist.

The following evaluations of soil and groundwater briefly review the COPCs identified by the preliminary screening and outline the exposure pathways that currently exist or could exist in the future, focusing on the major routes for potential human exposure. The magnitude of exposure and the likelihood of potential adverse health effects are assessed qualitatively, through comparisons with appropriate risk-based concentrations that are available.

7.2 Subsurface Soil

The analytical data for subsurface soil samples are summarized in Tables 5-2 though 5-4, along with New York State TAGM 4046 recommended soil cleanup objectives that were used as screening criteria. In addition, Table F-1 summarizes the TICs. Although the TAGM 4046 values were developed to be health protective, they do not provide indication of the actual or potential health risks posed by site soil contamination. For most metals, the cleanup levels are not risk-based at all, but are based on typical background levels. Many of the more stringent values listed for organic chemicals are based on protection of groundwater that might be used as a drinking water source; such groundwater use at this site is not expected. Most of the remaining soil cleanup objectives for organic chemicals are risk-based values based on potential soil ingestion in a residential setting assuming a magnitude of exposure considerably greater than would reasonably be expected at this site.

Based on the preliminary screening, COPCs identified in subsurface soil include several VOCs (mainly chlorinated hydrocarbons), SVOCs (mainly PAHs), and some metals. Many VOCs and some SVOCs that are fairly soluble will tend to migrate downward with infiltrating precipitation, eventually reaching groundwater. Such migration is expected to occur at the site. Less soluble contaminants are generally less mobile, but over time some may also reach groundwater. (Potential exposures to groundwater contamination are discussed in the following subsection.) VOCs in subsurface soil can also diffuse via soil gas up to the surface, where vapors may be released to ambient air, or vapors can migrate into subsurface structures such as manholes, tunnels, and basements.

The Frontier Chemical Site is currently an inactive industrial site and is surrounded by other industrial sites. Access is limited by a perimeter fence. Current human receptors would include site visitors who enter for specific purposes, such as site investigation, and possibly trespassers. Generally, current site visitors are not expected to have direct contact with subsurface soil contamination, and contact with surface soil will be limited, since most of the site is paved or covered by site structures. Contaminant levels in surface soils are not known, because no samples were collected, but it is not unreasonable to expect that non-volatile contamination in surface soil might be similar to the levels in shallow subsurface soil. (Due to volatilization, VOC levels in surface soil are expected to be lower than in subsurface soil.) Site visitors may also be exposed to VOCs via inhalation of vapors that have migrated from subsurface soil to the air.

The potential for encountering contaminants also exists for utility/sewer workers that need to excavate in the area or near the property and handle the soils or bedding material, or to enter manholes or other excavations for maintenance reasons. Although this is not an everyday occurrence, it does present a potential short-term exposure risk.

In the future, the site could remain inactive or it might be redeveloped for other industrial or commercial uses. It is assumed the site will not be used for residential purposes. If the site was redeveloped for commercial of industrial use, site workers could be exposed to soil contaminants by the same pathways that currently exist for visitors, but the magnitude of potential worker exposures would be much greater due to the expected higher intake rates, greater exposure frequency, and longer exposure duration. In addition, because soil excavation and other disturbances during redevelopment could unearth subsurface soils, future workers could potentially have direct contact with some of the contamination that is now inaccessible.

Comparisons of chemical concentrations in subsurface soils to risk-based concentrations developed for industrial soil, based on direct contact exposure (USEPA 2002) and on potential vapor migration/inhalation exposures (TNRCC 2002), indicate that the risks to future commercial or industrial workers from long-term exposure to site soil contamination will not exceed risk levels regarded as acceptable by USEPA. Note that short-term exposure rates for some workers during site redevelopment or during utility work may be greater than the standard worker exposure assumptions. Particularly during excavation activities, construction/utility workers would be expected to have higher rates of exposure from direct contact routes and dust inhalation. Furthermore, they could potentially be exposed to higher ambient vapor concentrations in excavations and manholes. Such exposures are expected to be relatively brief, however, and may be mitigated by appropriate monitoring, engineering controls, and use of personal protective equipment. Risk to current and future visitors, whose potential exposures are considerably less than workers, are well below levels of concern.

7.3 Groundwater

Tables 5-5 through 5-13 present the chemicals detected and the concentrations measured in site groundwater along with the New York State Class GA groundwater standards and guidelines that were used as screening criteria. In addition, Tables F-2 and F-3 summarize the TICs. Although the GA criteria are intended for the protection of groundwater as a drinking water source, the values are not strictly health-based. Secondary standards and some guidance values are based on aesthetic considerations such as taste, odor, and appearance of drinking water. Many of the standards were determined by technical feasibility or analytical limitations in addition to health considerations. When the regulatory values are compared to risk-based concentrations that have been developed for drinking water by USEPA (2002, 2000); some are higher, some are about the same, and some are much lower than the risk-based values. The risk-based concentrations, which were calculated using assumptions about water consumption and vapor inhalation from household use, provide a better gauge of the relative risks that the contaminants would pose if present in drinking water.

Considering that site and regional groundwater is contaminated and that potable water is supplied to the site and surrounding area, it is unlikely that site groundwater would be used as a source of drinking water. The site and surrounding area are served by the city water system, which draws its supply from the Niagara River. Generally, groundwater from the site flows into sewer tunnels, and the majority of on-site groundwater likely is diverted for treatment at the Niagara Falls Sewage Treatment Plant before it reaches the river. Although some untreated groundwater from the site may reach the river, especially during high-flow conditions, the contaminant concentrations are expected to be considerably lower than those on site.

The analytical results show that groundwater sitewide is contaminated by VOCs, mostly chlorinated hydrocarbons including PCE and TCE and their degradation products (dichloroethanes, dichloroethenes, and vinyl chloride), chlorobenzenes, and MCTs (tentatively identified). The highest concentrations of VOCs, which are hundreds or thousands of times greater than Class GA standards and risk-based concentrations for drinking water, were detected in on-site groundwater. Contaminant levels in at least two thirds of the wells sampled, if present in drinking water, would pose unacceptably high cancer risks (e.g., above the 1×10^{-4} benchmark), mainly due to TCE and vinyl chloride, and could also cause non-cancer health effects, mainly due to cis-1,2-dichloroethene, chlorobenzene, dichlorobenzenes, and MCTs.

SVOCs, pesticides, and inorganic analytes detected in site groundwater are present at concentrations exceeding class GA groundwater standards, but to a lesser extent than the VOCs. Considering the rates of detection and overall concentrations reported in site groundwater compared to risk-based concentrations for drinking water, exposures to most of these chemicals would not pose significant health risks, with a couple of exceptions. Arsenic concentrations in more than half the wells, if present in drinking water, would pose a significant cancer risk and a possibility of non-cancer health effects. Lead has no risk-based concentrations (due to a lack of approved toxicity values), but the concentrations in almost half the wells are above the federal action level for lead in drinking water (15 μg/L), which was set for protection from lead's known toxic effects.

Under existing site conditions, with no groundwater use, there is no pathway for direct contact with contaminated groundwater. However, vapors from volatile groundwater contaminants can be transported upward in soil gas or via sewer manholes and released through cracks in pavement or unpaved areas to ambient air, potentially exposing site visitors via the inhalation route. Site visitors' exposures are not likely to reach levels of concern because the total exposure time from infrequent, short-duration visits will be relatively small. However, if the site were redeveloped for commercial or industrial use, the exposure time for future workers would be considerably greater, possibly 40 hours per week over a period of many years. Furthermore, if a building were constructed over the plume, infiltration of vapors through cracks in the foundation could expose workers to higher vapor concentrations in indoor air. During site redevelopment, construction workers might also be exposed to higher ambient vapor concentrations in manholes and excavations. Comparisons to risk-based screening levels that have been developed for groundwater based on potential vapor migration to outdoor air (TNRCC 2001) suggest that long-term inhalation of vapors from the highest concentrations of vinyl chloride and TCE in groundwater could pose significant cancer risks to future site workers.

Under an industrial use scenario, groundwater could conceivably be used in the plant processes, potentially exposing future workers to contamination by incidental contact and by inhalation of volatile contaminants released from the water to ambient air. If so, the magnitude of potential worker exposures would not be as great as it would from drinking water use. Nevertheless, due to the extremely high levels of some VOCs present in the groundwater, worker exposures might reach levels associated with unacceptably high cancer risks and other adverse health effects.

Vinyl chloride has been shown to cause liver cancer in workers that are occupationally exposed. TCE has been shown to cause liver tumors in rats and is considered to be a probable human carcinogen. The liver is also the target organ for potential non-cancer effects from TCE, vinyl chloride, chlorobenzene, and dichlorobenzenes. Animal studies have reported blood changes from low exposures to cis-1,2-dichloroethene and chlorotoluenes.

7.4 Human Health Risk Summary

In summary, site contamination may pose a health risk to human receptors when a complete exposure pathway exists and when the magnitude of exposure is sufficient to cause adverse health effects. At the Frontier Chemical Site, the major COPCs identified in subsurface soil and groundwater were VOCs, mainly chlorinated hydrocarbons.

Under existing site conditions, visitors could potentially be exposed by direct contact with soil contaminants and by inhalation of vapors emanating from VOC contamination in groundwater and subsurface soil, but the magnitude of these exposures is unlikely to reach levels of concern.

If the site were redeveloped for industrial use, the following pathways could be complete and associated exposures might be great enough to pose significant human health risks, based on comparisons between measured concentrations and relevant risk-based criteria.

- Migration of VOCs from groundwater to ambient air and long-term inhalation by future site workers could pose significant cancer risks, due mainly to high concentrations of vinyl chloride and TCE; and

- Direct contact with contaminated groundwater and inhalation of vapors released directly from groundwater to air, should groundwater be used in plant processes, could potentially expose workers at levels that would pose an unacceptably high cancer risk (from TCE and vinyl chloride) and that might cause non-cancer effects (from cis-1,2 dichlorethane, chlorobenzene, dichlorobenzenes, and MCTs).

During site redevelopment, exposures from direct contact with contaminated subsurface soils and from inhalation of higher concentrations of ambient vapors in excavations and manholes could also pose health risks to construction workers. Appropriate protective measures should be used to limit such exposures.

8

Summary and Conclusions

8.1 Project Summary

8.1.1 Summary of Site Investigation

The site investigation involved an initial site reconnaissance; development of a work plan; a records search; subsurface soil and groundwater investigations and sampling; base map development; and submittal of this draft SRI report. The investigations began in May 2001 with the site reconnaissance, the work plan was submitted in July 2001, and fieldwork was performed between October and December 2001.

The site reconnaissance, work plan development, records search, and generation of this report were performed by E & E; field investigations were performed by E & E and their subconsultant Watts Engineers; the base map was developed by McIntosh & McIntosh, P.C.; laboratory analyses were performed by E & E's ASC and Paradigm Analytical Laboratories; and data validation was performed by ChemWorld Environmental, Inc.

8.1.2 Nature and Extent of Contamination

In general, the nature and extent of on-site contamination at the Frontier Chemical Site has been defined by data collected during the SRI.

The following is a summary of the investigations conducted and the contaminants of concern detected at the site:

8.1.2.1 Subsurface Soils

At least one subsurface soil sample was collected from each of the nine Geoprobe borings, 11 Geoprobe piezometers, six overburden well borings, and one B-fracture bedrock well boring. One additional sample was collected in the MW-01-1OB and BH87-4B(R) borings due to multiple contaminated soil horizons. In addition, test pit excavations were performed to determine if utility bedding along the southern site boundary was acting as a conduit for contaminant migration.

Subsurface Sample Results from Borings

The following is a summary of the sample results:

- High concentrations of total VOCS in the subsurface soils were detected in the central, south-central, and southeastern portions of the site. The highest concentration of total VOCs was 2,089,000 ppb (PZ-01-10);
- The highest concentrations of MCTs was 7,884,000 ppb (MW-88-20B);
- The highest concentration of Group I VOCs was 3,000 ppb (PZ-01-5);
- The highest concentration of Group II VOCs was 1,394,000 ppb (PZ-01-5);
- The highest concentration of Group III VOCs was 2,070,000 ppb (PZ-01-10);
- The highest concentration of Group IV VOCs was 7,898,300 ppb (MW-88-2OB[R]);
- The highest concentration of Group V VOCs was 4,160 ppb (MW-7[R]);
- The highest concentration of total phenols was 6,700 ppb (MW-01-1OB) in the south-central portion of the site. MW-01-1OB is approximately 50 feet east of the former sludge setting surface impoundment, which was believed to be the source of phenol contamination in previous investigations; and
- Metals were widespread throughout the site, most of which are due to natural occurrence in the soils. The highest concentrations were: aluminum at 13,900 ppm (GP-01-8); chromium at 562 ppm (PZ-01-08); lead at 1,160 ppm (MW-88-2OB[R]); mercury at 2.9 ppm (MW-01-1OB); and nickel at 61 ppm (BH87-4B[R]);
- Dioxins were detected in all three boreholes tested (MW-01-1OB, BH87-4B(R), and MW-88-2OB(R)) at concentrations of 0.563, 765, and 2,680 ppt, respectively; and
- Of the same three wells tested, only one compound (TCE), failed hazardous characteristic testing in MW-01-1OB at a concentration of 2.32 ppm.

Test Pit Excavations

Four test pits were excavated in the southern portion of the site. The purpose of these excavations was to determine if contaminants were migrating off site through the utility bedding material. Instrument screening (i.e., organic and explosive vapor monitoring) and visual observations did not indicate the presence of contamination; therefore, no soil samples were collected from the test pits. Since the utilities investigated were above the water table and there are no apparent source areas along the southern portion of the site, it is unlikely that these utility beds are acting as conduits for contaminant transport.

8.1.2.2 Groundwater Investigation

Groundwater occurs in the overburden, A-fracture, B-fracture, and C-fracture bedrock zones beneath the site. The following is a summary of the results of the groundwater investigation:

Overburden Groundwater

Groundwater samples were collected from the six newly installed overburden monitoring wells, 11 newly installed overburden piezometers, and 17 existing overburden monitoring wells. The following is a summary of the sample results:

- As with the subsurface soils, most of the very high concentrations of total VOCs in the overburden groundwater were detected in the central and south-central portion of the site. However, two of the three overburden groundwater "hot spots" are offset from soil “hot spots.” The highest concentrations of total VOCs were 394,300 ppb (PZ-01-4) (whereas the highest in soil was 160 feet to the southwest at PZ-01-5); 182,710 ppb (PZ-01-6) (which corresponds well with the high soil VOCs at that location); and 119,460 ppb (MW-88-6OB) (located 140 feet southwest of PZ-01-10, which had high soil VOCs);

- The highest concentration of MCTs was 264,000 ppb (BH87-4B[R]), which corresponds well with the high concentration of MCTs in subsurface soil at this location;

- The highest concentration of Group I VOCs was 7,100 ppb (MW-01-1), which corresponds well with the high concentration in subsurface soil at this location;

- The highest concentration of Group II VOCs was 268,000 ppb (PZ-01-4). High concentrations of Group II VOCs in subsurface soil were noted only at PZ-01-5;

- The highest concentration of Group III VOCs was 172,000 ppb (PZ-01-6), which corresponds well with the high concentration in subsurface soil at this location. However, the highest concentration in the soil was at PZ-01-10;

- The highest concentration of Group IV VOCs was 266,900 ppb (BH87-4B[R]), which corresponds well with the high concentration in subsurface soil at this location;

- The highest concentration of Group V VOCs was 7,100 ppb (MW-7[R]). High concentrations also occurred in subsurface soils at MW-7(R);

- The highest concentration of total phenols was 4,600 ppb (MW-7[R]) detected in the south-central portion of the site, which corresponds well with the high concentration in subsurface soil at this location; and

- Metals were detected frequently throughout the site, which may be a function of interference due to turbidity (i.e., turbidity in many of the existing site wells was high, despite efforts taken during well development and purging to reduce turbidity) and the natural occurrence of metals in soil and rock. The highest concentrations were: aluminum at 12,800 (MW-88-7OB[R]); arsenic at 193 ppb (MW-7[R]); lead at 36 ppb (MW-88-6OB); and cyanide at 552 ppb (MW-01-1OB).

A-fracture Bedrock Groundwater

Groundwater samples were collected from the four newly installed A-fracture zone monitoring wells and 21 existing A-fracture zone monitoring wells. The following is a summary of the sample results:

- As with the subsurface soils and overburden groundwater, most of the high concentrations of total VOCS in the overburden groundwater were detected in the east-central, central, southeast portions of the site. The highest concentration of total VOCs in this groundwater zone was 354,064 ppb (MW-88-8A). This concentration is very similar to the concentration detected in the overlying overburden groundwater zone at this location.

- The highest concentration of MCTs was 42,900 ppb (MW-88-3A[R]). This area is located several hundred feet southeast of the area in which a high concentration was detected in overburden groundwater.

- The highest concentration of Group I VOCs was 4,300 ppb (MW-88-3A[R]). Concentrations in the overlying overburden groundwater zone were slightly higher, and located to the southwest.

- The highest concentration of Group II VOCs was 69,510 ppb (MW-88-8A). Although this concentration is lower than that detected in the overlying overburden groundwater zone, it is at the same general location.

- The highest concentration of Group III VOCs was 97,470 ppb (MW-88-3A[R]). As with the Group II VOCs, the concentration is slightly lower than in the overlying overburden groundwater..

- The highest concentration of Group IV VOCs was 47,040 ppb (MW-88-3A[R]). This well is in a northwest/southeast line with other wells with high concentrations, indicating potential migration of contaminants along a fracture zone with a northwest/southeast orientation. VOCs without MCTs (Figure 5-4) do not similarly extend to the northern and western boundaries of the site. This indicates the possibility of an off-site source of MCT. The levels of contaminants are generally lower in the A-fracture zone than those detected in the overlying overburden groundwater, and are to the northeast, potentially indicating two separate source areas.

- The highest concentration of Group V VOCs was 4,510 ppb (MW-2). This concentration is slightly lower than in the overburden, but it corresponds well with contamination detected in the overburden.

- The highest concentration of total phenols was 4,400 ppb (MW-88-2A[R]). This concentration and location are relatively the same as in the overburden zone. MW-88-2A is immediately north of the former sludge settling surface impoundment, which was believed to be the source of phenols in previous investigations.

- Metals were widespread throughout the site, which may be a function of interference from turbidity (i.e., turbidity in many of the existing site wells was high, despite efforts taken during well development and purging to reduce turbidity) and the natural occurrence of metals in soil and rock. The highest concentrations were: aluminum at 2,640 ppb (MW-17); arsenic at 1,040 ppb (MW-88-3A[R]); lead at 157 ppb (MW-88-12A); and cyanide at 936 ppb (MW-88-3A[R]).

B-fracture Bedrock Groundwater

Groundwater samples were collected from the newly installed B-fracture zone monitoring well and 21 existing B-fracture zone monitoring wells. The following is a summary of the sample results:

- The highest concentrations of total VOCs in the B-fracture zone bedrock groundwater occur in the south central portion of the site. The highest concentration of total VOCs was 93,271 ppb (MW-11). This concentration is similar to the concentration detected in the overlying A-fracture groundwater zone.

- The highest concentration of MCTs was 47,400 ppb (MW-11). This concentration is similar to that detected in the overlying A-fracture groundwater zone.

- The highest concentration of Group I VOCs was at the same location as the total 2,800 ppb (MW-11). The concentration is similar to that detected in the overlying A-fracture groundwater zone.

- The highest concentration of Group II VOCs was 31,500 ppb (MW-11). A high concentration of Group II VOCs also occurred at this location in the A-fracture groundwater zone. However, the concentrations were lower in the A-fracture zone than in the B-fracture zone , thus indicating downward migration of Group II VOCs from the A-fracture zone to the B-fracture zone.

- The highest concentration of Group III VOCs was 48,100 ppb (MW-11). The concentration is slightly lower than in the overlying A-fracture zone groundwater.

- The highest concentration of Group IV VOCs was 50,220 ppb (MW-11). The concentration and distribution of this group of contaminants does not correspond well with those detected in the overlying A-fracture groundwater zone.

- The highest concentration of Group V VOCs was 10,040 ppb (MW-88-5B). The concentration and the distribution of this group of contaminants does not correspond well with those detected in the overlying A-fracture groundwater zone.

- The highest concentration of total phenols was 11,000 ppb (MW-88-5B). This concentration is higher but occurred at the same relative location as the overlying A-fracture groundwater zone, indicating downward migration of contaminants. MW-88-5B is immediately south of the former sludge settling surface impoundment, which was believed to be the source of phenols in previous investigations.

- Metals were widespread throughout the site, which may be a function of interference from turbidity (i.e., turbidity in many of the existing site wells was high, despite efforts taken during well development and purging to reduce turbidity) and the natural occurrence of metals in soil and rock. The highest concentrations were: aluminum at 1,230 ppb (MW-90-1B); arsenic at 339 ppb (MW-88-5B); lead at 665 ppb (MW-88-8B); and cyanide at 1,230 ppb (MW-88-5B).

C-fracture Bedrock Groundwater

Only two (MW-88-4C and -5C) of the three existing C-fracture zone wells were sampled (the third well [BH87-5B] was unusable). MW-88-4C is an upgradient well located along the northern boundary of the site, and MW-88-5C is a downgradient well located in the south-central portion of the site where most of the groundwater contamination (especially in the overlying B-fracture zone) has been detected. The following is a summary of the sample results from these wells:

- High levels of total VOCs (3,590 ppb), MCTs (4,410 ppb), Groups I through IV VOCs (77; 1,525; 1,750; and 4,580 ppb, respectively), and phenols (31 ppb) were detected in MW-88-5C. This location corresponds with the high levels of the same contaminants in the overlying B-fracture zone, indicating downward migration of these contaminants. MW-88-4C contained low levels of some of these contaminants (only 4 ppb total VOCs and 4 ppb of Group III VOCs).

- No Group V VOCs were detected in either well.

- As with the overlying groundwater zones, metals were widespread throughout the site, which may be a function of interference from turbidity (i.e., turbidity in many of the existing site wells was high, despite efforts taken during well development and purging to reduce turbidity) and the natural occurrence of metals in soil and rock. Of the metals of concern, lead was detected in MW-88-5C at 14.6 ppb. This level was slightly lower than in the overlying B-fracture zone groundwater.

NRTMP Parameters

To determine the potential effects of substances deemed as "Priority Toxics" on the Niagara River, NRTMP parameters were analyzed on a select number (five) of well samples (MW-9, MW-11, MW-88-6A, MW-88-13A, and MW-01-9A). Of these parameters, the following were detected above screening criteria:

- PCE was detected in four (MW-88-13A, MW-88-6A, MW-11, and MW-9) of the five wells, at concentrations up to 12,000 ppb;
- Aroclor 1254 was detected in one well (MW-01-9A) at 1.3 ppb;
- Three pesticides: 4,4-DDT and alpha chlordane in MW-88-6A at an estimated of 0.24 and 0.14 ppb, respectively; and dieldrin in MW-01-9A at an estimated concentration of 0.014 ppb; and
- Arsenic in all five samples at concentrations up to 327 ppb.

In addition, dioxins were detected in all five samples from 0.0024 ppt to 1.68 ppt. There is no NYSDEC criteria for dioxins.

8.1.3 Fate and Transport

Source Areas

Current sources of contaminants at the site include unsaturated soil contamination associated with the numerous and varying historical uses of the property. Various factors associated with the source areas make it difficult to clearly define the potential sources and associated contamination. These factors include the following:

- Releases occurred at various points over an over an extended period of time;
- Some source areas were in proximity to others;
- The facility operations varied over time; and
- Similar contamination may be associated with different operations/sources.

For discussion purposes, the source areas were divided into five general areas. The contamination associated with each general source area is described below.

- Between former buildings 12, 22, and 50 and buildings 18, 24, 51, and 55, the historical land uses included: drum storage, acid/organic steam stripping, and tanks. Samples collected in this area include soil borings PZ-01-05 (11 to 13 feet BGS), PZ-01-08 (4 to 6 feet BGS) and MW-01-1OB (4 to 6 and 10 to 12 feet BGS). The primary contaminants detected in these samples are Group II, III, and IV VOCs, phenols, and various metals including chromium, iron, and zinc.

- ■ In the vicinity of the former sludge settling basin and spray pond, the historical land uses included: truck unloading, sludge settling basin, spray pond, and tanks. Samples collected in this area include soil borings MW-88-2OB (4 to 6 feet BGS), MW-7(R) (8 to 10 feet BGS), and BH87-4B(R) (11 to 13 feet BGS). The primary contaminants detected in these samples are Group II, III, and IV VOCs, phenols, and various metals including iron and zinc.

- ■ In the vicinity of former buildings 14, 16, and 25, the historical land uses included: a wastewater monitoring station and tanks. Samples collected in this area include soil borings PZ-01-12 (5 to 7 feet BGS) and GP-01-08 (12 to 14 feet BGS). The primary contaminants detected in these samples are phenols, metals including iron, and Group II VOCs at PZ01-12 and Group III VOCs at GP-01-08.

- ■ Between former buildings 8, 9, and 12, the historical land uses included: drum storage and tanks. Samples collected in this area include soil borings PZ-01-10 (8 to 10 feet BGS) and MW-88-7OB(R) (3 to 5 feet BGS). The primary contaminants detected in these samples are Group III VOCs, SVOCs including PAHs and phenols, metals including chromium, iron, mercury, and zinc, and Group IV VOCs at MW-88-7OB(R).

- ■ At the northeastern portion of site, the historical land uses included: a truck gate and scale, truck unloading, a liquid bleach sludge pond, drum storage, and tanks. Samples collected in this area include soil borings PZ-01-01 (12 to 14 feet BGS), GP-01-05 (4 to 5.5 feet BGS), and MW-88-12OB(R) (13 to 15 feet BGS). The primary contaminants detected in these samples are Groups I and III VOCs; metals including chromium, copper, iron, mercury, and zinc; and PAHs in GP-01-05.

In addition, based on contaminants detected in groundwater collected from upgradient on-site wells (to the north and northwest of the site), there appears to be some contributing off-site sources to groundwater contamination. A regional groundwater plume is located in the area of the site. The areas upgradient of the site contain various industries that may be contributing to groundwater contamination. Therefore, the presence of upgradient contamination is not unexpected. The primary upgradient contaminant detected was MCT. The source of this contamination is not known.

Routes of Migration

The following primary transport pathways for site contaminants have been identified.

- Surface water flow that allows lateral migration of contaminants to drainage structures, topographic low areas, or infiltration through the ground surface primarily during precipitation events.
- Infiltration of precipitation in areas not covered by a relatively impermeable barrier, followed by the leaching of water through the unsaturated zone to groundwater.
- Overburden groundwater flow that allows for both vertical and lateral migration of contaminants located within the saturated zone, as well as contaminants that migrate into the saturated zone from the overlying unsaturated zone due to infiltration.
- Bedrock groundwater flow (in A-, B-, and C-fracture zones) that allows for both vertical and lateral migration of contaminants through fractures in the Lockport Dolomite.
- Subsurface utilities and their bedding material that likely act as preferential pathways for subsurface flow at the site, especially the New Road and Falls Street Tunnels located adjacent to the site. Bedrock groundwater is expected to enter the tunnels from areas located both north and south of the tunnel, and a portion of the overburden groundwater flow is also expected to enter the tunnels.
- Volatilization of contamination in soil and groundwater followed by soil gas migration to utility beddings above the groundwater table, and ultimately to the ambient air at the ground surface.

In addition, based on analytical test results (high concentrations in soil and groundwater concentrations greater than 1% of the compounds solubility), DNAPL may be present at the site.

Observed and Predicted Migration

Based on the persistence and behavioral characteristics of the predominant contaminants detected at the site and the observed presence of chemicals in the various media tested, the potential significant migration pathways include surface water flow, groundwater (including infiltration), and volatilization.

- **Surface Water Flow.** Surface water flow may be a site mechanism that allows lateral migration of contaminants, if present in surface soils or as residuals on demolition debris, decommissioned tanks, etc. Although no surface soils were collected for analytical testing during this study, the 20% of open ground space is not expected to be significantly contaminated. However, historical site activities may have resulted in surface soil contamination at sporadic locations. Contaminated stormwater that does not pond for evaporation and infiltration, may discharge to the off-site municipal storm sewer system via site drainage structures. Stormwater samples in the on-site and off-site sewer systems were not collected. Therefore, this contaminant migration is expected but has not been confirmed.

- **Overburden Groundwater.** The overburden groundwater samples collected at the site include numerous VOCs, as well as select SVOCs (primarily phenols) and inorganic compounds, likely the result of leaching from site soils. Most of the high-level contaminants were detected in areas either coincident with or slightly offset from soil hot spots. The majority of VOCs detected (not including MCT) was halogenated aliphatic compounds, likely due to their higher relative mobility.

  In general, the contaminants are expected to flow at rates less than groundwater. Groundwater migration is expected to spread the contamination in the direction of groundwater flow (southeasterly) and vertically downward to lower water bearing zones. As the contamination migrates, the natural organic carbon in the soil will adsorb many of the detected compounds, thus slowing the advance of the plume. Horizontal migration rates of select VOCs and SVOCs were calculated to be about two to 71 times slower than overburden groundwater (approximately 6 feet per year). VOCs will also be attenuated in response to dispersion, volatilization, and degradation, among other factors. Migration of metals in groundwater is expected to occur, but is less significant than migration of VOCs.

  Overall contaminant concentrations in the overburden groundwater have declined since earlier rounds of groundwater sampling, as contaminants have migrated and attenuated. For example, volatile organic concentrations dropped from 575 to 73 μg/L in MW88-4OB between 1988 and 2001. Additional comparisons of 1988 and 2001 data are found in Table 5-6B, which lists the available 1988 data in comparison to 2001 data. Contaminants in the overburden are expected to enter the stormwater tunnels located adjacent to the site, and to migrate horizontally to the southeast, generally towards the Niagara River, and may be impacting off-site properties.

- **Bedrock Groundwater.** Analytical test results from the bedrock groundwater monitoring wells indicate the presence of numerous site contaminants, including VOCs, SVOCs (primarily phenols), and inorganic compounds. This, along with groundwater elevation data from the wells indicating a downward vertical gradient, indicates a hydraulic connection between the overburden and bedrock groundwater bearing zones and the discharge of overburden groundwater into the bedrock groundwater. In general, contamination in groundwater decreases with depth, from the overburden downward through the three evaluated fracture zones. Most of the high level contaminants were detected in areas corresponding with high concentrations in the overburden groundwater. However, in some cases the contaminant migration occurs along preferential pathways in the bedrock (along fractures), and thus in directions other than the overall groundwater gradients.

The contaminants in the fractured bedrock are expected to flow at rates less than groundwater, which is estimated to be 90 and 290 feet per year for fracture zones A and B, respectively. (Based on the limited number of wells in the C-fracture zone, estimates of groundwater flow velocity in this zone could not be determined.) Also, due to the complex nature of groundwater flow in bedrock, an accurate rate of contaminant migration could not be determined. However, based on the local and regional flow patterns of upper dolomite bedrock groundwater, the New Road and Falls Street tunnels are expected to intercept the bedrock groundwater. It is anticipated that some portions of the bedrock groundwater flow may be impacting off-site properties prior to entering the tunnels, based on the measured direction of groundwater flow. In addition, it should be noted that the tunnels are reported to receive impacted groundwater from other contaminated sites in the area, both at upstream and downstream locations.

Overall contaminant concentrations in the bedrock groundwater have declined since earlier rounds of groundwater sampling, as contaminants have migrated horizontally and vertically and attenuated. For example, volatile organic concentrations dropped from 292 to 4 μg/L in MW88-1B between 1988 and 2001. Additional comparisons of 1988 and 2001 data are found in Tables 5-8B, 5-10B, and 5-12B which lists the available 1988 data in comparison to 2001 data.

- **Volatilization.** VOCs within the site overburden groundwater and soils may volatilize into the unsaturated soil zone. Soil vapors may discharge into the atmosphere, and into on-site or off-site subsurface structures such as basements, manholes, or sumps. In addition, volatilization of VOCs may occur at groundwater discharge locations, such as sumps, the stormwater tunnels, and/or surface water features.

8.1.4 Qualitative Human Health Risk Evaluation

COPCs identified by the preliminary screening in both soil and groundwater were evaluated along with current and potential future exposure pathways with respect to potential human exposure. The magnitude of exposure and likelihood of potential adverse health effects were assessed qualitatively through comparisons with appropriate risk-based concentrations that were available. The following is a summary of the evaluations.

Subsurface Soil

Since the Frontier Chemical Site is currently an inactive industrial site, current human receptors would include site visitors and possibly trespassers. Therefore, exposure to site contaminants would only be through surface soil contact or soil vapors. The presence of surface soil or ambient air contamination is unknown. If the site were redeveloped, site workers could be exposed to soil contaminants by the same pathways that currently exist for visitors, but the magnitude of potential worker exposures would be much greater due to the expected higher intake rates, greater exposure frequency, and longer exposure duration. In addition, because soil excavation and other disturbance during redevelopment could unearth contaminated subsurface soils, future workers could potentially have direct contact with some of the contamination that is now inaccessible.

Comparisons of chemical concentrations in subsurface soils to risk-based concentrations developed for industrial soil indicate that the risks to future commercial or industrial workers from long-term exposure to site soil contamination will not exceed risk levels regarded as acceptable by EPA. Short-term exposure rates for some workers may be greater than standard worker exposure assumptions. Such exposures are expected to be relatively brief and may be mitigated by appropriate monitoring, engineering controls, and use of personal protective equipment. Risk to current and future visitors, whose potential exposures are considerably less than workers, are well below levels of concern.

Groundwater

It is not likely that site groundwater would ever be used directly as a source of drinking water. The site and surrounding area are served by the city water system, which draws its supply from the Niagara River. Generally, groundwater from the site flows into adjacent New Road and Falls Street sewer tunnels, where the majority of site groundwater is diverted during normal flow conditions into the Southside Interceptor where the discharge is effectively treated at the City of Niagara Falls Sewage Treatment Plant before it reaches the river. However, some of the contaminated groundwater from the site may reach the river via weir overflow during storm events resulting in direct discharge of contaminated water within the Falls Street Tunnel into the river. In addition, off-site migration of site contaminants within the bedrock groundwater is possible within the lower bedrock fracture zones (C-fracture zone and possibly lower uncharacterized zones).

Under existing site conditions, with no groundwater use, there is no pathway for direct contact with contaminated groundwater. However, vapors from volatile groundwater contaminants can be transported upward through the soil and released from the ground surface to ambient air through sewer manholes, cracks in pavement, or in unpaved areas to ambient air, potential exposing site visitors via the inhalation route. Site visitors’ exposures are not likely to reach levels of concern, because the total exposure time from infrequent short-duration visits will be relatively small. On the other hand, if the site were redeveloped for commercial or industrial use, the exposure time for future workers would be considerably greater, possibly 40 hours per week over a period of many years. Furthermore, if a building were constructed over the plume, infiltration of vapors through the foundation could expose workers to higher vapor concentrations in indoor air. During site redevelopment, construction workers might also be exposed to higher ambient vapor concentrations in manholes and excavations. Comparisons to risk-based screening levels that have been developed for groundwater based on potential vapor migration to outdoor air (TNRCC 2001) suggest that long-term inhalation of vapors from the highest concentrations of vinyl chloride and TCE in groundwater could pose significant cancer risks to future site workers.

Under an industrial use scenario, groundwater could conceivably be used in the plant processes, potentially exposing future workers to contamination by incidental contact and by inhalation of volatile contaminants released from the water to ambient air. If so, the magnitude of potential worker exposures would not be as great as it would from drinking water use. Nevertheless, due to the extremely high levels of some VOCs present in the groundwater, worker exposures might reach levels associated with unacceptably high cancer risks and other adverse health effects.

8.2 Conclusions

Results of the SRI activities and analytical data indicate that the site soil and groundwater is highly contaminated, and contamination is migrating off site. Based on this investigation and other historical data from the immediate site vicinity, site contaminants are predominantly migrating into the adjacent sewer tunnels. Under dry weather conditions, the majority of this water is likely being diverted to the Niagara Falls Sewage Treatment Facility. However, during periods of high precipitation, site groundwater in the Falls Street Tunnel may bypass diversion weirs and discharge directly into the Niagara River. In addition, groundwater from the site may also undergo subsurface migration to the south toward the river.

8.2.1 General Conclusions

The following is a summary of the general conclusions derived from this investigation:

- There were multiple source areas on site, as well as unidentified off-site sources to the north and northeast of the site.

- Because the site is inactive and underwent several source removal actions, which were completed by March 1995, no addition contaminate contribution to the existing and remaining source areas is expected.

- The site is mainly contaminated by VOCs. Significant SVOC contamination (predominantly PAHs and phenols) is also present to a lesser degree, along with dioxins, and metals. There are also minor amounts of pesticides in excess of criteria.

- VOC contaminant concentrations range up to 7,900,000 ppb or 0.8% in soils and 350,000 ppb or 0.03% in groundwater.

- Although no surface soils were collected, the 20% of open ground space is not expected to be significantly contaminated. This is supported by the relatively clean nature of most of the subsurface soils tested in these open areas (i.e., only two open areas exhibited subsurface contamination: PZ-01-01 and PZ-01-06. PZ-01-01 is at the former location of a larvacide pond, and PZ-01-06 is at the former location of the terminus of the larvacide pond and loading dock drainage ditch).

- Contamination levels in groundwater decrease with depth (i.e., the highest levels of contaminants were detected in overburden groundwater, and concentrations decrease in the underlying A-fracture, B-fracture, and C-fracture bedrock zones).

- Lateral contaminant migration in the groundwater is generally to the southeast (in the direction of groundwater flow); and vertical migration is downward.

- Due to the lack soil sampling for analytical testing in previous investigations, a baseline for degree of soil contamination was not established. However, it appears from this investigation that unsaturated soil contaminants in the subsurface soils continue to leach into shallow groundwater.

- Overall contaminant concentrations in both overburden and bedrock groundwater have declined since 1990, except for VOCs in one of the C-fracture bedrock wells (MW-88-5C). In addition, most of the hot spots have migrated either vertically deeper into the bedrock, or laterally approximately 100 feet.

- The New Road and Falls Street tunnels, and South Side Interceptor sewer line all intersect the B-fracture bedrock zone. However, due to the nature of construction (i.e., unlined blasted tunnels), there is a highly conductive hydraulic zone present above each tunnel which allows for the downward migration of groundwater from the overlying A-fracture bedrock zone and overburden.

- It appears that the New Road and Falls Street tunnels intercept most of the groundwater exiting the site and other regional groundwater from adjacent sites.

8.2.2 Data Limitations and Recommendations for Future Work

The high levels of subsurface soil and groundwater contamination have been well documented in this and previous investigations. However, there are some minor data gaps to consider:

- No surface soils were collected from the open areas of the site. Although contact is limited because the site is inactive and fenced, exposure to trespassers, future site investigation workers, and limited wildlife may be of concern. Therefore, limited surface soil sampling may be warranted.

- Groundwater is highly contaminated and extends to considerable depth in the underlying bedrock. Historically, there were only three C-fracture bedrock zone wells, and there are only two that are currently functional. Contamination levels in the downgradient C-fracture wells have increased since 1990. Additional C-fracture wells may be warranted to help determine if a significant portion of the contamination is migrating off site beneath the tunnels.

- It is assumed, based on regional and site hydrology, that most of the contamination is being captured by the sewer tunnels. However, to verify that this occurs, additional bedrock well clusters (A-, B-, and C-fracture zones) may be warranted on the south side of the South Side Interceptor tunnel.

- In order to determine more accurate retardation factors for site contaminants, total organic carbon (TOC) analysis of site subsurface soils is warranted.

9

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A

Photographic Logs

FRONTIER CHEMICAL ROYAL AVENUE
SITE NO. 9-32-110
NIAGARA FALLS, NEW YORK
PHOTO LOG
MAY 29, 2001

CAMERA: DIGITAL KODAK DC240 ZOOM
SERIAL NO.: EKL91702424
PHOTOGRAPHER: GENE FLORENTINO – ECOLOGY AND ENVIRONMENT

Photo No.	Description
0395	Panoramic view of site to the north taken from the gate south of the truck scale near the northeast corner of the site.
0397	Panoramic view of site to the northwest taken from the gate south of the truck scale near the northeast corner of the site.
0399	Panoramic view of site to the southwest taken from the gate south of the truck scale near the northeast corner of the site.
0401	Panoramic view of site to the south taken from the gate south of the truck scale near the northeast corner of the site.
0403	View to west (northern site boundary) from NE corner of site.
0404	View to south from drum storage area between buildings 56 and 73.
0405	View to south from Building 70 of western site boundary.
0406	View to north from Building 70 of western site boundary.
0407	View to southeast of Tanks 104, 103, 102, and 101.
0408	Drums in rubble at former Drum Storage DS-3
0415	View to north (western site boundary) from SW corner of site.
0417	View to northeast from SW corner of site.

B

Sanborn Maps

C

Geoprobe, Boring, Well Installation, and Well Development Logs

D

Inventory of Investigation-Derived Waste

E

Data Usability Summary Reports

F

Auxillary Analytical Data Tables (TICs and Dioxins)

G

Analytical Data Summary Forms

Monitoring Wells Installed Prior to 1987

Monitoring Wells Installed in 1987

Monitoring Wells Installed in 1988

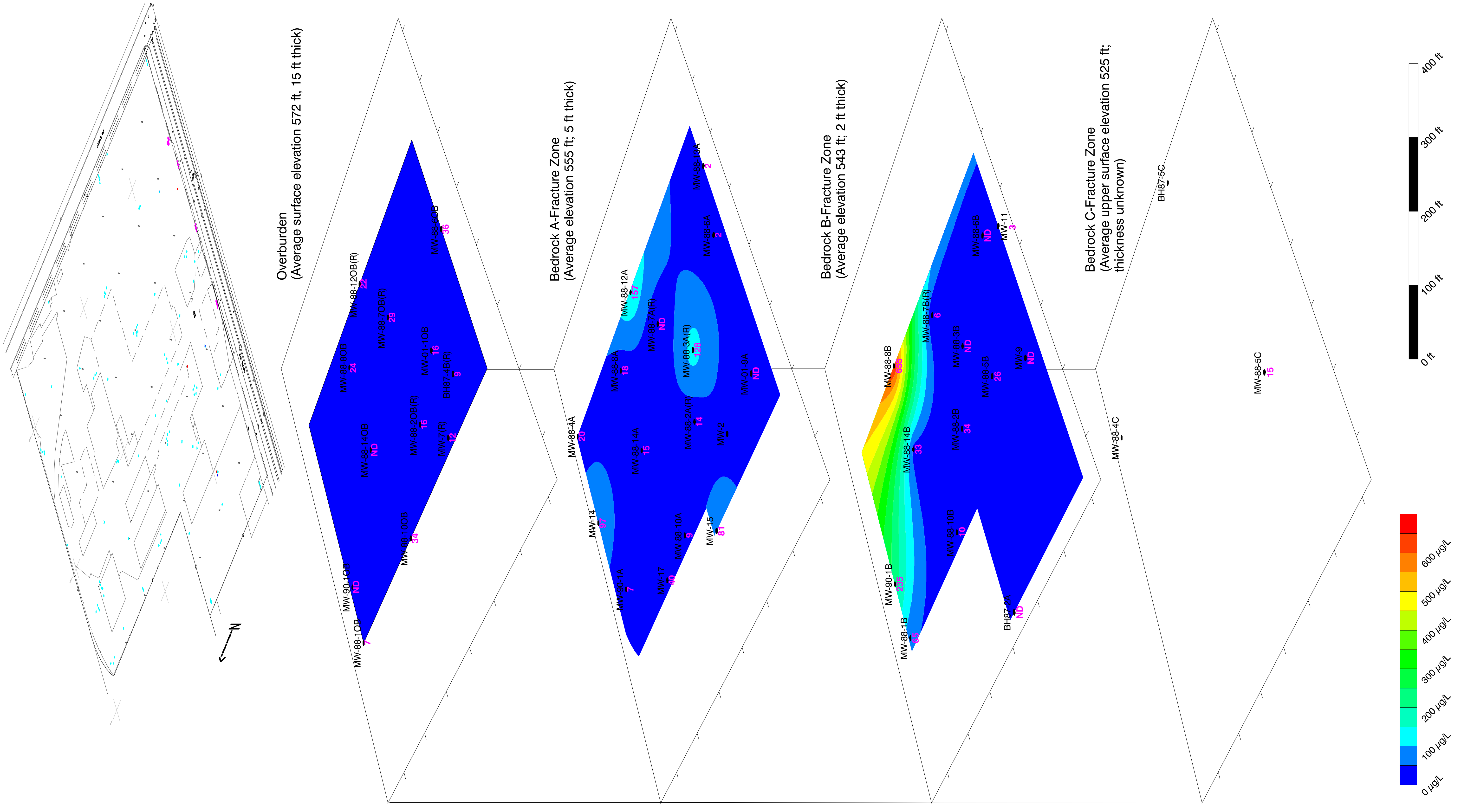
Monitoring Wells Installed in 1990

Monitoring Wells Installed in 2001

Geoprobe Piezometers Installed in 2001

Trip Blanks

02:000699_NV05_02_02-B0899
Fig5-14.cdr-7/9/02-GRA



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer “C” due to limited number of data points.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.
4. Groundwater samples were collected using bailers; and a number of them had very high turbidity measurements (greater than 50 NTu), indicating the presence of suspended solids. Turbidity in groundwater samples can cause interference with the analysis. Therefore, the actual concentrations of dissolved inorganics may be much lower than those measured.

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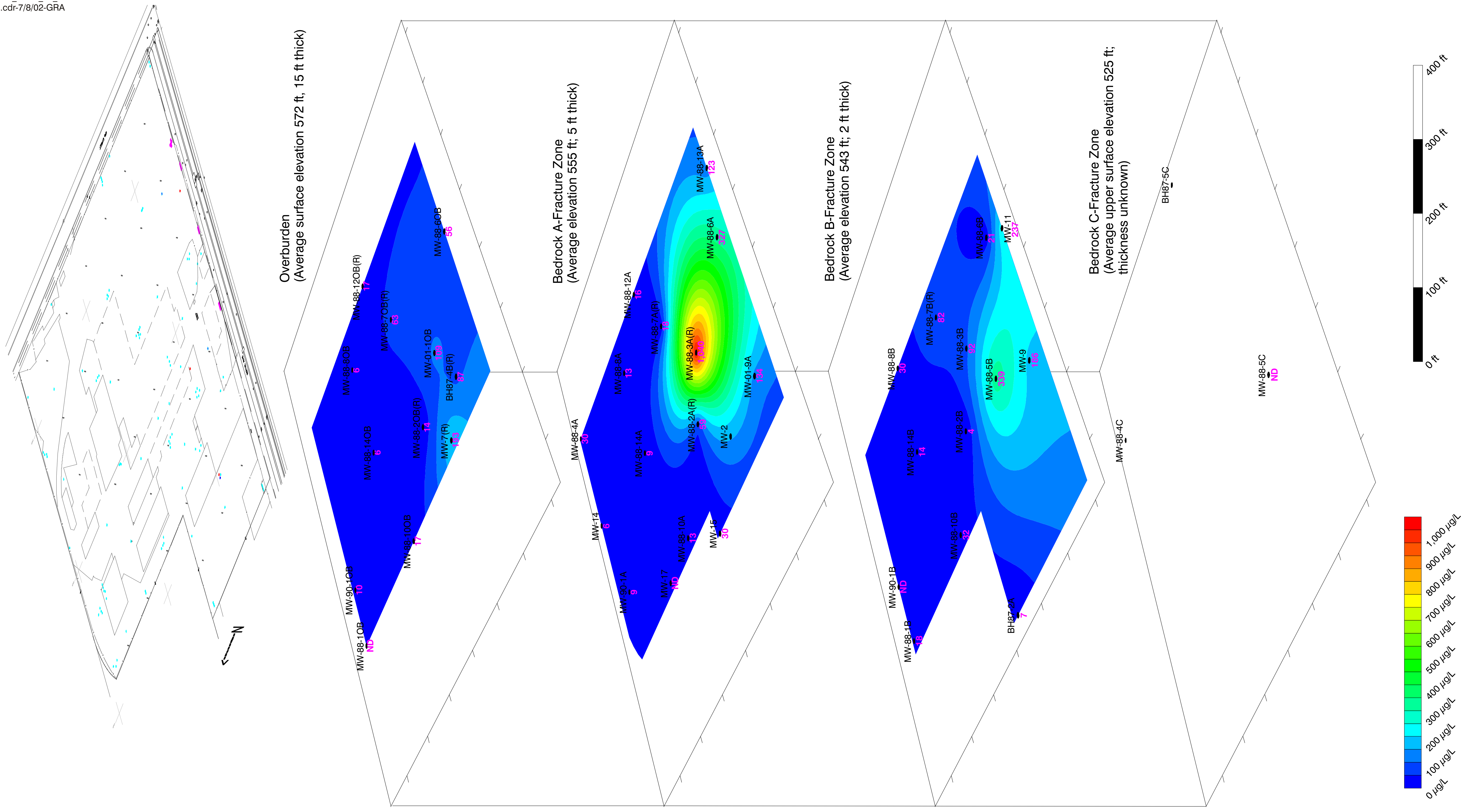
Figure 5-14 Three-Dimensional View of Lead Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-13.cdr-7/8/02-GRA



Notes:

1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.
4. Groundwater samples were collected using bailers; and a number of them had very high turbidity measurements (greater than 50 NTu), indicating the presence of suspended solids. Turbidity in groundwater samples can cause interference with

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Figure 5-13 Three-Dimensional View of Arsenic Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-12.cdr-7/9/02-GRA

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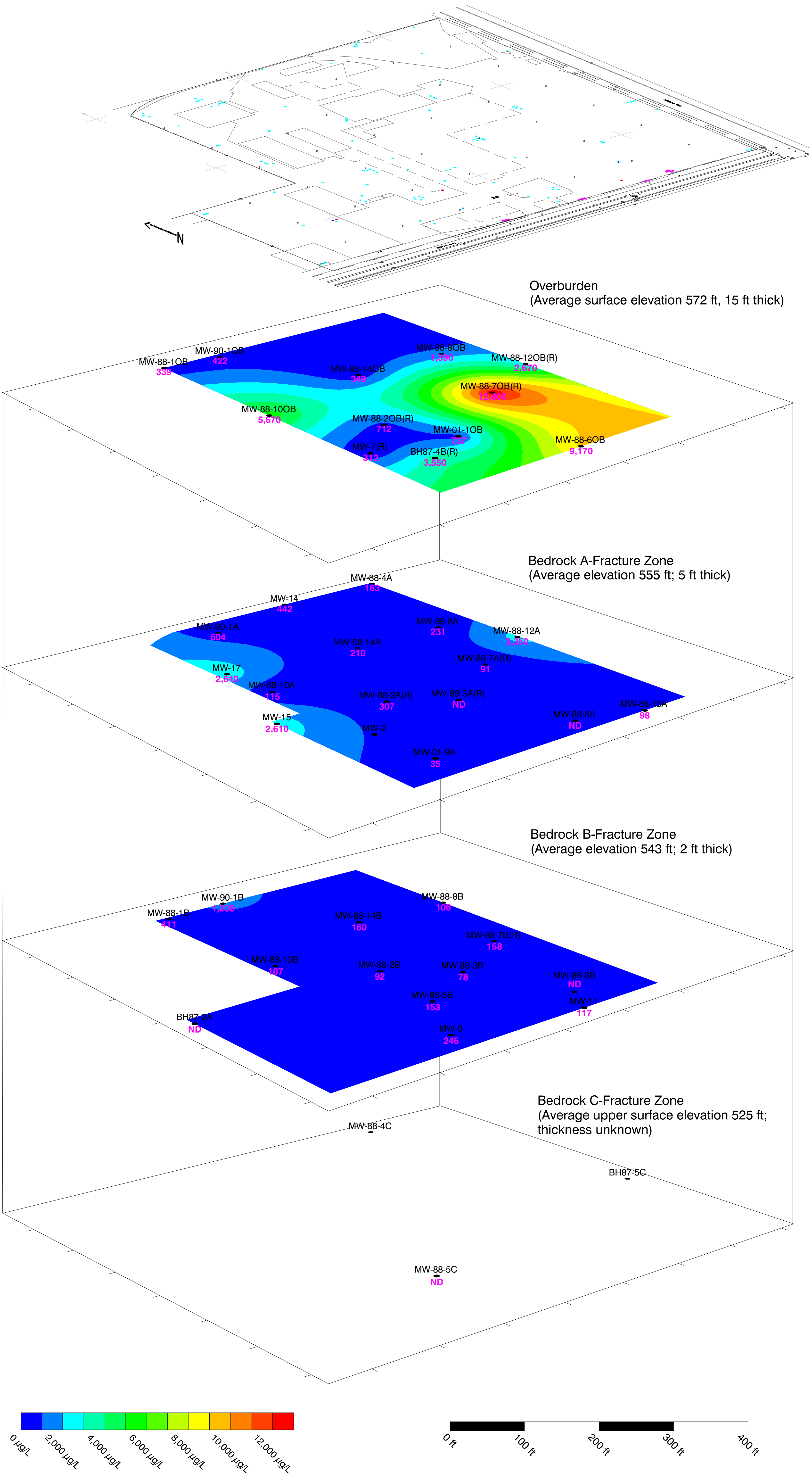
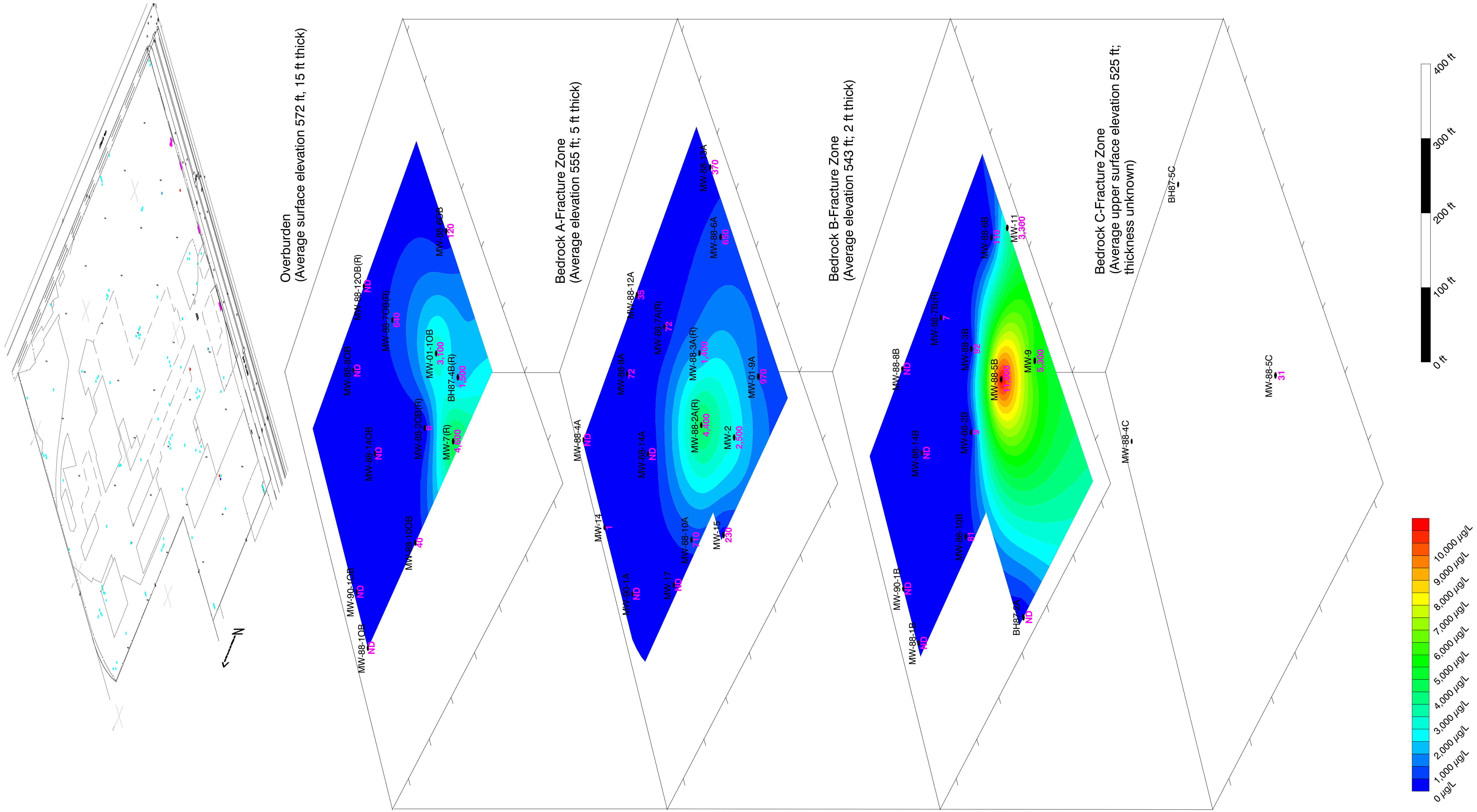


Figure 5-12 Three-Dimensional View of Aluminum Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

Notes:

1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.
4. Groundwater samples were collected using bailers; and a number of them had very high turbidity measurements (greater than 50 NTU), indicating the presence of suspended solids. Turbidity in groundwater samples can cause interference with the analysis. Therefore, the actual concentrations of dissolved inorganics may be much lower than those measured.

02:000699_NV05_02_02-B0899
Fig5-11.cdr-7/9/02-GRA



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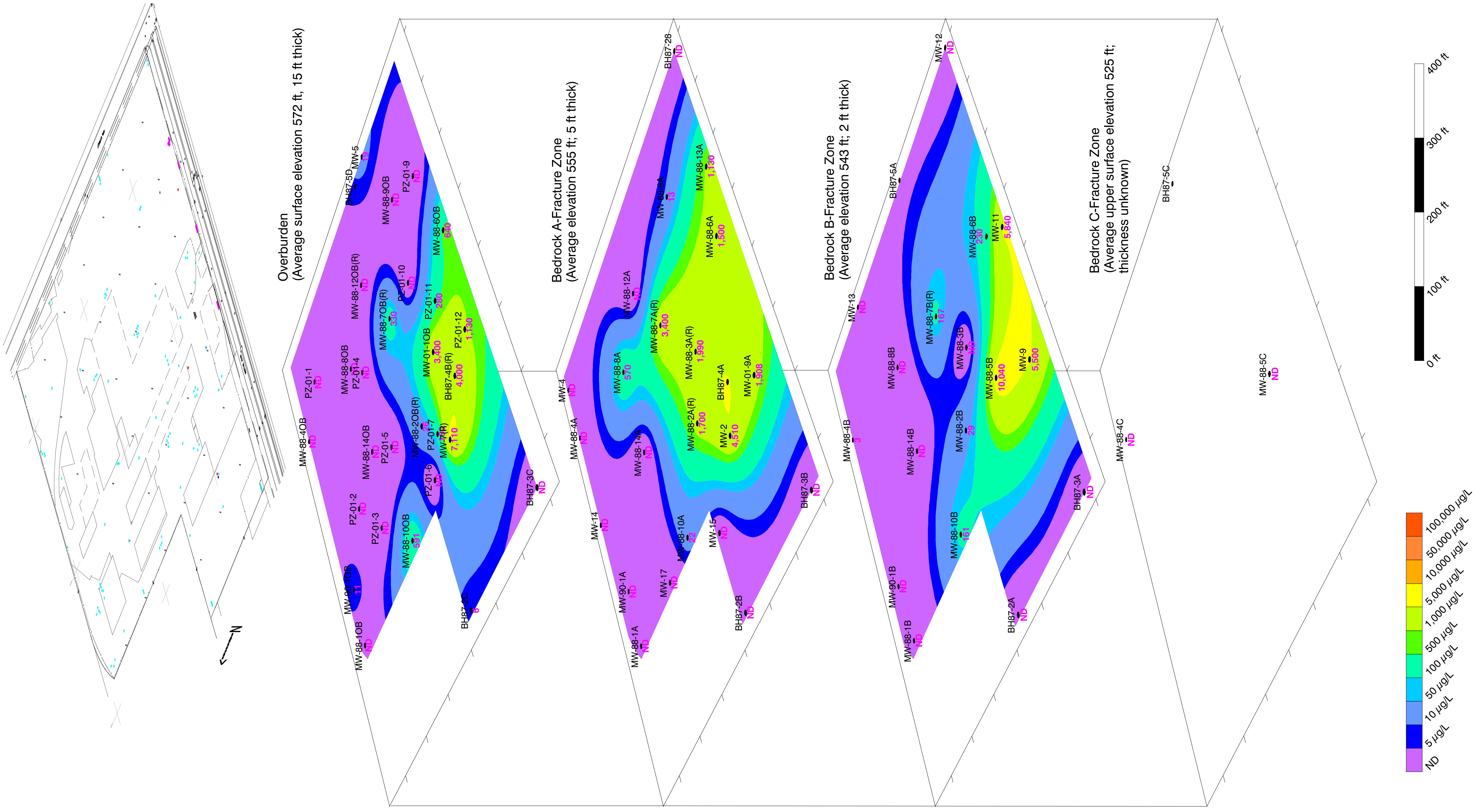
Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

Figure 5-11 Three-Dimensional View of Total Phenol Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-10.cdr-7/9/02-GRA



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. See text for description of Group V VOCs.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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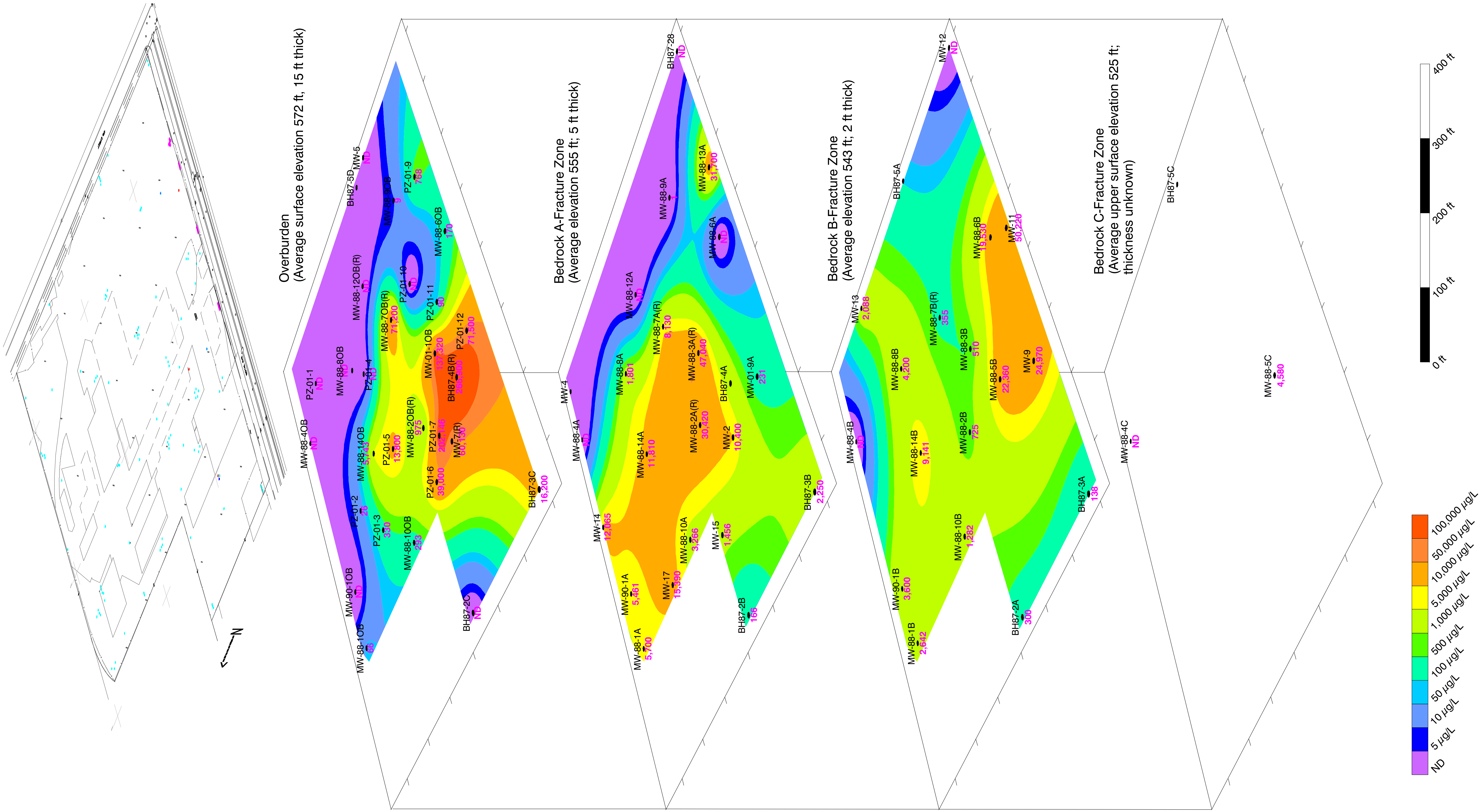
Figure 5-10 Three-Dimensional View of Group V VOC Concentrations in Groundwater
Former Frontier Chemical Waste Process, Inc. Site



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. See text for description of Group IV VOCs.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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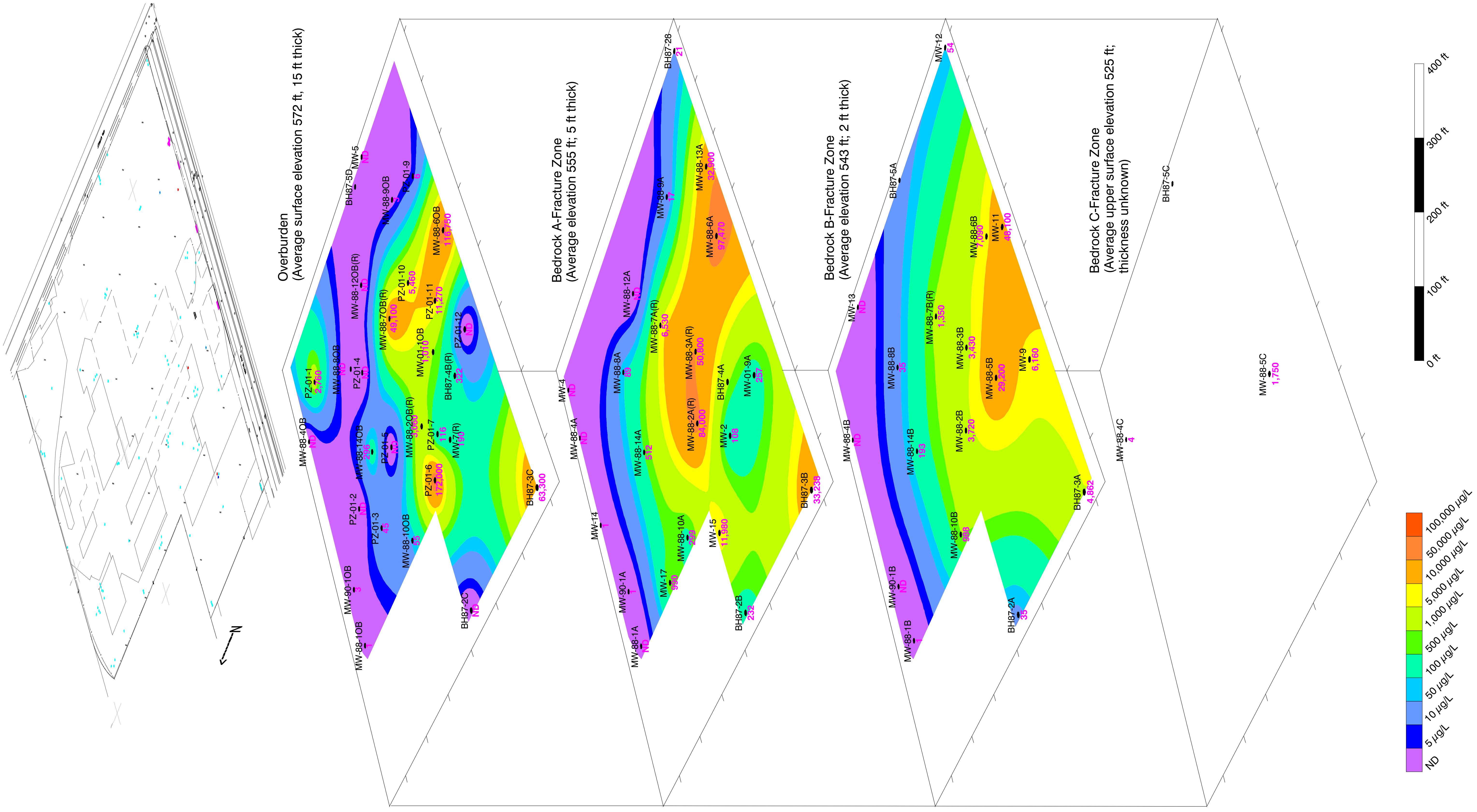
Figure 5-9 Three-Dimensional View of Group IV VOC Concentrations in Groundwater
Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-8.cdr-7/9/02-GRA



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. See text for description of Group III VOCs.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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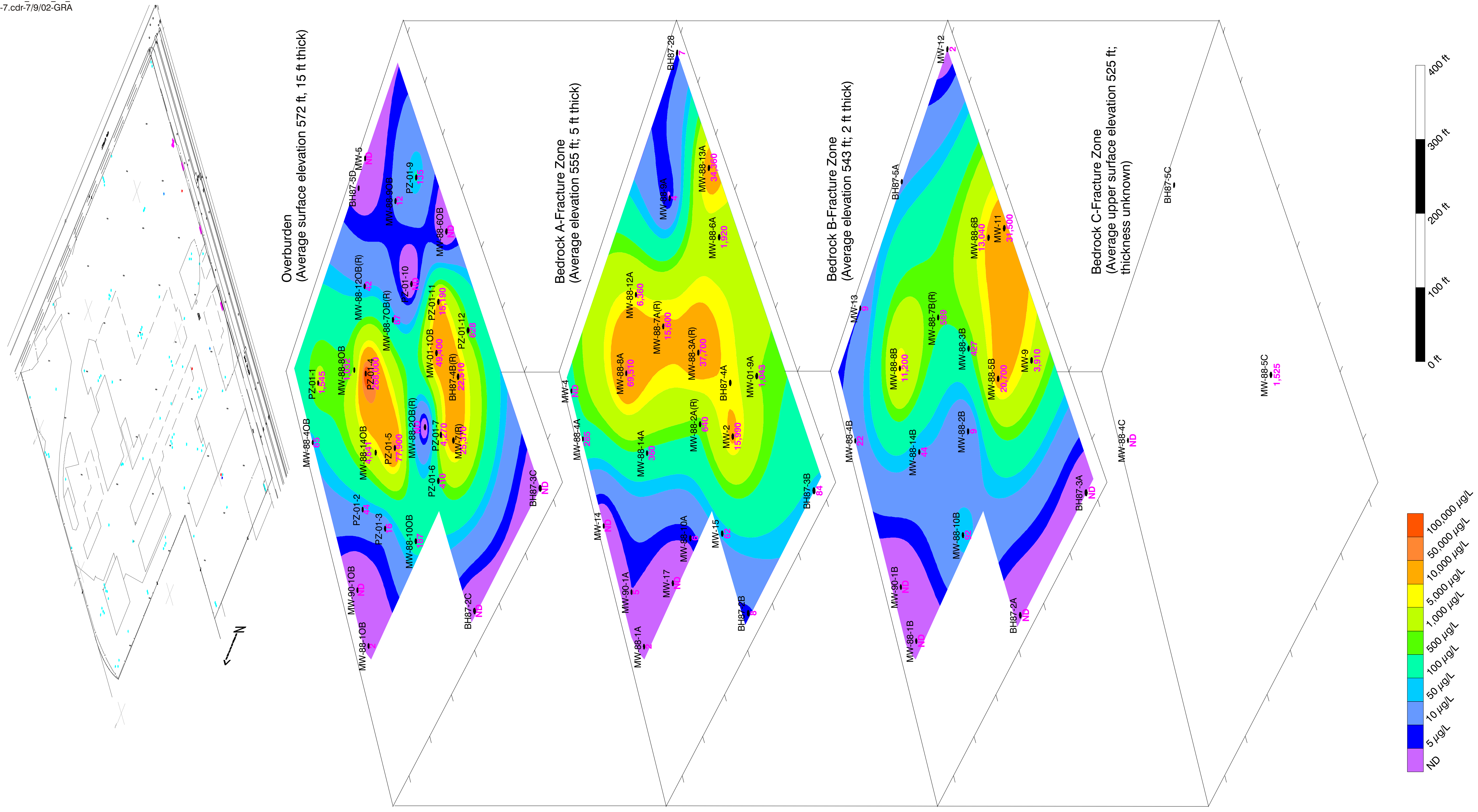
Figure 5-8 Three-Dimensional View of Group III VOC Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-7.cdr-7/9/02-GRA



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. See text for description of Group II VOCs.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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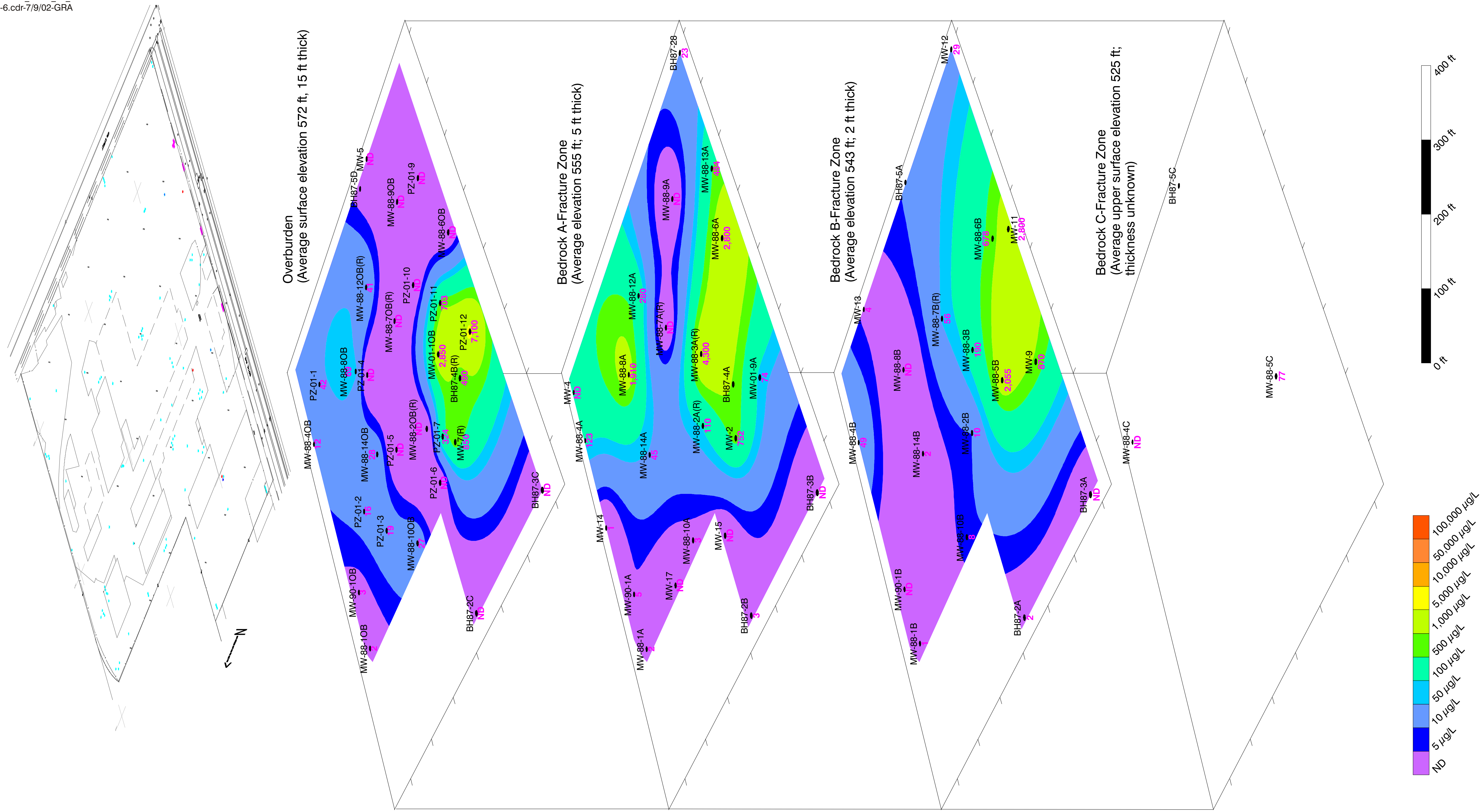
Figure 5-7 Three-Dimensional View of Group II VOC Concentrations in Groundwater
Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-6.cdr-7/9/02-GRA



Notes:
1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. See text for description of Group I VOCs.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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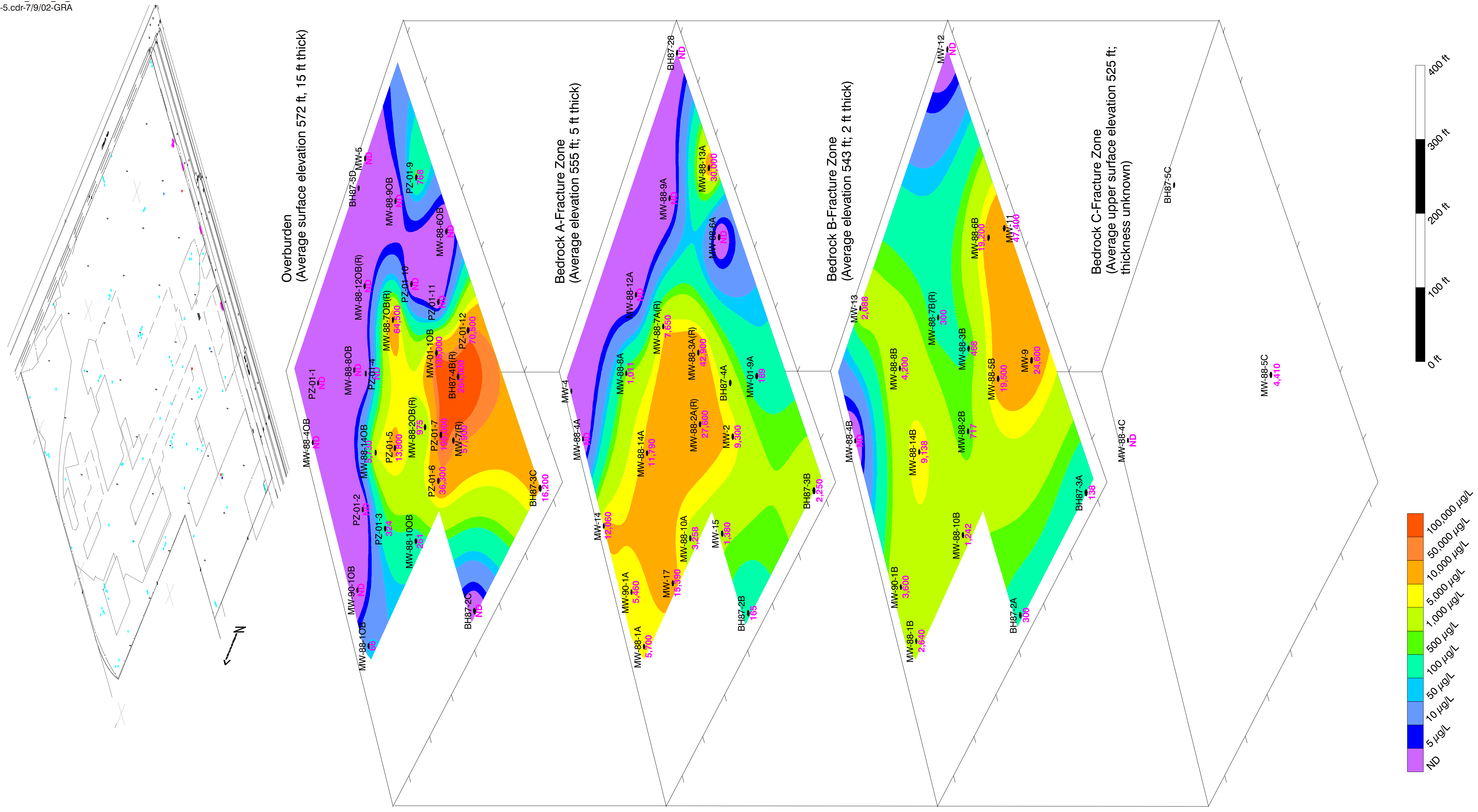
Figure 5-6 Three-Dimensional View of Group I VOC Concentrations in Groundwater
Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-5.cdr-7/9/02-GRA



Notes:
1. Monochlorotoluene (MCT) is a tentatively identified compound.
2. Samples collected November 2001.
3. Contours not provided for Bedrock Layer "C" due to limited number of data points.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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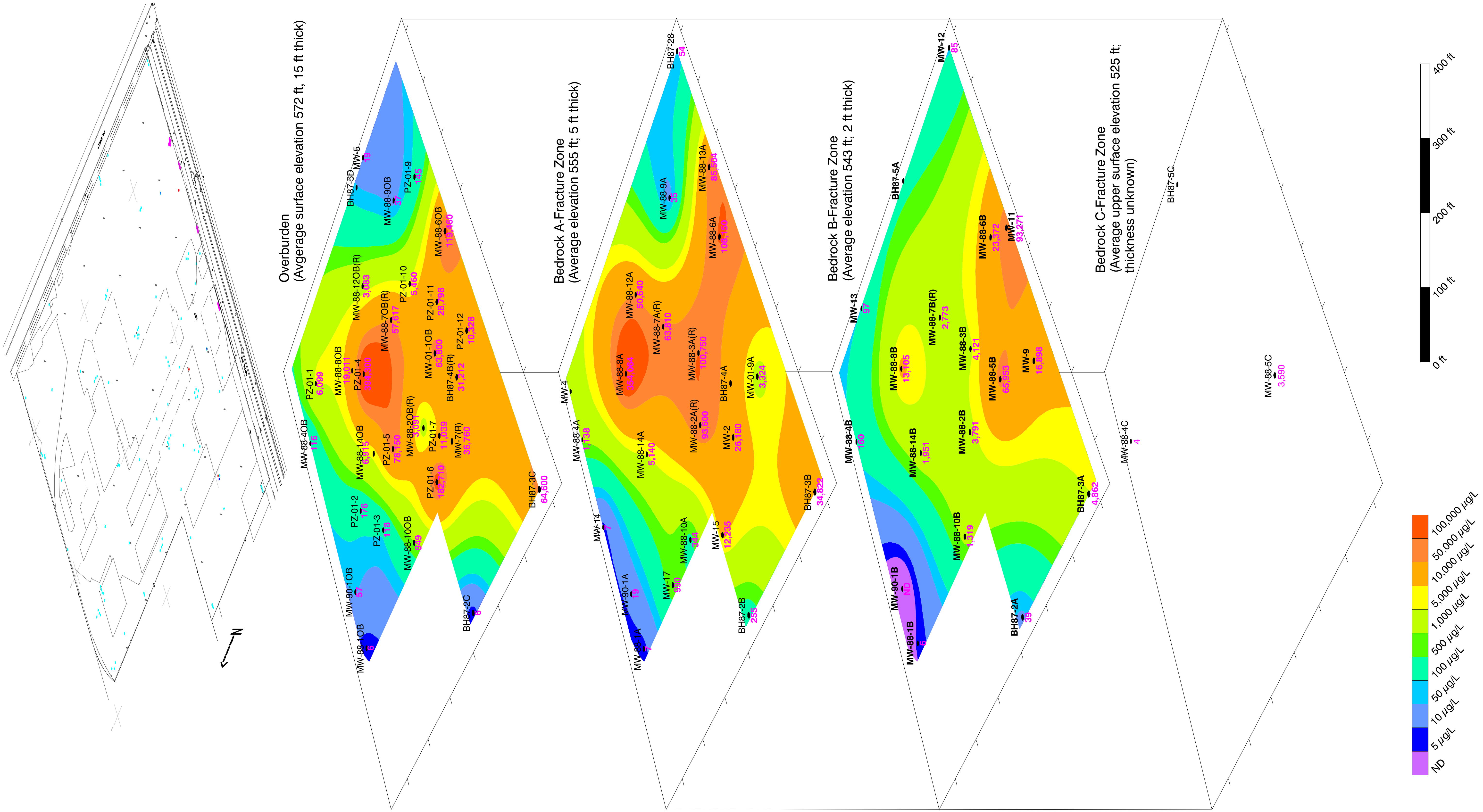
Figure 5-5 Three-Dimensional View of Monochlorotoluene Concentrations in Groundwater Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-4a.cdr-10/10/02-GRA



Notes:
1. Samples collected November 2001.
2. Monochlorotoluene not included in total volatile organic compounds (VOCs).
3. Contours not provided for Bedrock Layer “C” due to limited number of data points.
4. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.

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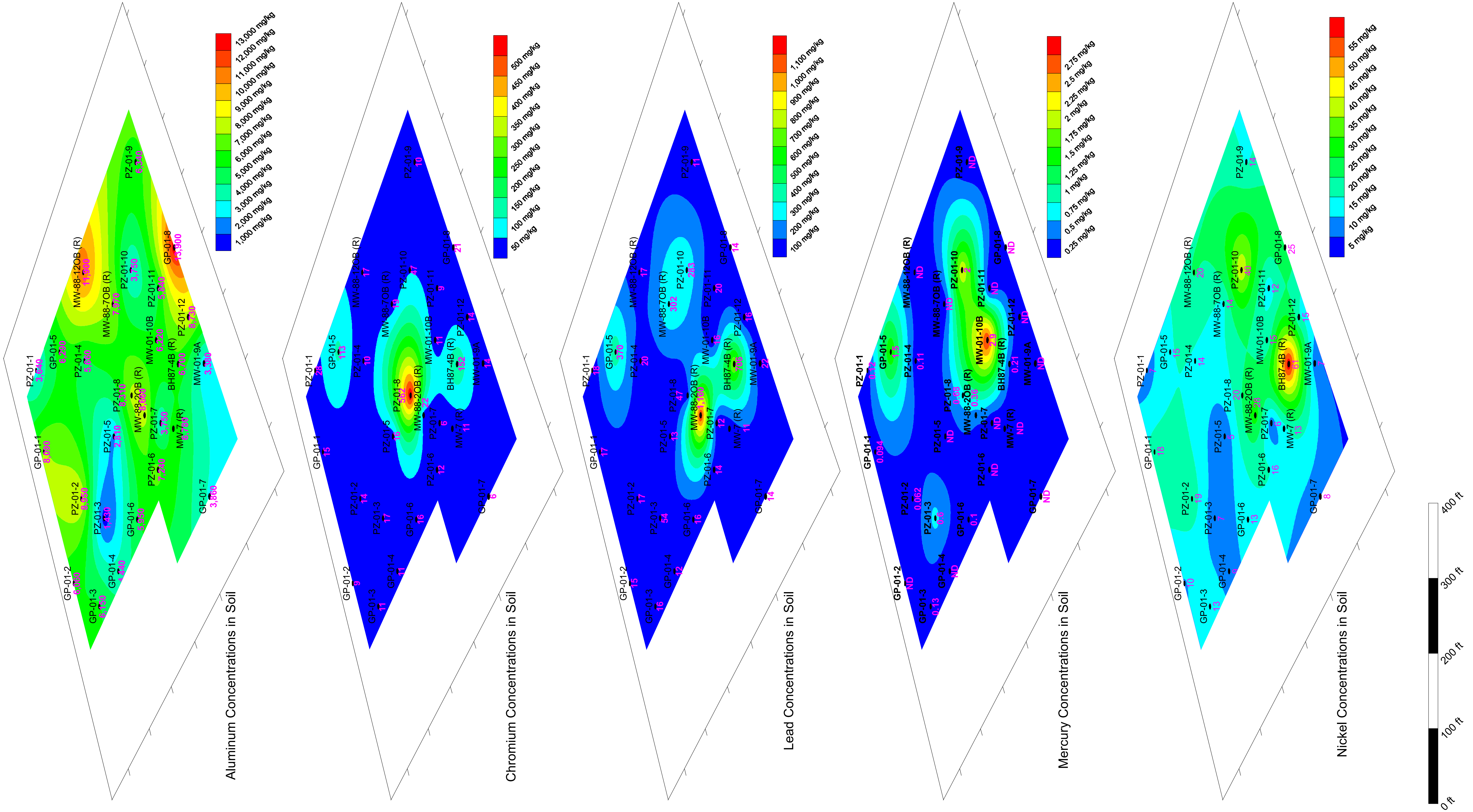
Figure 5-4 Three-Dimensional View of Total VOC Concentrations (Minus MCT) in Groundwater
Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-3.cdr-7/9/02-GRA



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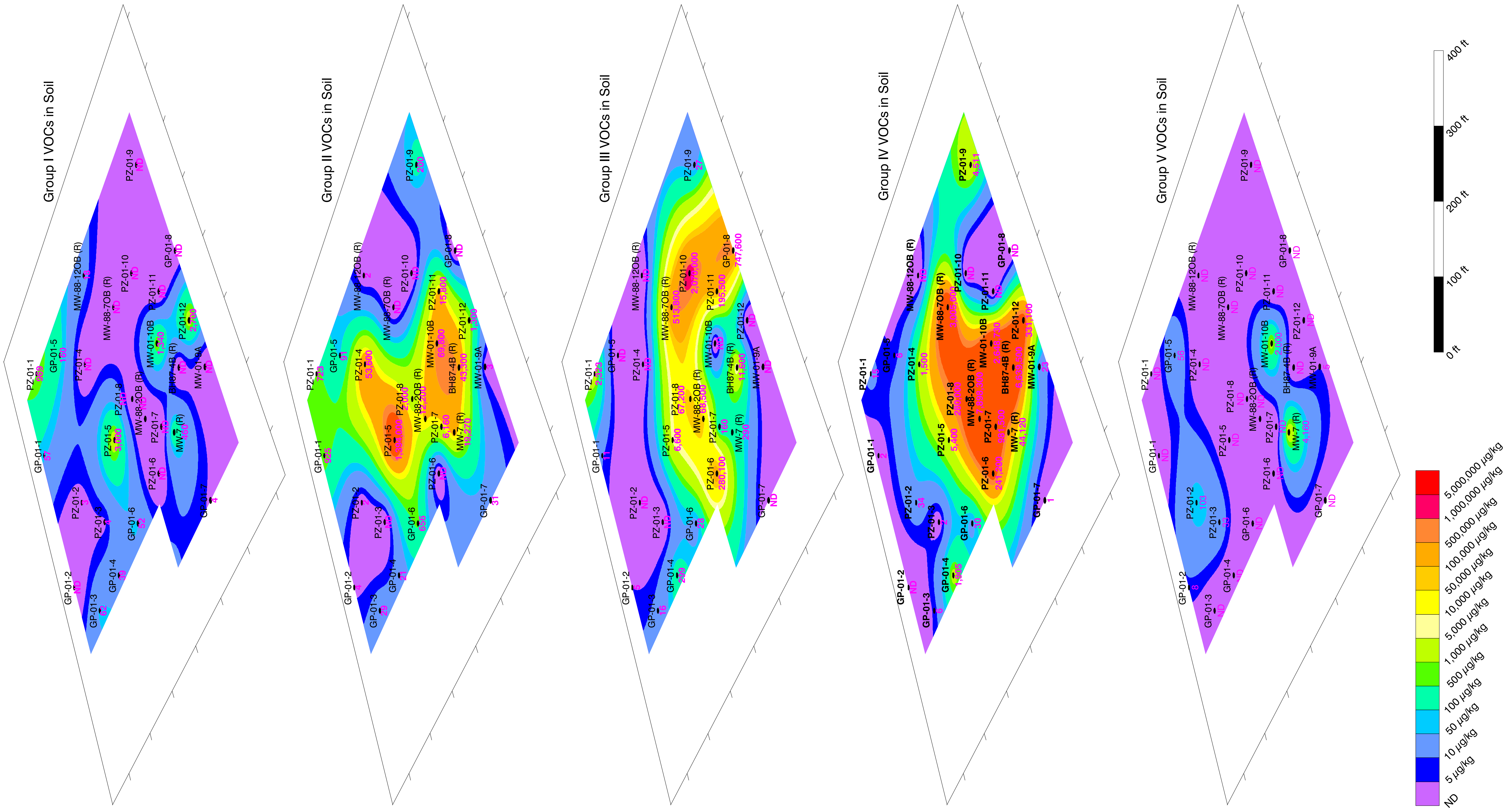
Notes:
1. Samples collected November 2001.
2. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced borings, and are presented for illustrative purposes.

Figure 5-3 Contour Plots of Selected Metals Concentrations in Soil
Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig5-2.cdr-7/8/02-GRA



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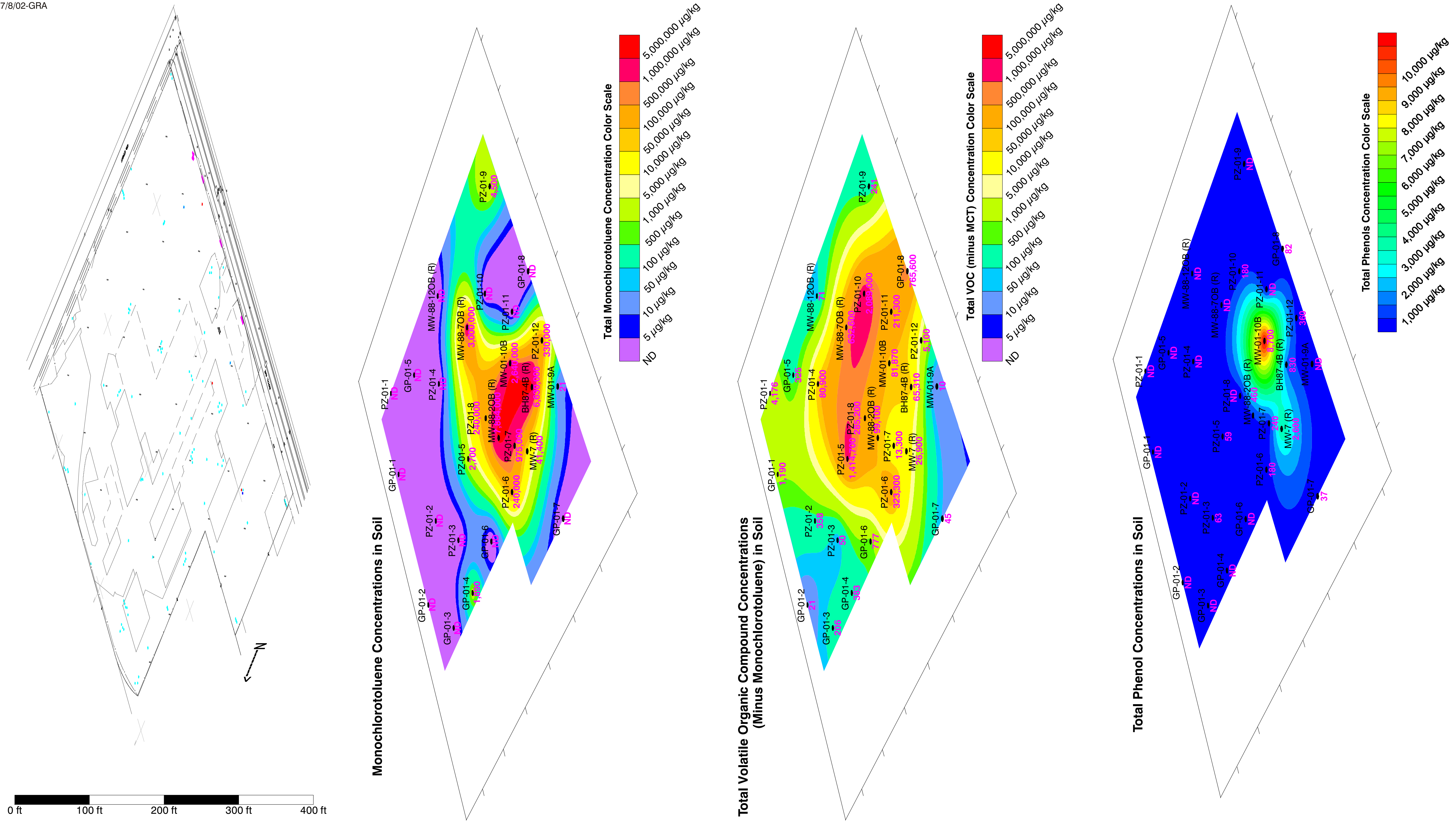
Notes:
1. Samples collected November 2001.
2. See text for a description of the VOC Groups.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced borings, and are presented for illustrative purposes.

Figure 5-2 Contour Plots of Group I, II, III, IV, and V VOC Concentrations in Soil Former Frontier Chemical Waste Process, Inc. Site

02:000699_NV05_02_02-B0899
Fig-5-1a.cdr-7/8/02-GRA



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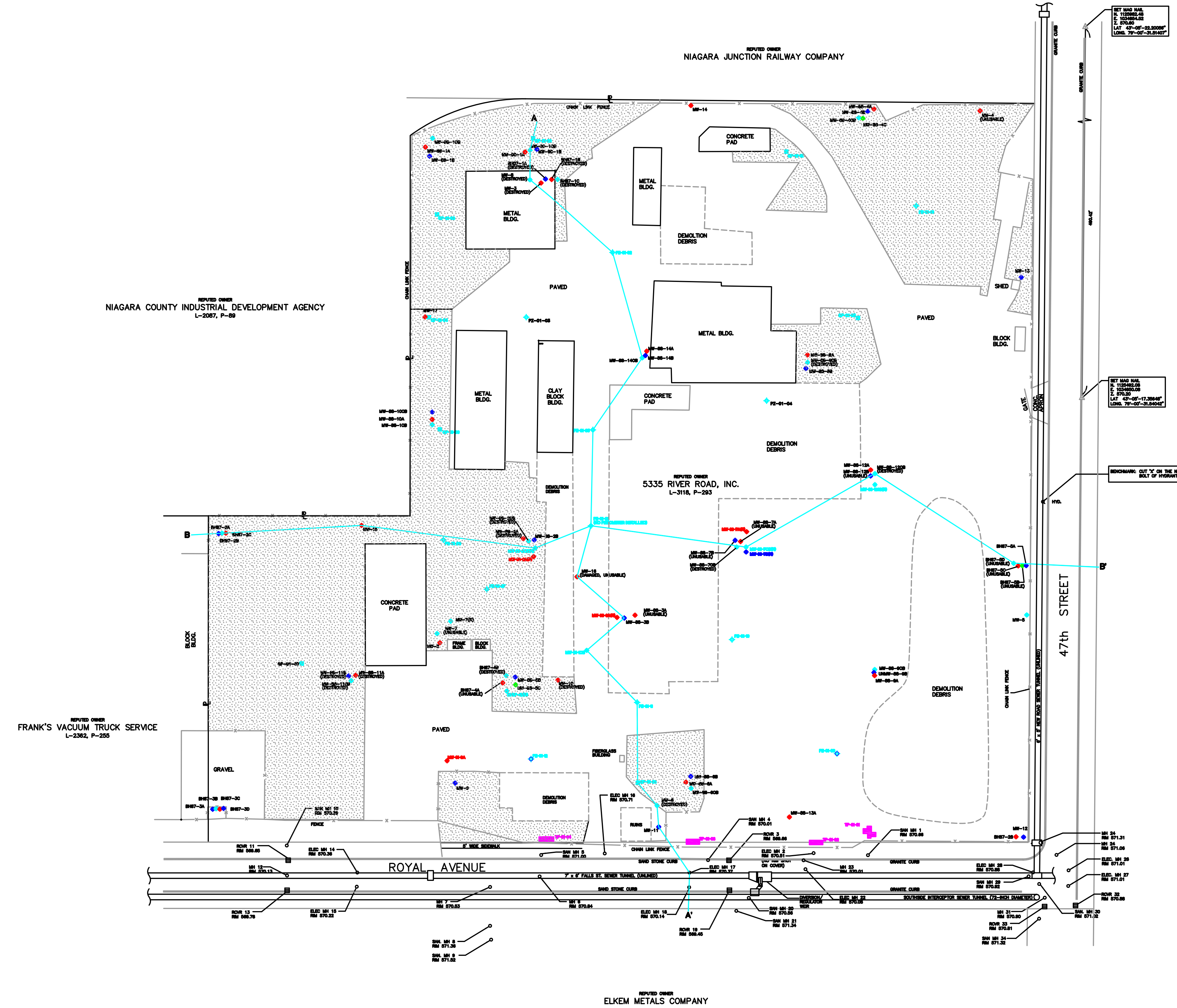
Notes:
1. Monochlorotoluene (MCT) is a tentatively identified compound.
2. Samples collected November 2001.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced borings, and are presented for illustrative purposes.

Figure 5-1 Contour Plots of Total VOC Minus MCT, MCT, and Phenol Concentrations in Soils Former Frontier Chemical Waste Process, Inc. Site



LEGEND

▨	UNPAVED AREAS
—℄—	PROPERTY LINE
MW-88-90B ◆	OVERBURDEN MONITORING WELL
MW-88-9A ◆	A-FRACTURE ZONE BEDROCK WELL
UNMW-88-9B ◆	B-FRACTURE ZONE BEDROCK WELL
BH87-5B ◆	C-FRACTURE ZONE BEDROCK WELL
◆	SRI WELLS
◆	SRI PIEZOMETER LOCATION
■	SRI GEOPROBE SOIL BORING LOCATION
■	SRI TEST PIT LOCATION
A — A'	CROSS SECTION LINE
▤	RECEIVER
○	MANHOLE
— — —	OUTLINE OF DEMOLISHED BLDGS./ STRUCTURES OR DEBRIS PILE
——	OUTLINE OF BLDG. OR CONCRETE PAD
— x —	FENCE

BENCHMARK

1) PROJECT ELEVATIONS BASED UPON EXISTING BENCHMARK TBM 3 AS OBSERVED IN CONTROL PLACED FOR THE CITY OF NIAGARA FALLS GIS CONTROL PROJECT AS FOLLOWS: A SQUARE CUT ON THE NORTHWEST CORNER OF THE CONCRETE FOOTING AT THE NORTHWEST LEG OF TRANSMISSION TOWER #LN 32 TWR 97. LOCATED AT THE SOUTHWEST CORNER OF THE INTERSECTION OF PACKARD ROAD AND NIAGARA FALLS BOULEVARD. ELEV. 581.24 (NGVD 1929)

2) SITE TBM CUT 'X' ON THE N.-N.E. BONNET BOLT OF HYDRANT LOCATED ON WEST SIDE OF 47th STREET (ELEV. 572.86).

NOTES

1) HORIZONTAL DATUM IS BASED ON THE NEW YORK STATE PLANE COORDINATE SYSTEM WEST ZONE NAD83/92HARN (FEET).

2) REFERENCE MAP – CITY OF NIAGARA FALLS TAX MAP NO. 160.09.

3) PROPERTY LINES SHOWN ARE APPROXIMATE IN LOCATION AND ARE BASED UPON THE ABOVE REFERENCED TAX MAP. PROPERTY OWNER INFORMATION IS BASED ON THE TAX MAP AND CITY OF NIAGARA FALLS WASTEWATER FACILITIES DRAWINGS.

4) NOT ALL PLANIMETRIC/TOPOGRAPHIC FEATURES WERE IDENTIFIED AS PART OF THIS PROJECT SCOPE.

5) SRI WELLS/PIEZOMETERS/GEOPROBE/TEST PIT LOCATIONS ARE SHOWN WITH BOLD TEXT.

6) SRI = SUPPLEMENTAL REMEDIAL INVESTIGATION.

7) SELECT UTILITY LINES AND SEWER TUNNELS LOCATIONS AND SIZES ARE APPROXIMATE BASED ON DRAWINGS PROVIDED BY CITY OF NIAGARA FALLS DEPT. OF WASTEWATER FACILITIES.

8) BASE MAP PROVIDED BY McINTOSH & McINTOSH, P.C. ON 3/11/02. ECOLOGY & ENVIRONMENT FIELD OBSERVATIONS ALSO INCLUDED.

9) FIELD OBSERVATIONS NOTED HEREON, REGARDING THE FUNCTIONING OF WELLS (e.g., UNUSABLE), WERE MADE ON OCTOBER 9, 2001.

SCALE IN FEET
0 40 80 120

FORMER FRONTIER CHEMICAL
WASTE PROCESS, INC. SITE

NIAGARA FALLS NEW YORK

BASE MAP

SCALE	DATE ISSUED	C.A.D. FILE NO.	DRAWING NO.	REV.
1"=40'-0"	3/11/02	BASEMAP_FINAL	Figure – 2–1	

F:\FRONTIER\BASEMAP_FINAL.dwg
BUFF PLOTTED 11/4/02 KMK

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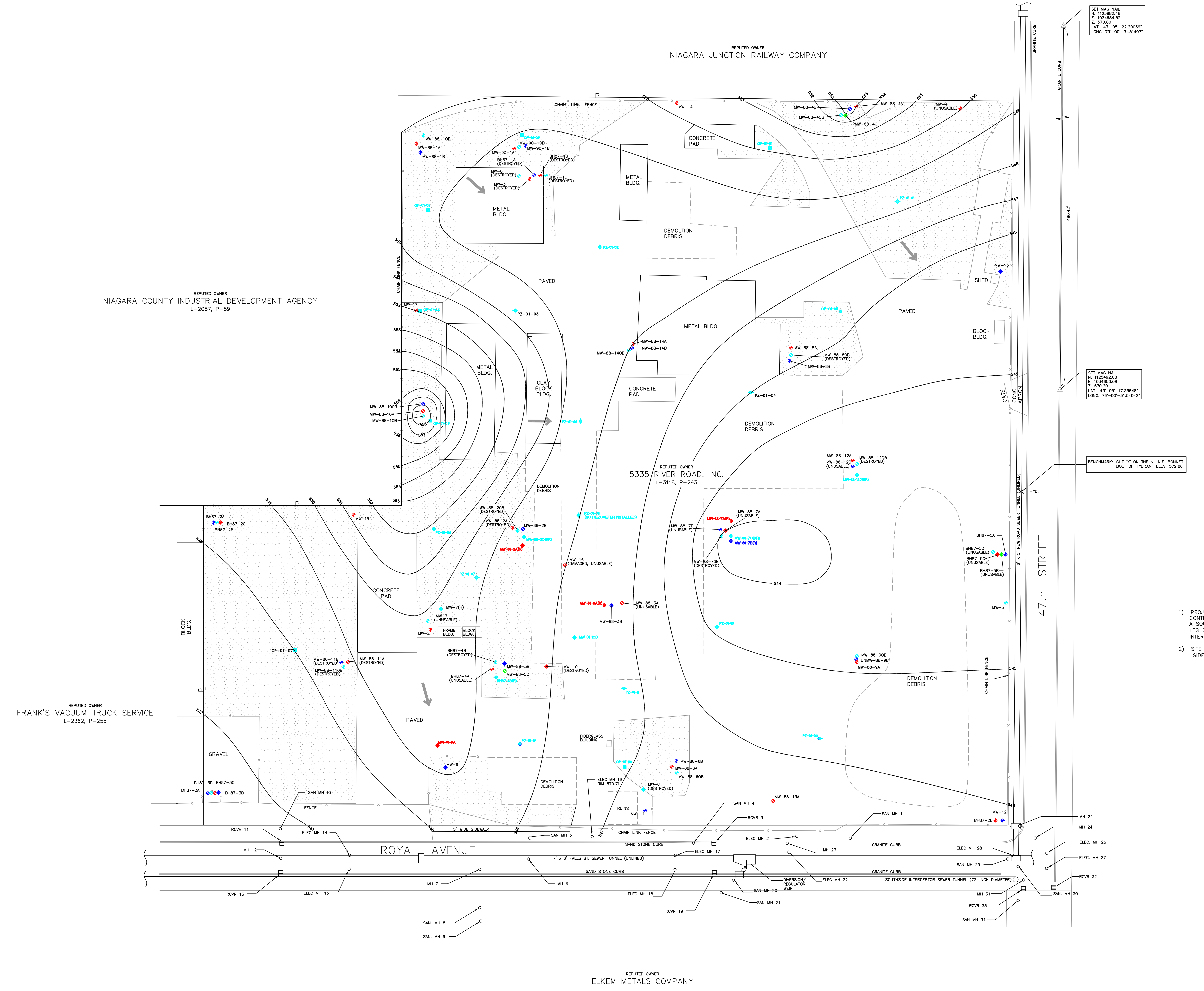

LEGEND

▨	UNPAVED AREAS
P/L	PROPERTY LINE
MW-88-90B	OVERBURDEN MONITORING WELL
MW-88-9A	A-FRACTURE ZONE BEDROCK WELL
UNMW-88-9B	B-FRACTURE ZONE BEDROCK WELL
BH87-5B	C-FRACTURE ZONE BEDROCK WELL
MW-88-3A(R)	SRI WELLS
PZ-01-01	SRI PIEZOMETER LOCATION
GP-01-01 ■	SRI GEOPROBE SOIL BORING LOCATION
▤	RECEIVER
○	MANHOLE
— — —	OUTLINE OF DEMOLISHED BLDGS./ STRUCTURES OR DEBRIS PILE
———	OUTLINE OF BLDG. OR CONCRETE PAD
— x —	FENCE
←	APPROXIMATE DIRECTION OF GROUNDWATER FLOW
——— 565	GROUNDWATER ELEVATION CONTOUR LINE

BENCHMARK

1) PROJECT ELEVATIONS BASED UPON EXISTING BENCHMARK TBM 3 AS OBSERVED IN CONTROL PLACED FOR THE CITY OF NIAGARA FALLS GIS CONTROL PROJECT AS FOLLOWS: A SQUARE CUT ON THE NORTHWEST CORNER OF THE CONCRETE FOOTING AT THE NORTHWEST LEG OF TRANSMISSION TOWER #LN 32 TWR 97. LOCATED AT THE SOUTHWEST CORNER OF THE INTERSECTION OF PACKARD ROAD AND NIAGARA FALLS BOULEVARD. ELEV. 581.24 (NGVD 1929)

2) SITE TBM CUT 'X' ON THE N.-N.E. BONNET BOLT OF HYDRANT LOCATED ON WEST SIDE OF 47th STREET (ELEV. 572.86).

NOTES

1) HORIZONTAL DATUM IS BASED ON THE NEW YORK STATE PLANE COORDINATE SYSTEM WEST ZONE NAD83/92HARN (FEET).

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7) SELECT UTILITY LINES AND SEWER TUNNELS LOCATIONS AND SIZES ARE APPROXIMATE BASED ON DRAWINGS PROVIDED BY CITY OF NIAGARA FALLS DEPT. OF WASTEWATER FACILITIES.

8) BASE MAP PROVIDED BY McINTOSH & McINTOSH, P.C. ON 3/11/02. ECOLOGY & ENVIRONMENT FIELD OBSERVATIONS ALSO INCLUDED.

9) FIELD OBSERVATIONS NOTED HEREON, REGARDING THE FUNCTIONING OF WELLS (e.g., UNUSABLE), WERE MADE ON OCTOBER 9, 2001.

10) GROUNDWATER ELEVATION CONTOURS WERE DEVELOPED BY INTERPOLATING BETWEEN WATER LEVEL ELEVATIONS IN WIDELY SPACED WELLS/PIEZOMETERS.

SCALE IN FEET
0 40 80 120

FORMER FRONTIER CHEMICAL
WASTE PROCESS, INC. SITE

NIAGARA FALLS **NEW YORK**

JANUARY 2002 B-FRACTURE ZONE BEDROCK
GROUNDWATER CONTOUR MAP

SCALE	DATE ISSUED	C.A.D. FILE NO.	DRAWING NO.	REV.
1"=40'-0"	3/11/02	B ZONE BEDROCK	Figure – 3-6	

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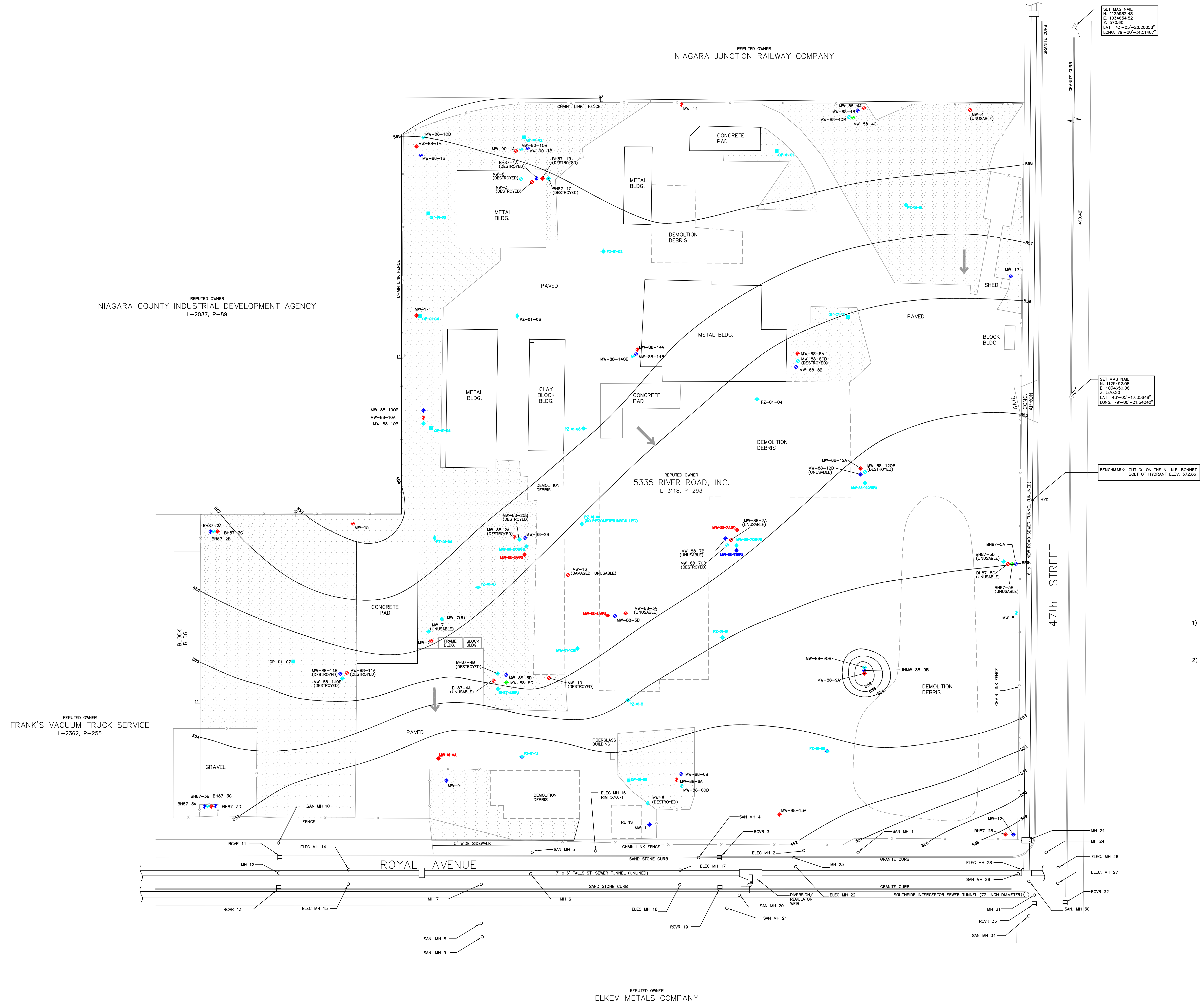
F:\FRONTIER CHEM\BEDROCK A ZONE.dwg
BUFF PLOTTED 11/4/02 KMK



LEGEND

▨	UNPAVED AREAS
P/L	PROPERTY LINE
MW-88-90B	OVERBURDEN MONITORING WELL
MW-88-9A	A-FRACTURE ZONE BEDROCK WELL
UNMW-88-9B	B-FRACTURE ZONE BEDROCK WELL
BH87-5B	C-FRACTURE ZONE BEDROCK WELL
MW-88-3A(R)	SRI WELLS
PZ-01-01	SRI PIEZOMETER LOCATION
GP-01-01 ■	SRI GEOPROBE SOIL BORING LOCATION
⊟	RECEIVER
○	MANHOLE
— — —	OUTLINE OF DEMOLISHED BLDGS./ STRUCTURES OR DEBRIS PILE
——	OUTLINE OF BLDG. OR CONCRETE PAD
— x —	FENCE
←	APPROXIMATE DIRECTION OF GROUNDWATER FLOW
—— 565	GROUNDWATER ELEVATION CONTOUR LINE

BENCHMARK

1) PROJECT ELEVATIONS BASED UPON EXISTING BENCHMARK TBM 3 AS OBSERVED IN CONTROL PLACED FOR THE CITY OF NIAGARA FALLS GIS CONTROL PROJECT AS FOLLOWS: A SQUARE CUT ON THE NORTHWEST CORNER OF THE CONCRETE FOOTING AT THE NORTHWEST LEG OF TRANSMISSION TOWER #LN 32 TWR 97. LOCATED AT THE SOUTHWEST CORNER OF THE INTERSECTION OF PACKARD ROAD AND NIAGARA FALLS BOULEVARD. ELEV. 581.24 (NGVD 1929)

2) SITE TBM CUT 'X' ON THE N.-N.E. BONNET BOLT OF HYDRANT LOCATED ON WEST SIDE OF 47th STREET (ELEV. 572.86).

NOTES

1) HORIZONTAL DATUM IS BASED ON THE NEW YORK STATE PLANE COORDINATE SYSTEM WEST ZONE NAD83/92HARN (FEET).

2) REFERENCE MAP – CITY OF NIAGARA FALLS TAX MAP NO. 160.09.

3) PROPERTY LINES SHOWN ARE APPROXIMATE IN LOCATION AND ARE BASED UPON THE ABOVE REFERENCED TAX MAP. PROPERTY OWNER INFORMATION IS BASED ON THE TAX MAP AND CITY OF NIAGARA FALLS WASTEWATER FACILITIES DRAWINGS.

4) NOT ALL PLANIMETRIC/TOPOGRAPHIC FEATURES WERE IDENTIFIED AS PART OF THIS PROJECT SCOPE.

5) SRI WELLS/PIEZOMETERS/GEOPROBE/TEST PIT LOCATIONS ARE SHOWN WITH BOLD TEXT.

6) SRI = SUPPLEMENTAL REMEDIAL INVESTIGATION.

7) SELECT UTILITY LINES AND SEWER TUNNELS LOCATIONS AND SIZES ARE APPROXIMATE BASED ON DRAWINGS PROVIDED BY CITY OF NIAGARA FALLS DEPT. OF WASTEWATER FACILITIES.

8) BASE MAP PROVIDED BY McINTOSH & McINTOSH, P.C. ON 3/11/02. ECOLOGY & ENVIRONMENT FIELD OBSERVATIONS ALSO INCLUDED.

9) FIELD OBSERVATIONS NOTED HEREON, REGARDING THE FUNCTIONING OF WELLS (e.g., UNUSABLE), WERE MADE ON OCTOBER 9, 2001.

10) GROUNDWATER ELEVATION CONTOURS WERE DEVELOPED BY INTERPOLATING BETWEEN WATER LEVEL ELEVATIONS IN WIDELY SPACED WELLS/PIEZOMETERS.

SCALE IN FEET
0 40 80 120

FORMER FRONTIER CHEMICAL
WASTE PROCESS, INC. SITE

NIAGARA FALLS NEW YORK

JANUARY 2002
A-FRACTURE BEDROCK
GROUNDWATER CONTOUR MAP

SCALE	DATE ISSUED	C.A.D. FILE NO.	DRAWING NO.	REV.
1"=40'-0"	3/11/02	BEDROCK A ZONE	Figure – 3-5	

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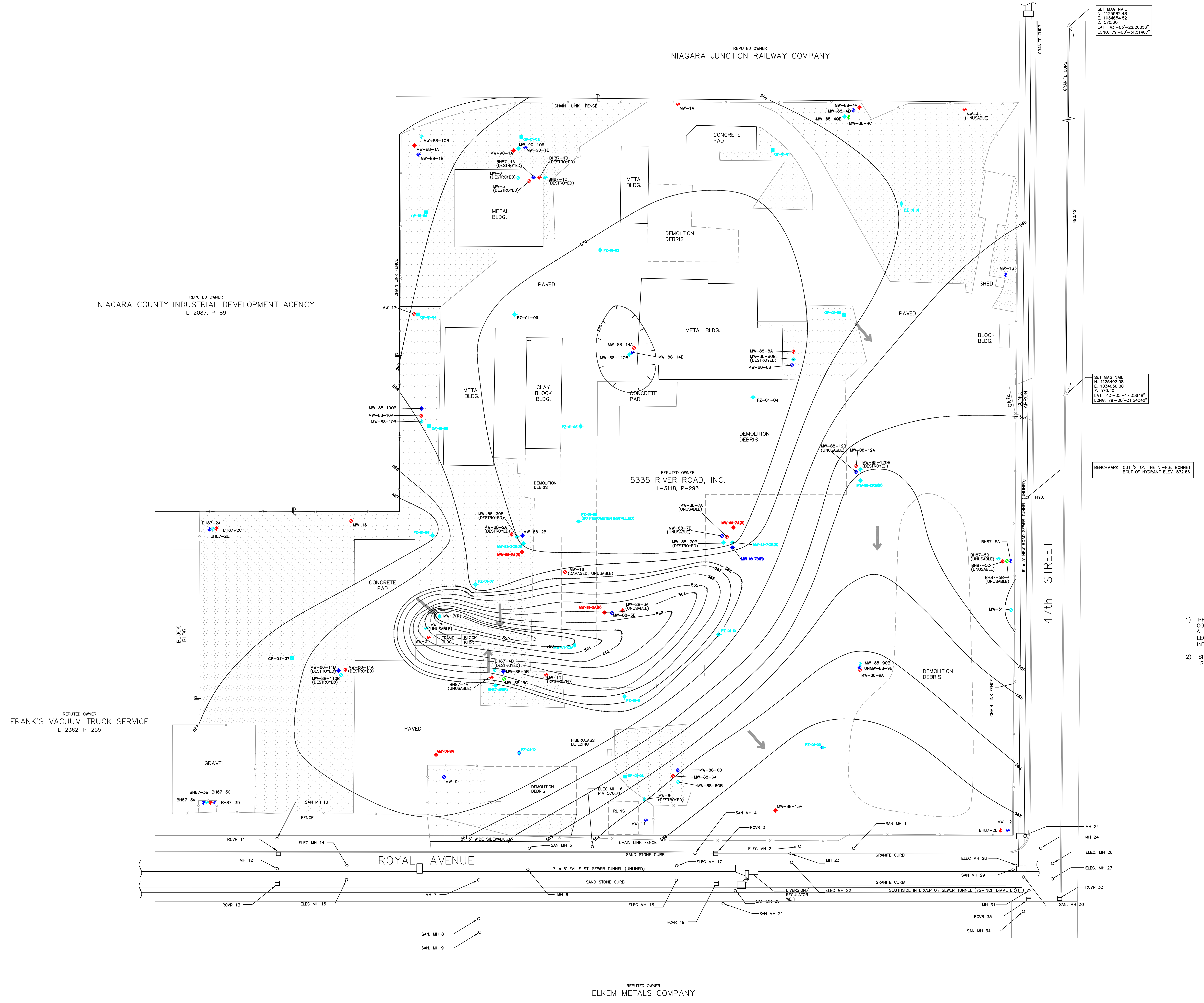

LEGEND

▨	UNPAVED AREAS
—℄—	PROPERTY LINE
MW-88-90B ⊕	OVERBURDEN MONITORING WELL
MW-88-9A ⊕	A-FRACTURE ZONE BEDROCK WELL
UNMW-88-9B ⊕	B-FRACTURE ZONE BEDROCK WELL
BH87-5B ⊕	C-FRACTURE ZONE BEDROCK WELL
MW-88-3A(R) ◆	SRI WELLS
PZ-01-01 ⊕	SRI PIEZOMETER LOCATION
GP-01-01 ■	SRI GEOPROBE SOIL BORING LOCATION
▤	RECEIVER
○	MANHOLE
— — —	OUTLINE OF DEMOLISHED BLDGS./ STRUCTURES OR DEBRIS PILE
———	OUTLINE OF BLDG. OR CONCRETE PAD
— x —	FENCE
←	APPROXIMATE DIRECTION OF GROUNDWATER FLOW
——— 565	GROUNDWATER ELEVATION CONTOUR LINE

BENCHMARK

1) PROJECT ELEVATIONS BASED UPON EXISTING BENCHMARK TBM 3 AS OBSERVED IN CONTROL PLACED FOR THE CITY OF NIAGARA FALLS GIS CONTROL PROJECT AS FOLLOWS: A SQUARE CUT ON THE NORTHWEST CORNER OF THE CONCRETE FOOTING AT THE NORTHWEST LEG OF TRANSMISSION TOWER #LN 32 TWR 97. LOCATED AT THE SOUTHWEST CORNER OF THE INTERSECTION OF PACKARD ROAD AND NIAGARA FALLS BOULEVARD. ELEV. 581.24 (NGVD 1929)

2) SITE TBM CUT 'X' ON THE N.-N.E. BONNET BOLT OF HYDRANT LOCATED ON WEST SIDE OF 47th STREET (ELEV. 572.86).

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SCALE IN FEET
0 40 80 120

FORMER FRONTIER CHEMICAL
WASTE PROCESS, INC. SITE

NIAGARA FALLS **NEW YORK**

JANUARY 2002 OVERBURDEN
GROUNDWATER CONTOUR MAP

SCALE	DATE ISSUED	C.A.D. FILE NO.	DRAWING NO.	REV.
1"=40'-0"	3/11/02	OVERBURDEN.dwg	Figure – 3 – 4	

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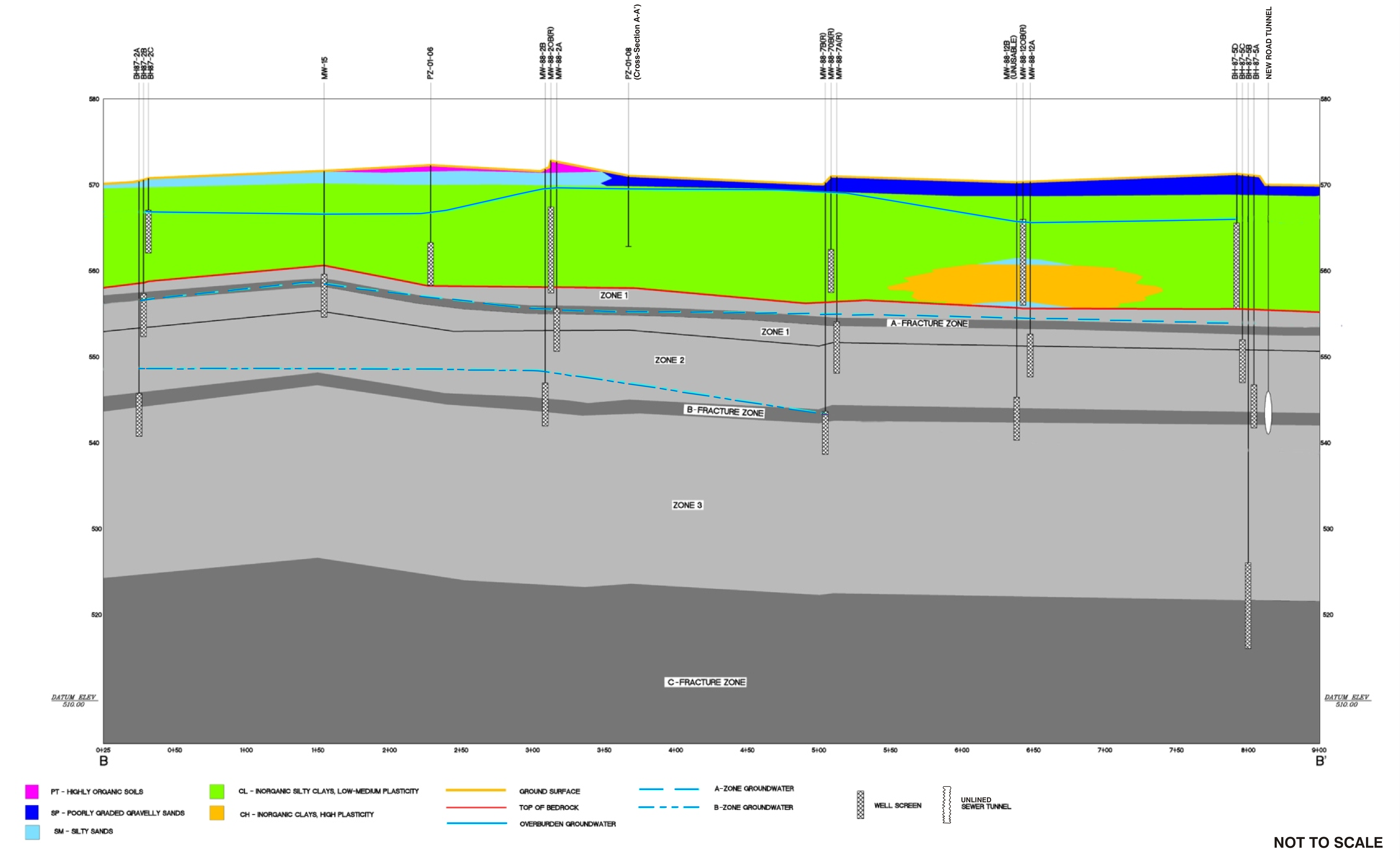
Buf Plotted 11/4/02 KMK

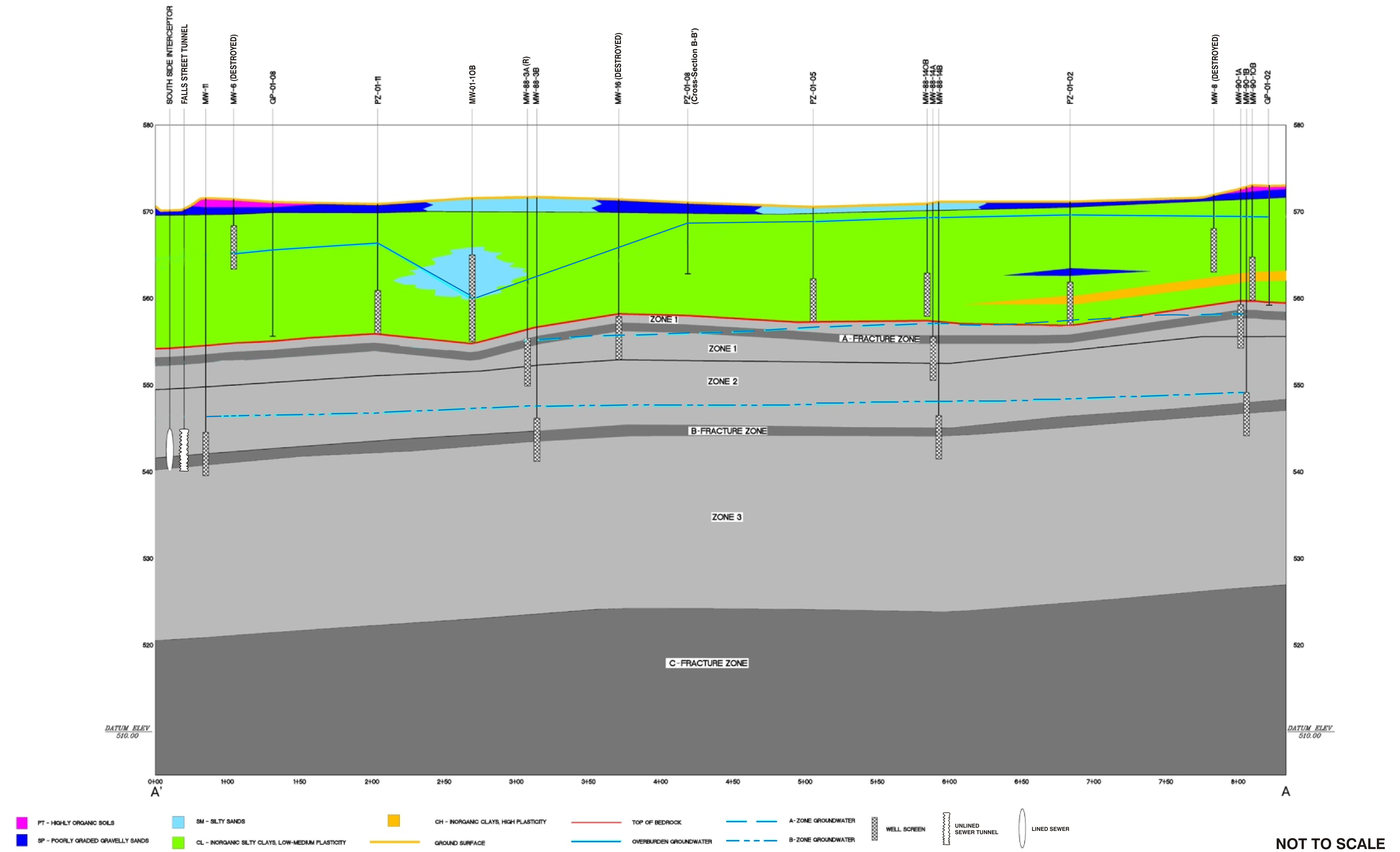
ecology and environment engineering, p.c.



NOTES:

1. This cross-section was developed by interpolating data between widely spaced borings and wells and is presented for conceptual purposes. Refer to Figure 2-1 for notes and locations of cross-section, site features and explorations.
2. Groundwater measurements are based on field measurements collected on January 10, 2002.

Figure 3-3 GEOLOGICAL CROSS SECTION B-B’



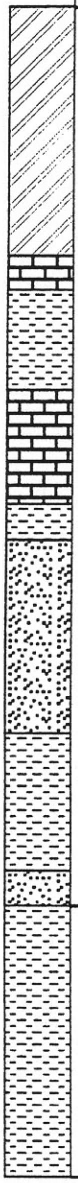
NOT TO SCALE

NOTES:

1. This cross-section was developed by interpolating data between widely spaced borings and wells and is presented for conceptual purposes. Refer to Figure 2-1 for notes and locations of cross-sections, site features, and explorations.
2. Groundwater measurements are based on field measurements collected on January 10, 2002.

Figure 3-2 GEOLOGICAL CROSS SECTION A-A'

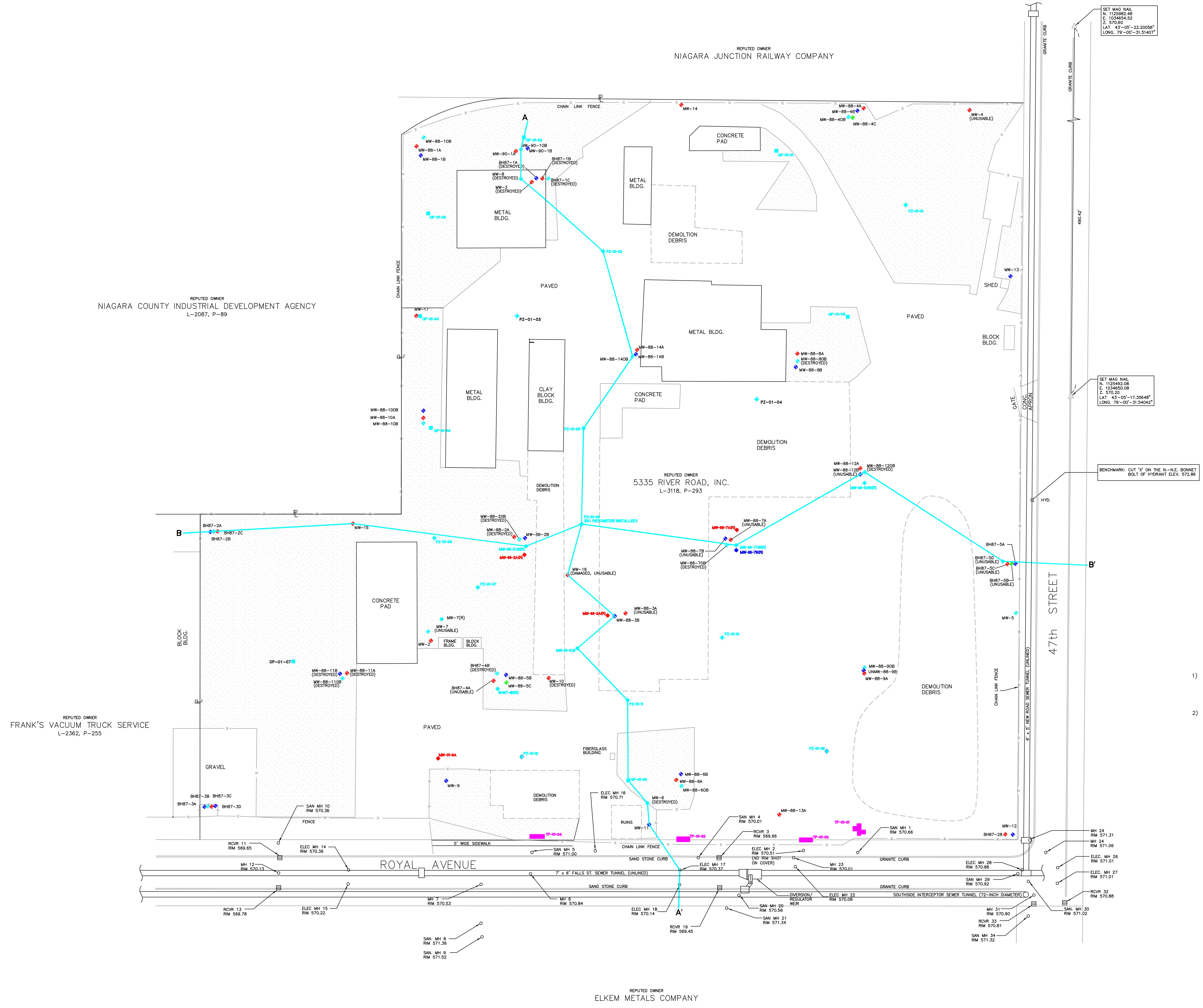
02: NM9902\OI203721.CDR



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

SOURCE: Miller and Kappel 1987, modified from Fisher, 1959.

Figure 3-1 STRATIGRAPHY OF THE NIAGARA FALLS AREA



N

LEGEND

▨	UNPAVED AREAS
—PL—	PROPERTY LINE
MW-88-90B	OVERBURDEN MONITORING WELL
MW-88-9A	A-FRACTURE ZONE BEDROCK WELL
UNMW-88-9B	B-FRACTURE ZONE BEDROCK WELL
BH87-5B	C-FRACTURE ZONE BEDROCK WELL
MW-88-3A(R)	SRI WELLS
PZ-01-01	SRI PIEZOMETER LOCATION
GP-01-01 ■	SRI GEOPROBE SOIL BORING LOCATION
TP-01-02 ▬	SRI TEST PIT LOCATION
A — A'	CROSS SECTION LINE
▤	RECEIVER
○	MANHOLE
— — —	OUTLINE OF DEMOLISHED BLDGS./ STRUCTURES OR DEBRIS PILE
——	OUTLINE OF BLDG. OR CONCRETE PAD
— x —	FENCE

BENCHMARK

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9) FIELD OBSERVATIONS NOTED HEREON, REGARDING THE FUNCTIONING OF WELLS (e.g., UNUSABLE), WERE MADE ON OCTOBER 9, 2001.

SCALE IN FEET

0 40 80 120

FORMER FRONTIER CHEMICAL
WASTE PROCESS, INC. SITE

NIAGARA FALLS NEW YORK

BASE MAP

SCALE	DATE ISSUED	C.A.D. FILE NO.	DRAWING NO.	REV.
1"=40'-0"	3/11/02	BASEMAP_FINAL	Figure 2-1	

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BUFF PLOTTED 11/4/02 KMK

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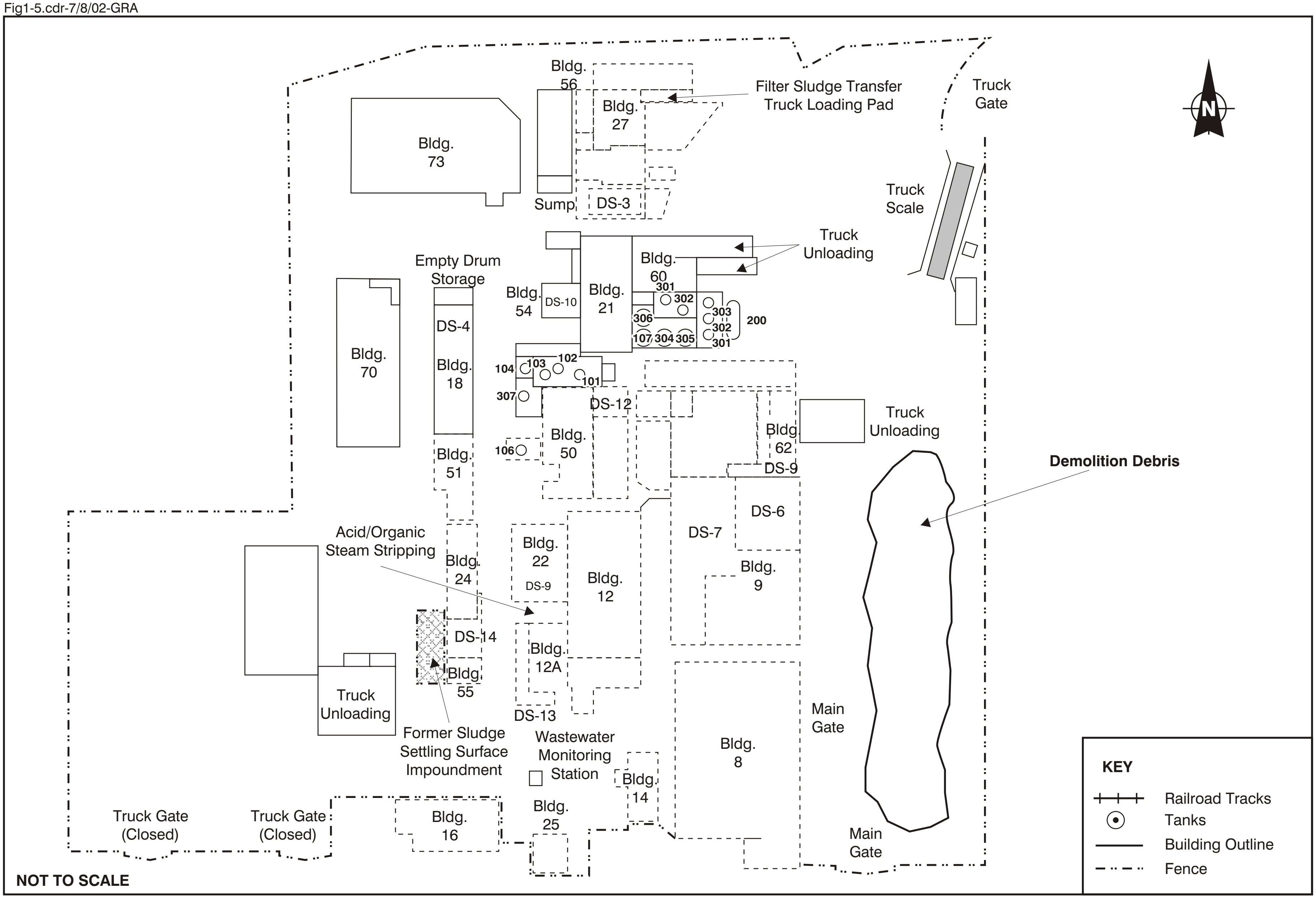
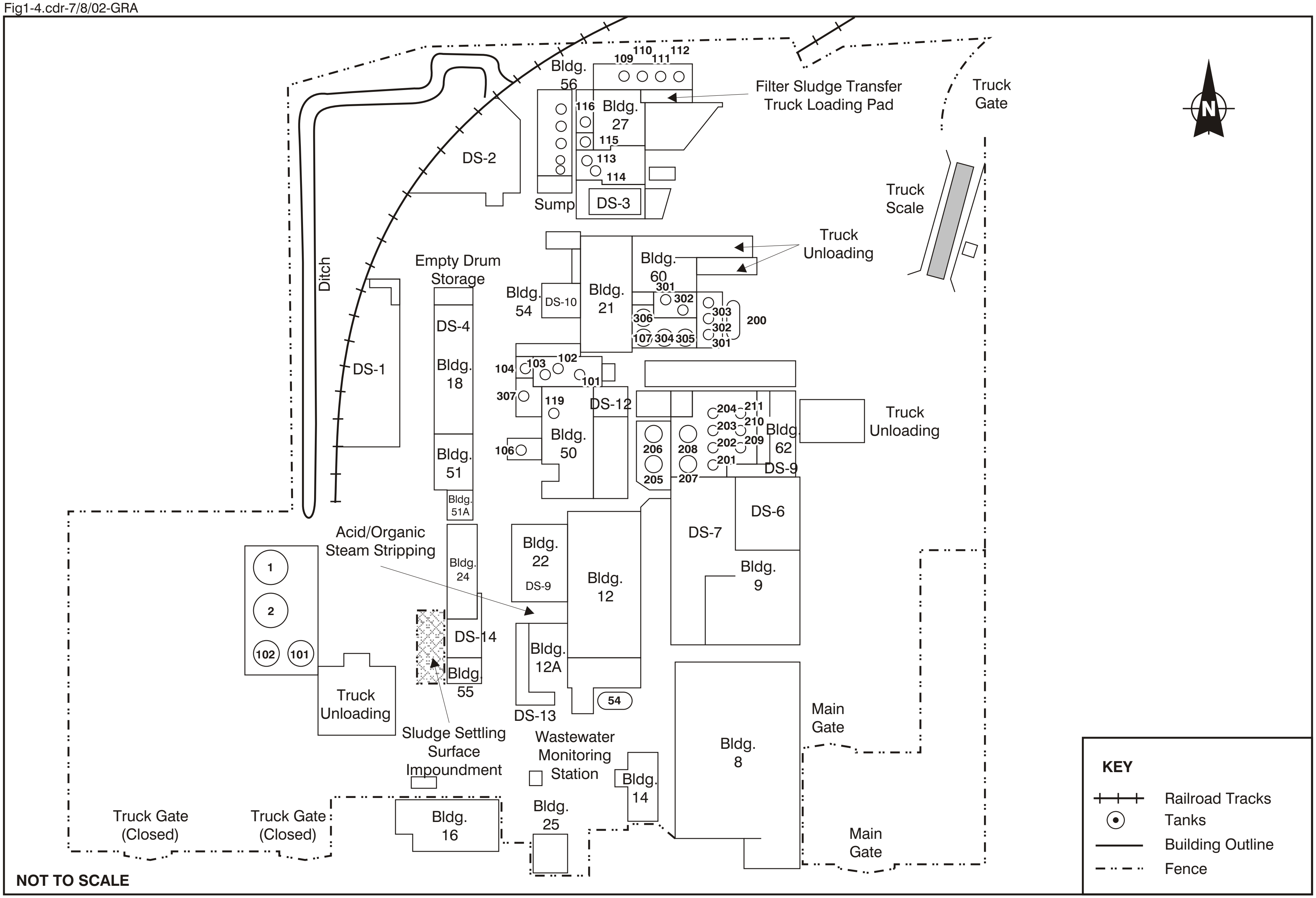
Fig1-5.cdr-7/8/02-GRA



SOURCE: Frontier Waste Process, Inc. historical drawings and E & E field observations in 2001.

Figure 1-5 FORMER FRONTIER CHEMICAL WASTE PROCESS, INC. SITE MAP, 2001

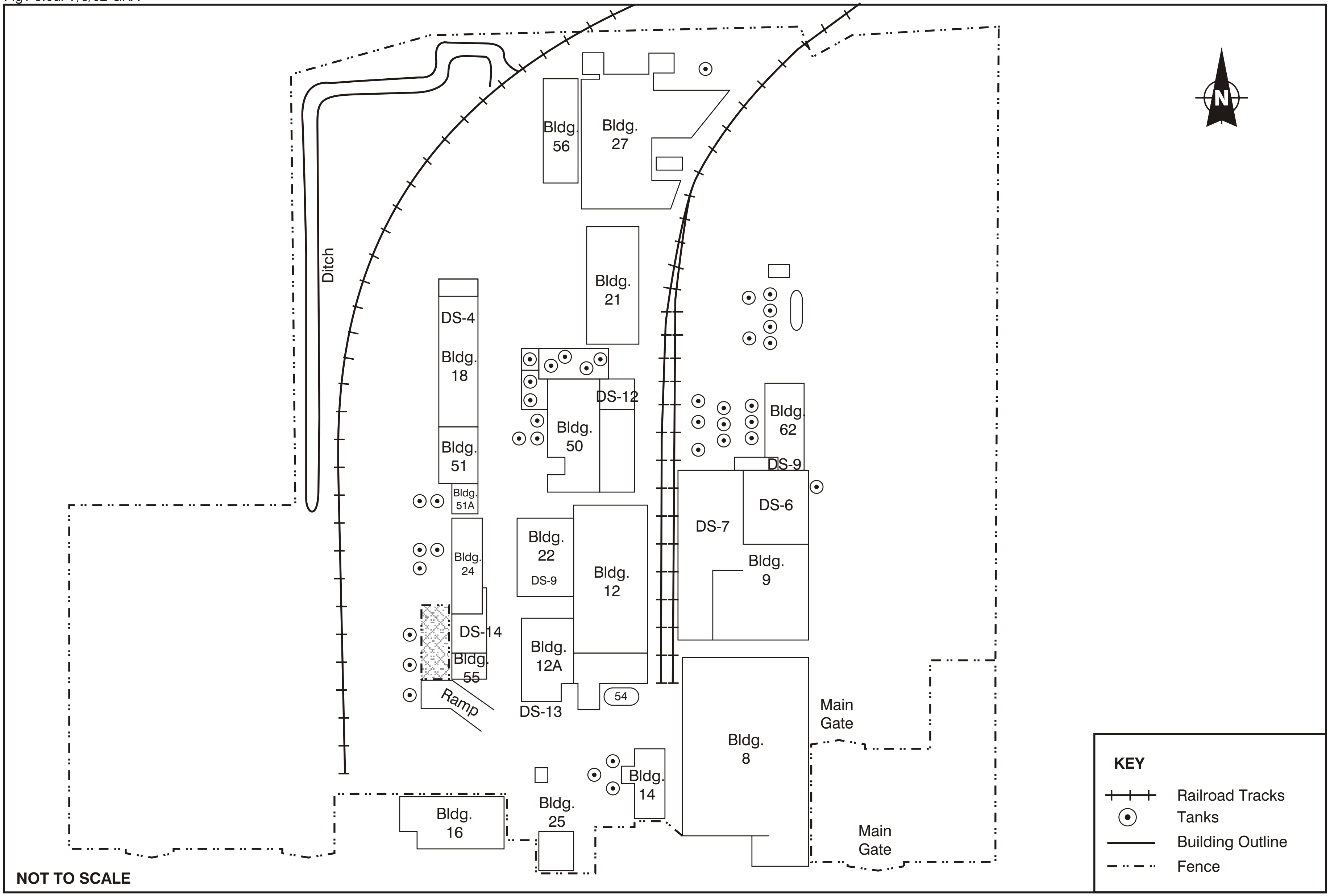
02:000699_NV05_02_02-B0899
Fig1-4.cdr-7/8/02-GRA



SOURCE: Frontier Waste Process, Inc. historical drawings.

Figure 1-4 FORMER FRONTIER CHEMICAL WASTE PROCESS, INC. SITE MAP, 1984

02:000699_NV05_02_02-B0899
Fig1-3.cdr-7/8/02-GRA



SOURCE: Frontier Waste Process, Inc. historical drawings.

Figure 1-3 FORMER FRONTIER CHEMICAL WASTE PROCESS, INC. SITE MAP, 1979

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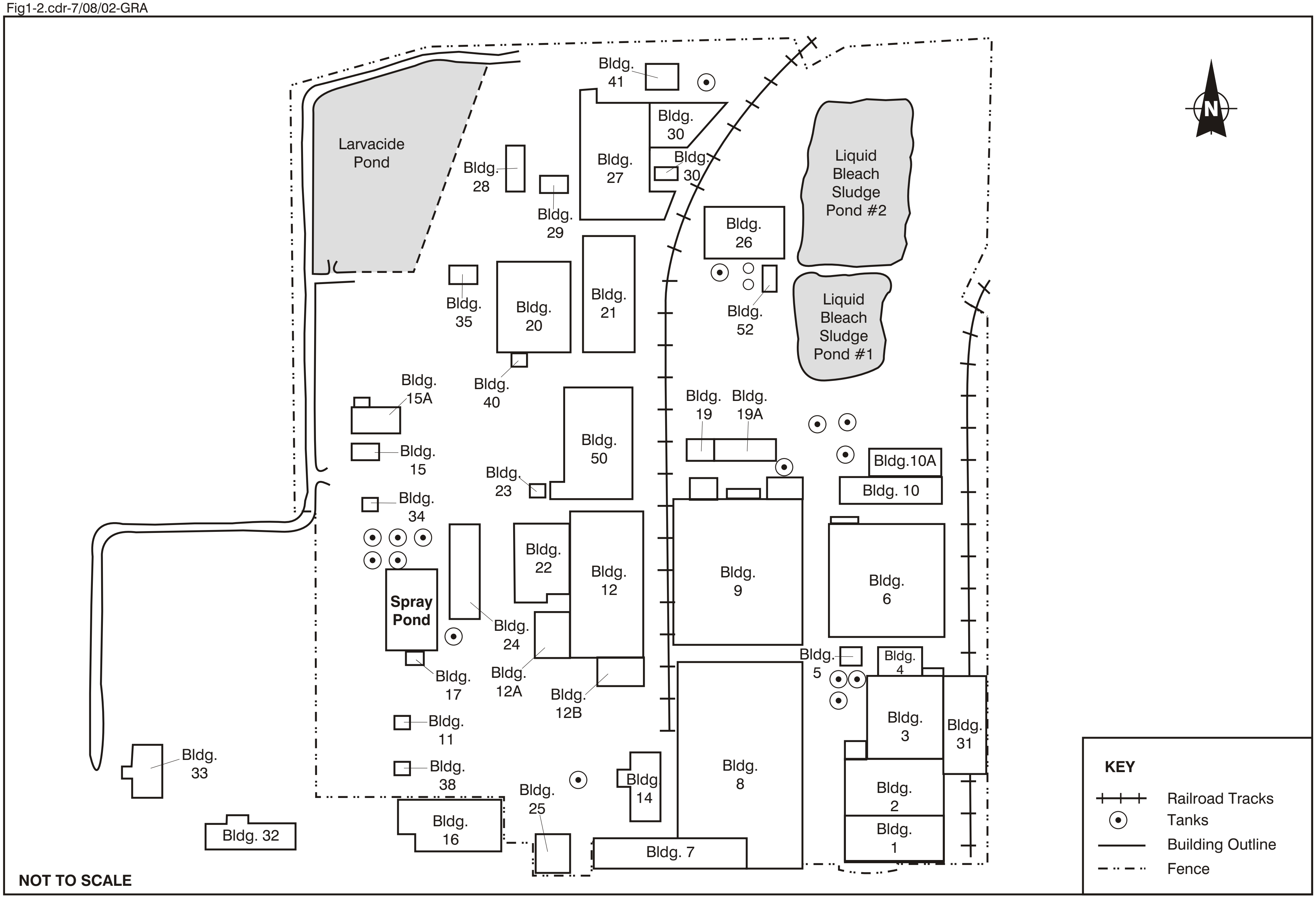
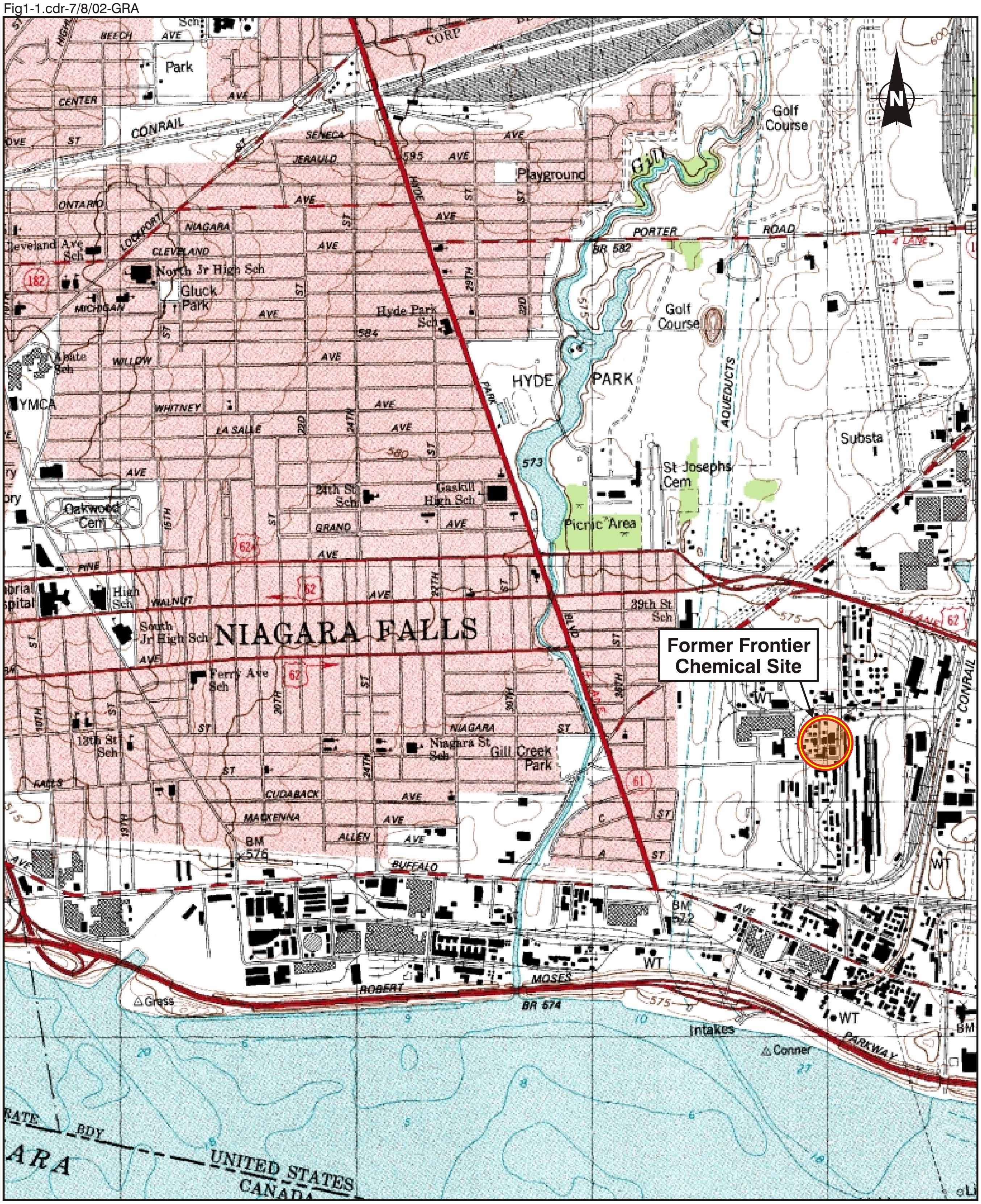
Fig1-2.cdr-7/08/02-GRA



SOURCE: Frontier Waste Process, Inc. historical drawings.

Figure 1-2 FORMER FRONTIER CHEMICAL WASTE PROCESS, INC. SITE MAP, 1956

02:000699_NV05_02_02-B0899
Fig1-1.cdr-7/8/02-GRA

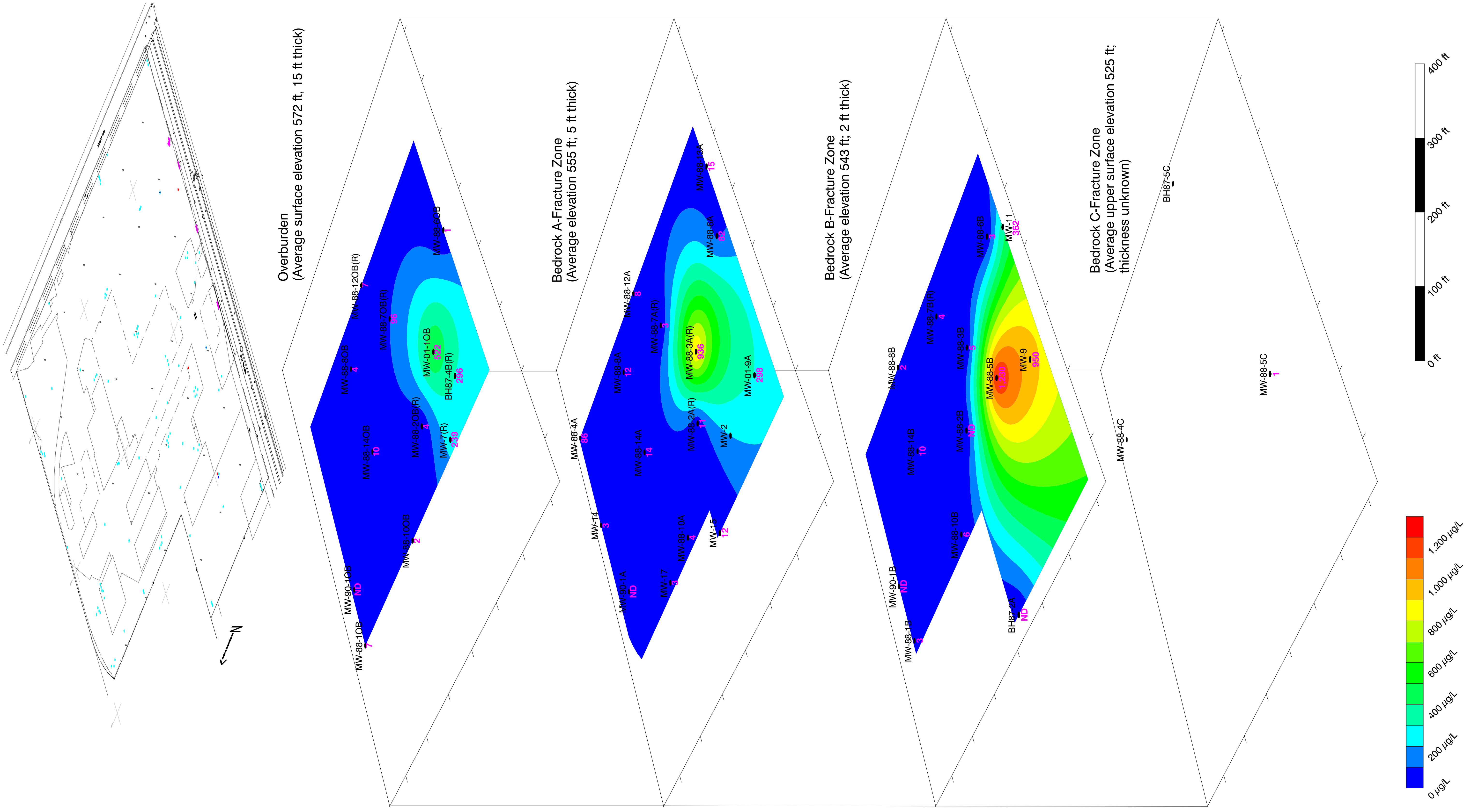

Former Frontier Chemical Site

SOURCE: Niagara Falls Quadrangle, 7.5 Minute Series Topographic Map 1980.

SCALE

0 0.5 1 Mile

Figure 1-1 SITE LOCATION MAP
FORMER FRONTIER CHEMICAL WASTE PROCESS, INC.



Notes:

1. Samples collected November 2001.
2. Contours not provided for Bedrock Layer "C" due to limited number of data points.
3. The plots are a conceptual representation of contaminant concentration contours, based on a mathematical interpolation of sample data from widely spaced wells/piezometers, and presented for illustrative purposes.
4. Groundwater samples were collected using bailers; and a number of them had very high turbidity measurements (greater than 50 NTu), indicating the presence of suspended solids. Turbidity in groundwater samples can cause interference with the analysis. Therefore, the actual concentrations of dissolved inorganics may be much lower than those measured.

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Figure 5-15 Three-Dimensional View of Cyanide Concentrations in Groundwater
Former Frontier Chemical Waste Process, Inc. Site