IMPROVING EARTH

Report of Findings
Brownfield Cleanup Program Remedial Investigation
IBM Gun Club - Former Burn Pit Area
Union, New York

SANBORN, HEAD & ASSOCIATES, INC.

IBM

8976 Wellington Road
Manassas, VA 20109

August 5, 2009

Mr. Jonathan Greco
NYSDEC
625 Broadway
Albany, NY 12233-7016

Re: Report of Findings – Brownfield Cleanup Program Remedial Investigation
IBM Gun Club – Former Burn Pit Area
Union, New York

Dear Mr. Greco,

Enclosed is the report prepared by Sanborn, Head and Associates, Inc. discussing data, observations, and inferences from investigative work conducted over a period of almost three years from April 2006 through December 2008 at the IBM Gun Club – Former Burn Pit Area. The draft report was submitted for the Agencies review on April 10, 2009, and the attached final version addresses comments and suggestions provided to IBM by the New York State Department of Environmental Conservation (NYSDEC) and New York State Department of Health (NYSDOH) in an email dated August 7, 2009.

The work was performed under the Brownfield Cleanup Program (BCP), administered by the NYSDEC. The work was conducted under the BCP Agreement #C704044 between IBM and NYSDEC, dated August 22, 2005, and in accordance with our approved RI Workplan[1] dated March 6, 2006 and subsequent Workplan addenda.

If you have any questions regarding the enclosed Report of Findings, please contact me at 703-257-2582.

Very truly yours,

K Whalen

Kevin Whalen
IBM Program Manager

Enclosures:
Report of Findings

cc: Justin Deming (NYSDOH), Desiree Gillerman (IBM Corp.), and Kevin O’Hara (Binghamton Country Club).

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[1] Sanborn, Head & Associates, Inc., March 6, 2006, Remedial Investigation Work Plan, IBM Gun Club, Former Burn Pit Area.

SHA
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SANBORN, HEAD & ASSOCIATES, INC.
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www.sanbornhead.com

August 5, 2009
File No. 2400.00

Mr. Kevin Whalen
IBM Corporate Environmental Affairs
8976 Wellington Road
Manassas, VA 20109

Re: Report of Findings
Brownfield Cleanup Program Remedial Investigation
IBM Gun Club – Former Burn Pit Area
Union, New York

Dear Mr. Whalen:

We have completed our Remedial Investigation of the IBM Gun Club – Former Burn Pit Area, and are transmitting the Report of Findings for your records. At your request we have also provided copies of the Report to the individuals listed below.

The work was conducted in accordance with our approved RI Workplan[1] dated March 6, 2006, and subsequent Workplan addenda under the Brownfield Cleanup Program agreement #C704044 between IBM and New York State Department of Environmental Conservation (NYSDEC). A draft report was submitted for the Agencies review on April 10, 2009, and the attached final version addresses comments and suggestions provided by NYSDEC and New York State Department of Health (NYSDOH). The undersigned had primary responsibility for the day to day performance of the activities under this agreement.

We trust that this report satisfies your present needs. We will be contacting you to see if you have any questions. In the interim, if you wish to discuss this matter, please contact us. We greatly appreciate the opportunity to be of service to IBM on this important project.

Very truly yours,
SANBORN, HEAD & ASSOCIATES, INC.

Allan H Horneman

Allan H. Horneman, Dr.Eng.Sci.
Senior Project Manager

Daniel B. Carr, P.E, P.G.
Principal

AHH/DBC:ahh

cc: Jonathan Greco (NYSDEC), Justin Deming (NYSDOH), Desiree Gillerman (IBM Corp.), and Kevin O'Hara (Binghamton Country Club).

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[1] Sanborn, Head & Associates, Inc., March 6, 2006, Remedial Investigation Work Plan, IBM Gun Club, Former Burn Pit Area.

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Report of Findings
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IBM Gun Club – Former Burn Pit Area
Union, New York

Prepared for
IBM Corporate Environmental Affairs

Prepared by
Sanborn, Head & Associates, Inc.

File 2400.00
August 2009

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EXECUTIVE SUMMARY

This report presents the findings of Remedial Investigations (RI) associated with the former Burn Pit Area of the IBM Gun Club Property (BPA). The work was conducted by Sanborn, Head & Associates, Inc. (SHA) under contract with the International Business Machines Corporation (IBM) under the New York State Brownfield Cleanup Program (BCP) administered by the New York State Department of Environmental Conservation (NYSDEC). The project was led by IBM Corporate Environmental Affairs under BCP Agreement No. C704044 executed by IBM and NYSDEC on August 22, 2005.

The IBM Gun Club property is a 53.4-acre parcel of land located on top of a hill west of Robinson Hill Road in the Town of Union in Broome County, New York. The focus of this work was to investigate environmental conditions that could be remaining from a historical disposal practice where solvents and oils were burned in an excavated pit. The primary incentive for this RI was the apparent on-going presence of certain volatile organic compounds (VOCs) in groundwater samples withdrawn from several bedrock monitoring wells. The wells were located in the vicinity of the BPA where IBM had voluntarily conducted removal of VOC-containing soils in the early 1980s.

This report communicates the data, inference, and conclusions derived from the RI. It also presents an assessment of the need and possible goals for remediation, and the identification and screening of potentially applicable remedial technologies. An analysis of remedial alternatives, referred to in the Brownfields Rules as an "Alternatives Analysis", is being conducted and will be submitted under separate cover.

The RI work included intensive investigation of subsurface conditions using a combination of technologies focused on characterizing suspected sourcing of VOCs from solvent mass diffused into extremely low permeability sedimentary bedrock. The work was also focused on characterizing bedrock fracturing that represents the primary migration pathway for VOCs in groundwater. The investigation included the sampling and analysis of groundwater, surface water, soil, subsurface vapors and rock. The primary findings are reviewed on the attached Executive Summary Figure.

Using innovative rock core analysis (CORE™) technology, the RI has confirmed and defined that the primary source of on-going groundwater contamination is VOC mass residing in the matrix of rock beneath about a 1.6 acre area, extending from the BPA in a southerly direction. Nearly all of the VOC mass resides in the rock matrix within the upper 15 ft of subsurface. The unfractured rock matrix is essentially impermeable to water flow and VOCs are physically and chemically sorbed to the rock solids. A minute fraction of the total mass resides in groundwater flowing through fractures in the rock fed by diffusion from the rock matrix. The overall volumetric and VOC mass flux in groundwater through this primary source rock is small, on the order of a few gallons per minute and tenths of a pound per year, respectively.

Detailed characterization of bedrock fracturing successfully identified zones of higher permeability where the majority of the groundwater flow occurs. The data document that groundwater breaks out as seeps and springs along the hill slope south of the BPA.

The extent of VOC contamination in groundwater exceeding relevant water quality standards is limited to the top 40 feet or less of the subsurface beneath IBM property and found within 1,000 feet downgradient beneath an undeveloped wooded area and a small portion of a golf course on property adjacent to IBM's Gun Club property. The limited extent is consistent with what is estimated based on transport modeling and not expected to expand with time.

Given the data collected to date, human exposure to site-related contaminants is not occurring through private or public water supplies or soil vapor under present site use conditions. There is limited potential for human exposure to IBM site trespassers to metal and polychlorinated biphenyl (PCB) containing soils. Human exposure to low levels of VOCs found in three areas of seeps and/or springs is possible. Although access is not restricted to these areas, we have observed no evidence of systematic use of these limited areas that would result in regular human contact which, if at all, would be incidental and primarily dermal in nature.

Although there is no proven technology to completely restore the BPA and its relevant vicinity, the Alternatives Analysis to follow this RI report will evaluate potential combinations of remedial technologies to reduce the downgradient VOC mass flux from the source zone, and reduce VOC source mass, and limit potential for human contact with soil and groundwater seepage. Pilot testing will be required to demonstrate the effectiveness of some of the alternatives, and/or to support full scale design, and better assess potential level of effort and cost.

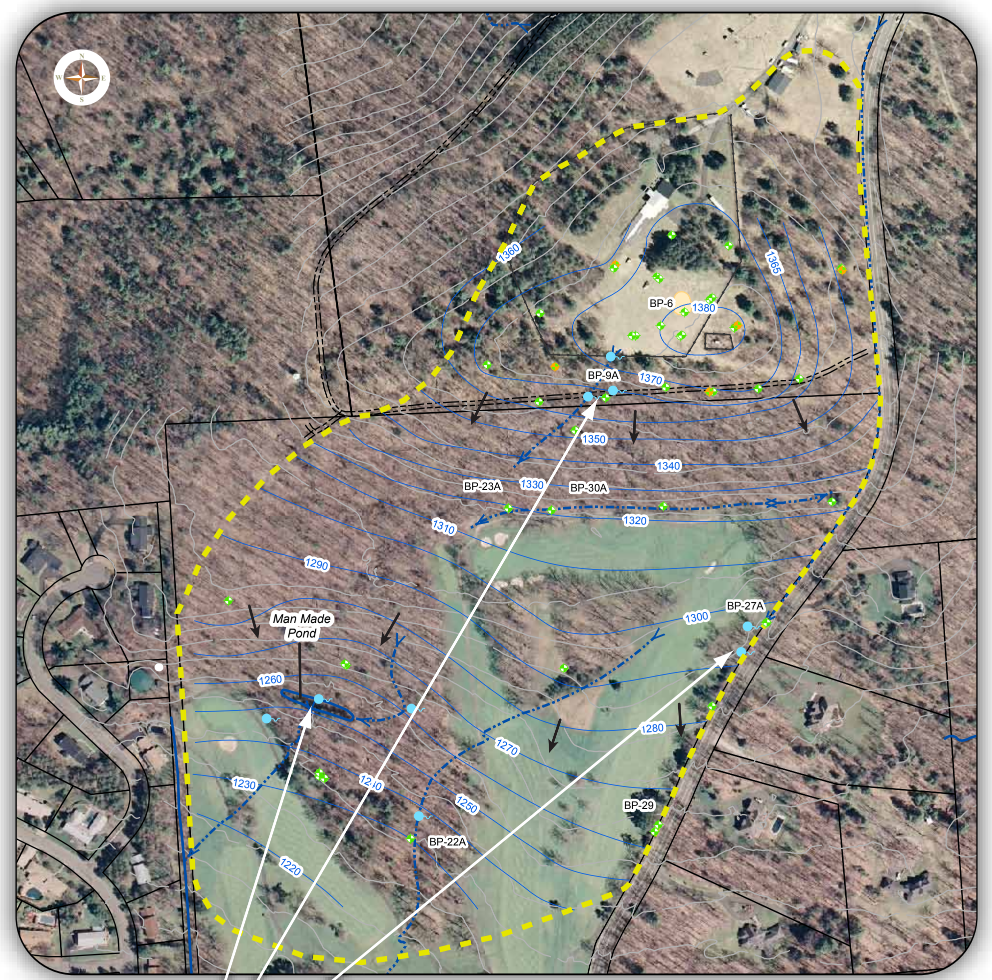
Executive Summary Figure

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By: S. Warner/J. Williams
Designed By: A. Horneman
Reviewed By: A. Horneman
Date: August 2009

C. GROUNDWATER FLOW INFLUENCED BY HORIZONTAL FRACTURING IN UPPERMOST HIGHLY FRACTURED ROCK



RAPID GROUNDWATER TRANSPORT IN FRACTURES

Majority of VOC mass transport is through horizontal bedding-parallel fractures in the upper 40 feet of rock driven by recharge of incident precipitation through the hilltop.

The flow of groundwater through the BPA and vicinity is expected to be on the order of a few gallons per minute.

Estimated groundwater travel times to points of groundwater discharge range from a few weeks to half a year.

Therefore, remediation that contains the primary source zone may lead to improved water quality conditions down gradient within a relatively short time.

GROUNDWATER DISCHARGE AS SEEPS AND SPRINGS

The majority of water recharged at or within the BPA flows radially away in horizontal fracturing. In a few places, this flow breaks out as seeps and springs along the hill slope.

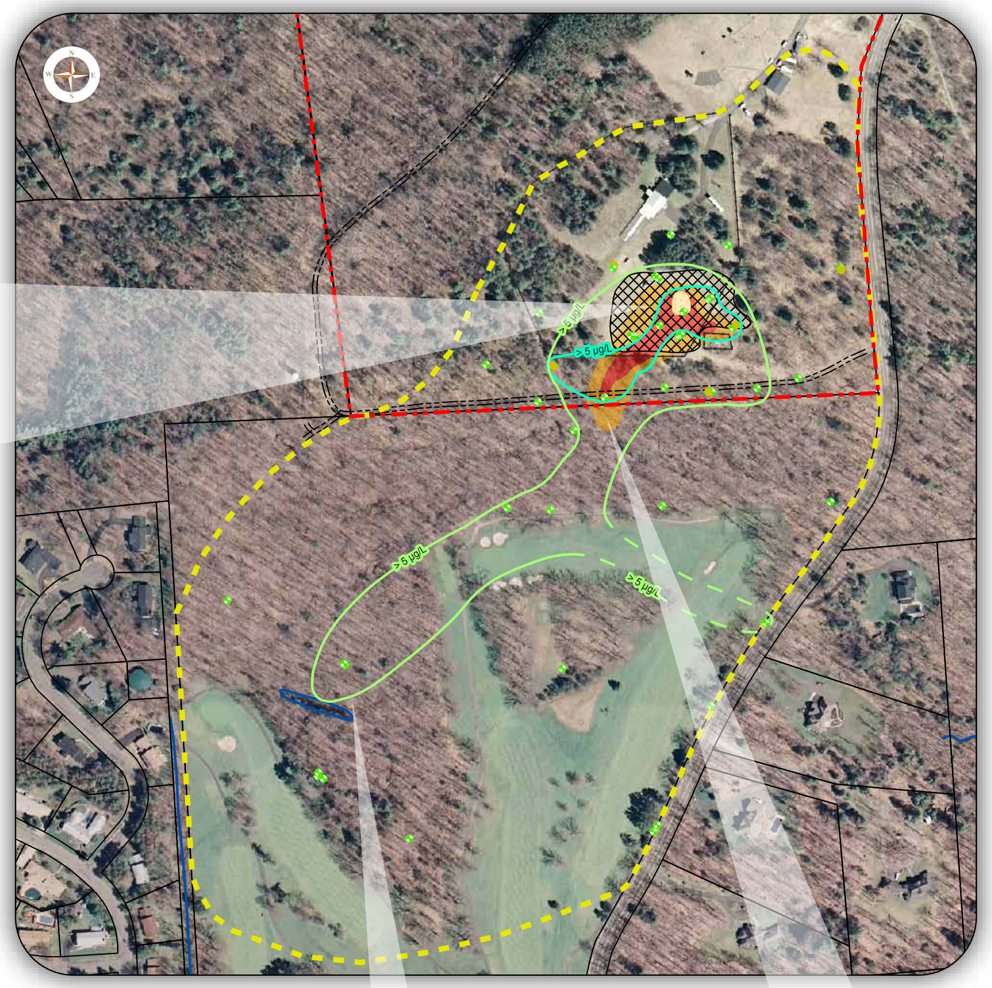
ROCK CORE ANALYSIS DATA INDICATES A MIXTURE OF PETROLEUM AND SOLVENTS

The data definitively show that the majority of VOC mass is beneath IBM property diffused into rock at about water table depth between 5 and 10 feet below ground. The most commonly detected VOCs include chlorinated ethenes, ketones, and constituents of petroleum.

The orange and red shaded areas represent key VOCs in the primary source rock that contain over 90% of the VOC mass, principally sorbed to the rock solids. Pore water concentrations in this rock are estimated to be on the order of 10,000s to 100,000s of µg/L.

The yellow and green shading reflects rock concentrations one to two orders of magnitude lower from diffusion of VOCs dissolved in migrating groundwater.

A. NATURE AND EXTENT OF CONTAMINATION UNDERSTOOD

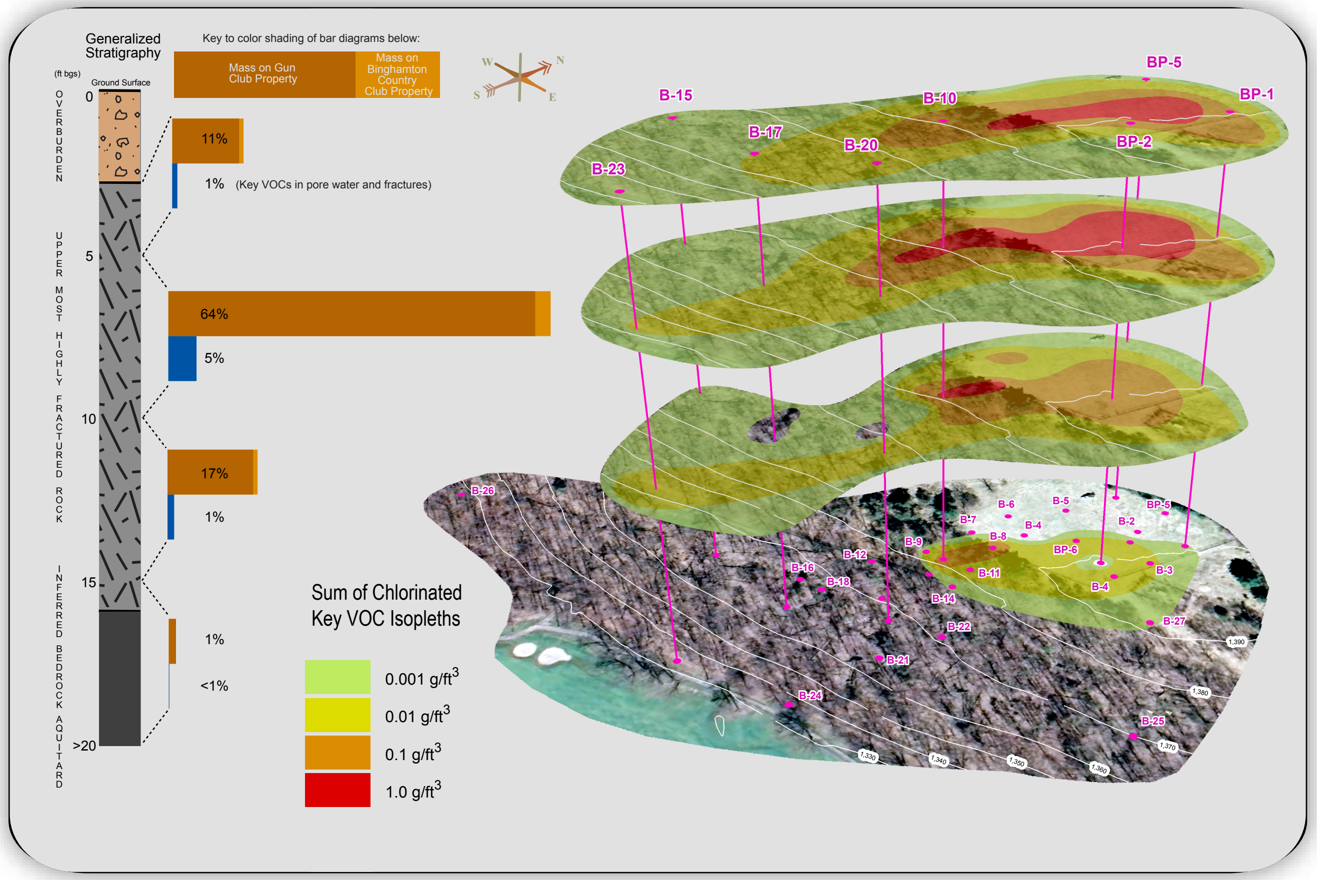


SUCCESSFUL REMOVAL OF RESIDUAL VOCs IN SOIL

1980's soil excavation was successful in removing soil containing residuals of oils and solvents from the BPA.

Trace metals and PCBs found in soil in the area of soil removal reflect residuals of former Burn Pit disposal, which are largely contained in the secure fenced area.

B. VOC SOURCING FROM ROCK MATRIX DEFINED BY ANALYSIS OF ROCK CORE SAMPLES



VOC SOURCING FROM SOLVENT MASS IN LOW PERMEABILITY SEDIMENTARY BEDROCK

Primary source of on-going presence of VOCs in groundwater is VOC mass residing in the matrix of rock beneath a one and one-half acre area extending southerly from the BPA along a trough-like depression in the bedrock surface as shown by orange shading.

This is believed to reflect the probable limit of the historical penetration of a mixture of separate phase oil and solvent into fractures. See Figure B for additional details.

OBSERVED EXTENT OF VOCs IN GROUNDWATER

Largely bounded in all directions and reflects limited transport at the water table in the uppermost highly fractured rock. Transport estimated at a few tenths of a pound per year is controlled by matrix diffusion, sorption, and biological degradation.

At depth, the extent of VOCs in groundwater exceeding water quality standards is only found beneath IBM property proximate to the BPA.

Given the limited mass transport and the attenuation mechanisms the extent is not expected to increase with time. No private or public water supplies are at risk.

Legend

⬭	Burn Pit
- - -	Approximate Extent of SHA Investigation
⌖	Monitoring Well
⌖	Multi Level System
Hydrogeologic Conditions	
↘	Inferred Groundwater Flow Direction
●	Seeps or Springs
— 1250 —	Groundwater Contours
— 1380 —	10 ft Topographic Contours
Contaminant Conditions	
▨	Burn Pit and Approximate Extent of 1980 Soil Removal and Disturbance (BPA)
-·-·-	Limit of Gun Club Property
🟧 🟥	Primary Source Zone in Rock
Limits of Groundwater TCE Concentrations Exceeding New York Standards	
> 5 µg/L	Water Table Monitoring Wells
> 5 µg/L	Deeper Wells

250 125 0 250 500 Feet

Notes

1. The figure is intended to summarize site conditions including hydrology and the presence and extent of VOCs in groundwater and rock matrix.

2. Refer to Executive Summary for additional discussion.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

1,1,1-TCA	1,1,1-Trichloroethane
1,1,2-PCA	Tetrachloroethane
1,1,2-TCA	1,1,1-Trichloroethane
1,1-DCE	1,1-dichloroethene
340º	azimuth range of 340º
Agreement	BCP Agreement No. C704044
Al	aluminum
AMSL	above mean sea level
As	arsenic
ATV/OTV	acoustic and optical televiewer geophysics
B665	Building 665 facility
bgs	below ground surface
BCA	Brownfield Cleanup Agreement
BCDOH	Broome County Department of Health
BCP	Brownfield Cleanup Program
BPA	Burn Pit Area including the Burn Pit and the Historical Excavation of Soil and Rock
BTEX	benzene, toluene, ethyl benzene, xylenes
C/C_O	concentration ratio
Ca	calcium
Cd	cadmium
cDCE	cis-1,2-dichloroethene
CF	chloroform
cm	centimeters
cm/sec	centimeters per second
cm^2/sec	square centimeters per second
CM	chloromethane
conjugate	secondary joint sets
Consortium	University Research Consortium
Country Club	Binghamton Country Club
Core™	Rock VOC Analysis
CPP	Citizen Participation Plan
Cr	chromium
Cr (III)	reduced species of chromium, trivalent chromium
Cr(VI)	oxidized species of chromium, hexavalent chromium
PCM	Carbon tetrachloride/Perchloromethane
Cu	copper
CVOC	chlorinated volatile organic compound
D_e	diffusion coefficient
DFN	Discrete fracture network
DQO	Data Quality Objective
DOE	Department of Energy
DOD	Department of Defense
DRO	diesel range orgnaics

DUSR	data usability review
e	fracture aperture
ELAP	Environmental Laboratory Accreditation Program
EPA	Environmental Protection Agency
Fe	iron
Fe(II)	reduced species of iron, ferrous iron
f_{oc}	fraction of organic carbon [unitless]
ft	feet
ft^3	cubic feet
ft/day	feet per day
ft/ft	feet per foot
FLUTe^{TM}	Flexible Liner Underground Technologies, Ltd. L.C.
g/cm^3	gram per cubic centimeter
g/ft^3	gram per cubic feet
gpd	gallons per day
gpm	gallons per minute
gpm/acre	gallons per minute per acre
GRO	gasoline range organics
Gun Club	IBM Gun Club
IBM	IBM Corporation
IBM CEA	IBM Corporate Environmental Affairs
K	potassium
K	hydraulic conductivity
K_h	horizontal hydraulic conductivity
K_v	vertical hydraulic conductivity
lbs	pounds
lb/ft^3	pounds per cubic foot
lb/yr	pounds per year
m	meters
m/sec	meters per second
m/yr	meters per year
MCL	maximum contaminant level
MEK	methyl ethyl ketone, 2-butanone
meq/L	milliequivalents per liter
mg/L	milligrams per liter
Mg	magnesium
Mn	manganese
Mn(II)	reduced species of manganese, divalent manganese
MS/MSD	matrix spike/matrix spike duplicate
MW	monitoring well
mV	millivolt
Na	sodium
NEH	New Environmental Horizons, Inc.
Ni	nickel
NTU	nephelometric turbidity units

NYSASP	New York State Analytical Services Protocol
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYS	New York State
O&M	operations and maintenance
ORP	Oxidation Reduction Potential (mV)
perimeter road	gated gravel road running along southern boundary
Pb	lead
PCA	pentachloroethane
PCBs	polychlorinated biphenyls
PCE	perchloroethene, tetrachloroethene, or tetrachloroethylene
PHCs	Petroleum hydrocarbons
ppb	parts per billion
PRB	permeable reactive barrier
PVC	poly vinyl chloride
QA/QC	Quality Assurance/Quality Control
R	unitless retardation factor
R^2	Coefficient of determination
RI	Remedial Investigation
S	storage coefficient
SCO	soil cleanup objective
Seep	refers to an area with wet ground
SHA	Sanborn, Head & Associates, Inc.
Site	IBM Gun Club – Former Burn Pit Area
SMCL	secondary maximum contaminant level
Spring	wet area where groundwater is observed discharging to the ground surface in a concentrated flow
SVOC	semi-volatile organic compound
t	time
TAL	Target Analyte List
TCE	trichloroethene
tDCE	trans-1,2-dichloroethene
TEAP	terminal electron accepting process
TOC	total organic carbon
Ton/yd^3	tons per cubic yard
THM	trihalomethane
TICs	tentatively identified compounds
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
UST	underground storage tank
V	seepage velocity
V_{solute}	solute transport velocity
VC	vinyl chloride
VOC	volatile organic compound
W_g	gravimetric moisture content

Zn	zinc
%	percent
µg/g	micrograms per gram
µg/L	micrograms per liter
µm	micrometer, microns
µS/cm	microsiemens per centimeter
θ_w	volumetric moisture content water-filled porosity (unitless fraction)
ρ_b	bulk density of soil (mass solid/bulk volume)
ρ_{dry}	dry bulk density
ρ_{wet}	wet bulk density
φ	porosity (dimensionless)
φ_f	fracture porosity
φ_m	matrix porosity
τ	tortuosity

1.0 INTRODUCTION

This report presents the findings of the Remedial Investigation (RI) associated with the former Burn Pit Area of the IBM Gun Club (Gun Club) property. International Business Machines (IBM) Corporation engaged Sanborn, Head & Associates, Inc. (SHA) to perform the RI and prepare this report. The RI work was completed under the New York State Brownfield Cleanup Program (BCP) administered by the New York State Department of Environmental Conservation (NYSEC) with IBM as a Participant. Investigations associated with the Burn Pit Area were performed under BCP Agreement No. C704044 executed by IBM and NYSDEC on August 22, 2005 (Agreement).

The IBM Gun Club property, which is shown on Figure 1, is a 53.4-acre parcel of land located at 1395 Robinson Hill Road in the Town of Union, Broome County, New York. The portion of the property identified as the initial focus of the RI is 4 acres in size. This area of RI focus encompasses the former Burn Pit and land disturbed during a 1980 soil removal action conducted voluntarily by IBM (referred to as the Burn Pit Area, or BPA). A Brownfields RI focused on a former skeet shooting range on the Gun Club property has been conducted by others on behalf of IBM and is not addressed in this report.

The RI was completed in accordance with the Work Plan prepared by SHA dated March 6, 2006, which was approved by the NYSDEC and New York State Department of Health (NYSDOH) in a letter dated February 24, 2006 (Work Plan). Citizen participation activities were guided by the Citizen Participation Plan dated September 2005 (CPP). The work was also conducted in consideration of NYS Rules for Environmental Remediation Programs 6NYCRR Part 375, and in particular the Brownfields Rules Subpart 375-3, effective December 14, 2006.

The RI was led by IBM Corporate Environmental Affairs (IBM CEA) and SHA. The NYSDEC and NYSDOH, collectively referred to as the Agencies', have been kept informed through regular telephone calls, meetings, and monthly progress reports submitted in accordance the Agreement.

1.1 Purpose and Objectives

The purpose of this report is to communicate the data, inference, and conclusions derived from the RI. It also presents an assessment of the need and possible goals for remediation, and the identification and screening of potentially applicable remedial alternatives. An analysis of remedial alternatives, referred to in the Brownfields Rules as an "Alternatives Analysis", is being conducted and will be submitted under separate cover.

The driver for this RI was the apparent on-going presence of certain volatile organic compounds (VOCs) in groundwater sampled from several bedrock monitoring wells. The monitoring wells were located in the vicinity of the BPA.

The principal focus of the work as stated in the Work Plan is to "sufficiently characterize subsurface conditions to determine whether remedial activities are required to address potential contaminant exposure and migration concerns and to determine if remedial activities are appropriate". Accordingly, the work has been primarily focused on assessing soil, bedrock, and groundwater conditions to develop a better understanding of the extent and magnitude of possible residual VOCs and potential migration pathways and mechanisms.

1.2 Scope of Work

The overall scope of the RI, completed over a three-year period, is consistent with that described in the Work Plan. Several amendments were submitted and approved by the Agencies during this period to expand either the number of explorations or the geographic area of investigation as a consequence of the on-going evaluation of data. Table 1 provides a more detailed chronology of major RI events, while Exhibit 1.1 provides an overview of the primary elements of RI work.

The RI scope of work was developed by SHA in consideration of known or inferred site conditions described in the Work Plan as the working conceptual model. For additional discussion regarding the conceptual model considered in developing the scope of work as summarized below, refer to Section 2.6 of the Work Plan.

Exhibit 1.1 - Application of Advanced Techniques/Technologies:

The investigation involved a combination of technologies that have only been applied to about a dozen or fewer sites worldwide which has been referred to as a discrete fracture network (DFN) approach[1]. Particularly notable major elements of the RI scope included:

Detailed hydrogeophysical logging of the existing bedrock boreholes and the installation and monitoring of a multilevel system to obtain data to better understand stratigraphy, lithology, fracture morphology, and hydraulic properties to support drilling of additional bedrock boreholes and siting of new monitoring points.

The term hydrogeophysical logging refers to geophysical logging, video logging, and hydraulic testing of open bedrock boreholes.

Collection and laboratory analysis of rock core samples for VOCs to confirm the presence of VOCs in the rock matrix as a source for groundwater contamination and to define the location and depth of such sources in rock. This work was coordinated, observed, and logged by SHA personnel in consultation with the individuals representing the Universities of Waterloo and Guelph Ontario.

VOC analysis of whole rock cores was conducted using a technology (CORE™) developed by Dr. Beth L. Parker and others, and is now being transferred to the private sector for application to sedimentary rock sites like the Gun Club. As outlined in Table 1, over 650 feet of rock core was sampled at 33 locations in three exploration events that were conducted in July 2006, April/May 2007, and June 2008. In total, about 670 rock samples were analyzed for VOCs.

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[1] Beth L. Parker, September 24-26, Investigating Contaminated Sites on Fractured Rock using the DFN Approach, *Proceedings of 2007 U.S. EPA/NGWA Fractured Rock Conference State of the Science and Measuring Success in Remediation.*

Drilling and logging of bedrock boreholes, and the installation and monitoring of both multilevel systems and conventional monitoring wells.
The drilling of bedrock boreholes was observed and logged at about 70 locations. Four overburden boreholes and 37 bedrock boreholes were completed as monitoring wells. Four new "deep" boreholes each penetrating up to about 240 feet of the subsurface were equipped with FLUTe™ multilevel monitoring systems[2] *screening six to seven borehole intervals. These intervals were selected on the basis of data derived from visual logging of the rock core and hydrogeophysical logging to target apparent zones of fracturing and/or zones believed to offer particular water transmission potential. With a total of 35 multilevel monitoring intervals, 41 monitoring wells, and two water supply wells, water levels and water quality have been monitored at 78 locations/depths in bedrock and overburden.*

Including the rock core sampling work, over 2,610 linear feet of bedrock borehole have been observed and logged, which is almost one-half mile of rock borehole.

Field and Laboratory Testing of Hydrogeologic Properties - In-situ properties relevant to groundwater flow and contaminant storage and transport were assessed through field and laboratory testing.

Hydraulic conductivity estimates were derived from packer testing of open borehole intervals, slug testing of monitoring well installations, pulse testing of multilevel monitoring ports, and laboratory testing of unfractured core samples of rock. These data, along with data from detailed logging of rock fracturing, were used to estimate fracture apertures and fracture porosity values that were later used in fracture transport modeling and hydrologic calculations. Rock core samples were also tested for key physical properties related to contaminant mass storage and transport.

The field explorations and testing were conducted over about a 60-acre area as shown on Figure 2. Sampling of water supplies, indoor air, and subslab soil vapor also was conducted in the Glen Crest Estates Subdivision.

The siting of the initial seven bedrock exploration and testing locations was informed by a review of contemporaneous and historical aerial photographs, and a bedrock fracture trace analysis conducted as a part of Work Plan development. The locations were also informed by a soil and soil vapor investigation conducted in April/May 2006. The subsequent bedrock drilling, rock core sampling, and monitoring well installation were informed by the initial data, groundwater monitoring results, and additional direct-push rock probe investigations. Over 150 rock probe borings were drilled to refusal on bedrock. Many of these rock probes were equipped with temporary PVC screen and riser, and used for collection and screening of shallow groundwater. Groundwater samples were collected from over 100 rock probe locations.

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[2] Cherry, J.A, B.L. Parker, and C. Keller, 2007, A New Depth-Discrete Multilevel Monitoring Approach for Fractured Rock, *Groundwater Monitoring & Remediation 27 No.2/Spring 2007, pgs 57 to 70.*

The investigation included collection and analysis of samples of soil and water for VOCs, as well as for certain metals and semivolatiles regulated as hazardous substances. For certain sampling events, the field screening and laboratory analysis included major cations and anions, and geochemical parameters useful in assessing general geochemical conditions, including conditions that could be associated with biochemical degradation of VOCs. Water samples were collected from groundwater monitoring installations and from surficial wet areas such as seeps, springs, and surface drainage courses. Eleven quarterly water quality sampling events were conducted over almost a three-year period from April 2006 through December 2008.

The field and laboratory data, and observations obtained in each step, were reviewed and analyzed as each phase of work was completed. These data and observations are summarized in tables, figures, and text that are documented as Appendices of this report. In addition to monthly progress reports and regular telephone discussions, seven meetings were held with the Agencies during the RI to review interim findings and next steps, including the following key meetings:

- December 5, 2006, when the findings of the initial phase of rock core sampling, and the drilling and installation of monitoring wells and multilevel equipped boreholes, were presented and discussed.
- March 28, 2007, when the scope of work to be completed in the spring of 2007 was presented and discussed. This work included the drilling and installation of two additional deep boreholes equipped with multilevel devices.
- October 10, 2007, when the findings of explorations that largely completed RI work on the Gun Club property were presented and discussed, along with plans for expanding investigations on the adjacent Binghamton Country Club to the south (Country Club).
- April 3, 2008, when the findings of initial screening level investigations and testing on the Country Club property were presented and discussed, including a plan for monitoring well and rock core explorations.
- March 31, 2009, when key findings and concepts outlined in this report including the findings of remedial technology screening and alternatives to be taken forward for analysis were presented and discussed.

During completion of the work, two fact sheets were prepared and distributed to interested parties identified through the CPP. A fact sheet summarizing the findings of investigations on the Gun Club property was distributed in November 2007, and a fact sheet summarizing the findings of work completed on the Country Club was distributed in July 2008. The fact sheets were distributed to the site contact list outlined in the CPP, and to contacts that were added to the list as the work proceeded. Copies of the fact sheets were also provided to the Country Club for distribution to their membership.

1.3 Organization of Report

Section 2.0 that follows this introduction summarizes background information believed to be foundational to the RI. Sections 3.0, 4.0, and 5.0 present the data and inference associated with geologic conditions, groundwater hydrology, and contaminant characterization, respectively.

Section 6.0 provides an updated conceptual model of site conditions as a backdrop for the qualitative exposure assessment included as Section 7.0. The site conceptual model and qualitative exposure assessment collectively informed the assessment of remedial objectives and technologies outlined in Section 8.0. Our conclusions and recommendations regarding next steps through the assessment of remedial alternatives are included in Section 9.0.

The supporting details associated with field exploration and testing elements and analysis of the field and laboratory data are included as Appendices of this report. Appendix A outlines the limitations associated with our work and this report. Appendix B presents basic physical data and logs associated with site explorations and testing. Appendix C presents data and inference derived from soil gas survey and soil sampling events. Information associated with testing of the existing boreholes, drilling logging, and testing of new borehole and monitoring installations, and the rock core sampling and analysis work are presented in Appendices D, E, and F, respectively.

Appendices G and H present our assessment of aqueous geochemistry and hydrogeologic conditions. Water quality data, data validation reports, and the raw analytical laboratory data are included as Appendices I, J, and K, respectively.

1.4 Acknowledgements and Recognition

We would like to acknowledge the leadership and guidance of IBM Corporate Environmental Affairs, notably Mr. Kevin Whalen, in completing this work.

The productive cooperation and input from representatives of the Binghamton Country Club is also recognized as a positive contribution. Mr. Kevin O'Hara and Mr. Thomas Harding served as Presidents of the Country Club during the period of work. The Golf Course staff, most notably the Superintendent, Mr. William Murtha; and the technical consultant to the Country Club, Mr. Mark O'Rourke, are acknowledged for their productive input and cooperation.

We acknowledge the substantial contributions of Dr. Beth L. Parker and Mr. Steven Chapman, both of the University of Guelph, and Dr. John Cherry of the University of Waterloo, Ontario. Mr. Chapman had an instrumental role in the rock core sampling events and modeling. These individuals provided valuable input in work planning and fate and transport modeling, and are acknowledged for their contribution to development of several of the technical concepts and technologies employed in the RI. In particular, the Rock VOC Analysis (CORE™) and FLUTe™ multilevel systems were developed and/or supported by the University Research

Consortium[3] led by Drs. Cherry and Parker (Consortium). The Consortium has been active since it was formed in 1988 with "seed" money from the IBM Corporation.

2.0 BACKGROUND

2.1 Site Description

The Gun Club is an approximately 53.4-acre parcel located on the west side of Robinson Hill Road, about 1/2- mile south of the intersection with Struble Road in the Town of Union, Broome County, New York. As shown on Figure 2, the initial investigative focus for the RI was an area referred to as the Burn Pit Area and surrounding land totaling 4-acres was defined as "the Site" in the Agreement. By the end of 2007, investigations had been conducted over about an 11-acre area of the Gun Club property. In January 2008, the field work expanded onto a roughly 45-acre area of Binghamton Country Club property as depicted on Figure 2.

Town of Union Tax Assessor's Office records list the Gun Club property as lot 20 of Section 126.18, Map 1, with a corresponding street address of 1395 Robinson Hill Road. The Gun Club property is zoned for Commercial use. As outlined in the BCA, the current site use is commercial, and the intended future use by IBM is for industrial or commercial purposes.

As shown on Figure 2, the initial investigative area consisted of an open grassed field surrounding the former Burn Pit location. The approximately 2-acre grassed field surrounding the former Burn Pit is believed to correspond to the limits of soil disturbance related to removal of VOC-containing soils in 1980. In the text to follow, the area encompassed by the soil removal action is referred to as the Burn Pit Area (BPA).

The present Gun Club property includes an open grassed trap and skeet shooting range and associated unoccupied buildings, and a former electronic testing facility operated by the IBM Printing Systems Division (Building 665). Until July 2009, the Building 665 facility (B665) was used for testing of electronic interference between printer components, an operation that does not require use of solvents or other hazardous materials. B665 and the Burn Pit Area are located in an approximately 6.8 acre area encircled by 6-foot-high, chain-link fence. Access to this area is restricted by locked gates. A radio tower that served an IBM ham radio club is located at the southeast corner of the B665 fenced area. The remaining portions of the Gun Club property are primarily wooded and undeveloped.

B665 housed approximately four IBM employees until July 2009. The current use includes storage facility for IBM contractors. The building is served by a septic system. Water for the washroom (toilets and sink) is provided by a drilled bedrock water supply well designated GC-A as shown on Figure 2. Although repeated sampling of this water supply has not indicated the presence of site-related contaminants, bottled water is used for drinking water.

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[3] *University Consortium for Field Focused Groundwater Contamination Research, formerly the Solvents In Groundwater Research Consortium.*

As shown on Figure 2, a gated gravel road runs along the southern Gun Club property boundary (perimeter road) from just north of the southeast site corner. This road is used for access to a water tower located just west of the southwest site corner. Three monitoring wells (MW-1 through MW-3) installed by others as part of the shooting range investigation, and a bedrock well that formerly served the shooting range buildings (GC-B), are also shown.

2.2 Surrounding Land Use

The lands surrounding the Gun Club, as shown on Figures 1 and 2, are under residential and recreational uses, or are undeveloped woodlands. Residences proximate to the Gun Club include:

- Five residences to the southeast in the Glen Crest Estates Subdivision;
- Residences to the northwest, west, and southwest in the Skylane Terrace and Valley View neighborhoods; and
- Two residences along Robinson Hill Road to the northeast and north.

The Binghamton Country Club is located south of the Gun Club property. Within about 0.5 miles of the Gun Club property boundary, the Country Club property is either undeveloped and wooded, or a part of the golf course. The nearest occupied building space associated with the Country Club is the maintenance shop located 2,700 feet south of the Gun Club. The clubhouse and restaurant building serving the Country Club is about 4,200 feet to the south.

Over 200 acres of public lands known as “The Glen” are located east of the Gun Club site across Robinson Hill Road. The Glen is a mature forested natural area with paved walking trails that was donated to the Fred L. Waterman Conservation Education Center by IBM. This area is referred to as the IBM Glen.

A review of records at the Broome County Department of Health (BCDOH) confirmed that properties west and southwest of the site are served by the public water supply system. As identified on Figure 3, seven individual residential properties located southeast, north and northwest of the Gun Club are served by private water supply wells. BCDOH records included a permit to operate the restaurant associated with the Country Club, which confirms the use of public water and sewer. BCDOH records support that irrigation water for the Binghamton Country Club is supplied by public water via a large water storage tank located southwest of the Gun Club.

The approximate locations of bedrock water supply wells serving residences in the Glen Crest Estates subdivision are shown on Figure 3. Based on discussions with the residents during water supply system sampling conducted in April and June 2008, the wells were drilled by the same water well contractor and are approximately 120 to 150 feet deep, completed with steel surface casings. Subsequent discussions with the water well contractor[4], BK Nalepa Well Drilling, did not reveal additional information about the depth and construction of the wells.

Based on BCDOH records reviewed in January 2007, the nearest public water supply well is associated with a former tennis club located just east of the intersection of Robinson Hill and Case Roads approximately 2/3 mile northeast of the Gun Club (not shown on Figures). A Vestal Water District well field is located approximately 2 miles southeast of the site and across the Susquehanna River. It is SHA's opinion that these public water supplies are hydrologically isolated from the watershed in which the Gun Club is located.

2.3 Topography and Drainage

The BPA is located at the top of a hill. As indicated on Figure 3, the overall topographic relief between the BPA, at an elevation of about 1,390 feet Above Mean Sea Level (AMSL), and the mapped upper reaches of the unnamed tributary located near the northwestern corner of the Gun Club is on the order of 200 feet or greater, while the relief between the BPA and Patterson Creek is on the order of 400 feet. Ground surface topography near the eastern property boundary slopes downward easterly toward the steeply cut Glen. Ground surface topography near the southern property boundary slopes downward southerly toward the Country Club.

As shown on Figure 3, the crest of the hill is located just southeast of the Burn Pit. Over most of the Gun Club property, the ground surface slopes from this high point downward northwest toward undeveloped woodlands. No intermittent or perennial streams are located directly within the BPA; however, as shown on Figure 3, a number of wet areas where water has been observed to be seeping to the ground surface at least seasonally have been identified within and adjacent to the Gun Club property. These wet areas have been observed at locations corresponding to ground surface elevations between 1,385 and 1,200 ft. AMSL and are discussed as "seeps" and "springs". The term "spring" connotes a wet area where water has been observed discharging to the ground surface in a concentrated flow, whereas "seep" refers to wet ground only.

The majority of the Gun Club and areas to the north and west appear to be drained by several intermittent, unnamed streams that converge in the area of Debonair Drive and flow westward before discharging into Patterson Creek. One such unnamed tributary to Patterson Creek appears to originate near the northwestern corner of the Gun Club. Patterson Creek flows in a southerly direction for about three miles to its confluence with the Susquehanna River.

A steeply incised drainage mapped as Gray Creek flows from north to south through "The Glen" just less than 2,300 feet east of the property toward discharge at the Susquehanna River. Land along the eastern boundary of the Gun Club property drains easterly toward Gray Creek. The Gray Creek drainage reaches the Susquehanna River about 1.5 miles downstream of the reach adjacent to the Gun Club.

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[4] Telephone Communication, July 2008, Conversation between Allan Horneman of SHA with Mr. Brian Nalepa of BK Nalepa Well Drilling of Endicott, New York.

A drainage ditch located at the northern limit of the Country Club golf course about 325 feet south of the property boundary has never been observed to carry running water. Surface runoff from the golf course flows to the southwest through intermittent drainages as shown on Figure 3, and to the east toward "The Glen" through a culvert under Robinson Hill Road. The westerly-most drainage originates from wet areas located adjacent to a man-made pond near the northwest corner of the Country Club property. As shown on Figure 3, the drainages running southwest join in a ditch that runs along the western property boundary of the Country Club to a point 2,600 feet south of the northwestern Country Club property boundary. At this point, the drainage diverts westerly through a residential area to join Patterson Creek half a mile downstream from the diversion.

A number of wet areas and drainage features shown on Figure 4 have been sampled periodically during the RI and are included in quarterly monitoring. Photo logs and records of the site reconnaissance observations, along with data from the initial sampling of these wet areas, are included in Appendix F.3.1 and F.4.1. The sampling locations include a subsurface drainage trench filled with crushed stone and equipped with a corrugated plastic riser pipe at the northwest corner of golf course fairway No. 9. The trench and riser pipe, designated No. 114 as shown on Figure 4, was constructed years ago by the Country Club to improve drainage of sand traps near the No. 9 green. The riser pipe intermittently contains water but has not been used to actively pump water from the subsurface and has no surface discharge.

2.4 Geologic Setting

According to regional geologic mapping[5,6] the site and surrounding region consists of glacial till overlying sedimentary bedrock of the Upper Devonian Period West Falls Group. Bedrock formations mapped in the vicinity of the site include a relatively shallow dipping, interbedded sequence of shale and siltstone at the base of the West Falls Group described as the Beers Hill Shale, Grimes Siltstone, and Dunn Hill, Millport, and Moreland Shales.

The Broome County Soil Survey published by the United States Department of Agriculture Natural Resources Conservation service (USDA) indicates that the site and vicinity is underlain by glacial till classified as silt loam derived from sandstone and siltstone. These soils are indicated to be moderately- to well-drained, up to 70 inches thick and with a low capacity to transmit water, and "low to very low available water capacity". The saturated hydraulic conductivity is indicated to be below $1x10^{-6}$ centimeters per second (cm/sec), or about $3x10^{-3}$ feet per day (ft/day).

Historical explorations have confirmed the presence of silty glacial till overlying an interbedded sequence of shale, siltstone, and fine sandstone. The silty till consists of a heterogeneous mixture of silt, sand, gravel, and clay. The thickness of the glacial till encountered during the

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[5] Cadwell, D.H., and others, 1986, *Surficial Geologic Map of New York, Finger Lakes Sheet*, New York State Museum – Geological Survey, Map and Chart Series #40.

[6] Rickard, L.V., and Fisher, D.W., 1970, *Geologic Map of New York, Finger Lakes Sheet*, New York State Museum and Science Service, Map and Chart Series #15.

1980 soil excavation was reported to be less than five feet. A thin (generally less than five feet thick) zone of weathered bedrock was reportedly encountered within portions of the 1980 soil removal area. We believe that weathered rock was also excavated during the 1980 soil removal.

The bedrock fracture trace assessment conducted as a part of Work Plan preparation included mapping of fracture orientations and frequency at outcrop locations on or near the Gun Club property. We also reviewed aerial photograph pairs with a stereoscope to identify linear features that may be associated with regional fracture patterns. The bedrock was observed to be consistent with descriptions of bedrock that are considered to be included in the "West Falls Group", primarily shale and siltstone interbedded with lesser amounts of sandstone.

We observed a predominance of bedding-parallel joints with less frequent steeply dipping to near vertical primary joint sets, with orientations in the azimuth range of 340 degrees (340^o) to 20^o, and secondary (conjugate) joint sets in the azimuth range of 60^o to 100^o. Observations at outcrops within the Gun Club property and nearly 1,700 feet away from the BPA are generally consistent, with little evidence of spatial variations in the orientation of jointing. The orientations of regional photolineaments overlap with, but do not directly correlate to, the orientation of the steeply dipping joints observed at outcrops. The observed photolineaments typically coincide with drainage features, such as intermittent and perennial streams.

Regional mapping indicates similar orientation of linear features inferred by Isachsen and McKendree[7] (1977) based on aerial photos and satellite imagery, but show no faults or shear zones in the vicinity of the site. Other mapping by the same researchers indicate that in the Binghamton area, joint sets in rock include a vertical or near vertical set of "greatest prominence" with azimuth of about 350^o, a near vertical set of secondary prominence at about 5^o, and sets with undifferentiated dip at about 70^o.

2.5 Environmental History of the Site

A review of historical aerial photographs of the Gun Club property, dating as far back as 1955, was conducted to assess historical site use conditions. We understand that IBM purchased the Gun Club property in 1935. Since the 1940s, the Gun Club property has included a trap and skeet shooting range, a rifle and shotgun target range, a dog hunting club, and a ham radio club. Building 665, houses the electronic testing facility and was constructed between the late 1960s and mid-1970s. Minor additions/modifications to Building 665 appear to have been made in the late 1980s and during the 1990s.

Aerial photographs from 1955 and 1965 support the location of the Burn Pit as shown on the report figures. The aerial photograph from 1955 and 1965 indicate that access to the BPA during the mid-1950s appears to be via the entrance off Robinson Hill Road near the southeastern corner of the Gun Club property. Aerial photography from 1977 shows the BPA largely

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[7] Isachsen, Yngvar W. and McKendree, William G., 1977, Preliminary Brittle Structures Map of New York, Hudson Mohawk Sheet. and 1977, Generalized Map of Recorded Joint Systems in New York.

consistent with what is shown for 1955 and 1965. Building 665 is not present in 1965 photo but is visible in the photo from 1977.

In 1979, IBM voluntarily undertook a hydrogeologic investigation of the BPA to identify and remove contamination to the extent practicable. The investigation included collection and analysis of soil samples, installation and sampling of two approximately 100-foot deep bedrock groundwater monitoring wells (wells GC-1 and GC-2), and sampling of bedrock water supply wells GC-A and GC-B.

The investigation identified VOCs in soil and groundwater samples collected from the monitoring wells. Laboratory analysis of certain soil samples also indicated the presence of metals, including cadmium, chromium, copper, iron, nickel, and zinc in one or more samples at concentrations exceeding published values for typical soils in the eastern United States[8]. Iron and zinc were the only metals detected in groundwater samples, but at concentrations generally near method detection limits. Site-specific soil testing was not conducted to establish background conditions.

The following year, 1980, IBM completed a removal action during which 30,000 cubic yards (yd^3) of soil were reportedly excavated from the BPA. The removal of soil reportedly encompassed areas where soil sampling indicated the presence of VOCs and/or the possible presence of one or more metals above the published typical background levels. IBM's records indicate that approximately 10,000 cubic yards of this soil were transported to the Model Cities Landfill near Niagara Falls, New York for proper disposal. The Burn Pit excavation area was backfilled and capped with topsoil, and then seeded and mulched. Aerial photography from 1986 was used to infer the area of soil removal and disturbance shown on Figure 2.

Since the 1980 removal action, water samples have been collected from the bedrock monitoring wells and water supply wells on a roughly semiannual basis, analyzed for VOCs, and reported to NYSDEC. The monitoring data for GC-1 indicate the presence of trichloroethene (TCE) at concentrations less than or equal to 100 micrograms per liter (µg/L), and TCE degradation product cis-1,2-dichloroethene (cDCE) at 12 µg/L. Historical monitoring of well GC-2 generally indicated lower concentrations of TCE. Past monitoring has also indicated the presence of carbon tetrachloride along with a limited number of additional VOCs, which were detected only sporadically at concentrations near method detection limits. VOCs have not been detected in sampling of the water supply wells.

In August 2003, IBM sampled the five drinking water supply wells serving the residences in Glen Crest Estates. Lab analysis of the samples revealed no evidence of water quality degradation that could be related to the Gun Club. This finding was confirmed through sampling of these water supplies in 2008. In February 2004, IBM sampled a newly installed well at a more recently constructed residence abutting the site to the north on the west side of Robinson Hill Road. Lab analysis of the sample did not find VOCs.

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[8] NYSDEC, January 24, 1994, *Technical and Administrative Guidance Memorandum #4046, Determination of Soil Cleanup Objectives and Cleanup Levels*, Appendix A, Table 4.

Broome County Department of Health (BCDOH) records reviewed in January 2007 did not indicate any known storage or use of oil or hazardous substances for the Gun Club property as part of historical or on-going operations

2.6 Environmental Information for Nearby Properties

SHA's review of BCDOH records in January 2007 for properties near the Gun Club indicated the following regarding spills or permits associated with petroleum or hazardous substances:

- The Binghamton Country Club and two lawn/landscaping companies are registered for storage and use of pesticides. Addresses for the two landscaping companies were indicated to be located about two-thirds of a mile or greater southwest of the site downslope in the Skyline Terrace residential development.

- Several closed files regarding historical spills of No. 2 fuel oil and gasoline for several properties located southwest of the site in the Skyline Terrace neighborhood.

- Several underground storage tanks were registered for the Country Club, presumably associated with fuel oil for heating of buildings remote from and downslope of the site. The records indicate the removal of a potentially leaking UST from the Country Club property in 1994.

Approximately as shown on Figure 2, debris and materials have been observed adjacent to paths in the wooded, undeveloped area of the Country Club just south of the Gun Club property boundary. The debris has been observed to include metals (corrugated steel piping, golf cart, kitchen appliances, gasoline or oil cans), furniture, tires, plastic drain piping, and woody materials (crates, downed trees, stumps, brush, and other vegetative matter).

3.0 GEOLOGIC CONDITIONS

The following discussion of geology summarizes the observations of site conditions relevant to groundwater flow and contaminant hydrology. Much of this discussion is focused on bedrock, which is believed to be the primary migration pathway for site-related VOCs.

3.1 Overburden

Consistent with USDA Soil Survey mapping, the soils that have been encountered over bedrock in the investigation area are fine-grained glacial till composed of an unsorted mixture of silt, clay, sand and gravel deposited by glacial ice. The thickness of glacial till encountered in the many exploratory borings ranged from 1 to 7 ft on Gun Club property, with an average of 3.7 ft. Over the entire investigative area, the thickness of glacial till ranged from 1 to 36 ft thick, and averaged approximately 6.6 ft thick. The till thickness encountered south of the man-made pond at the southwesterly limit of subsurface investigations is about 30 ft (at BP-21 and BP-22A illustrated on the cross-section B-B' on Figure 7), and 36 ft at the southern-most boring location along Robinson Hill Road (at BP-29). Interpolation of the bedrock surface elevation contours depicted on Figure 5 indicates an increased depth to bedrock between BP-23A and the man-made pond and to a lesser degree from BP-30A toward the southeast to BP-27A.

Soil gradation analysis of soil samples collected outside the area believed to be affected by the 1980 VOC-containing soil removal indicated fines content (silt and clay) ranging from about 20% to 70%, typically greater than 30%, with up to 80% gravel and lesser proportions of fine to coarse sand (Exhibit 3.1). The soil samples collected within the area of the historical soil excavation generally fell within the same gradation envelope but exhibited a higher proportion fines and smaller amounts of gravel suggesting that the area was backfilled with screened till.

%Silt and Clay	%Gravel	Dry Bulk Density (ρ_b) lb/ft^3	Porosity (ϕ) unitless fraction	% Gravimetric Moisture Content (Wg)
16 to 72	17 to 78	99 to 130	0.23 to 0.34	5 to 19

Exhibit 3.1. Summary of Estimated Physical Properties of Glacial Till Soils.

The dry bulk density and porosity estimates are based on testing of core samples of the glacial till and indicate median bulk density and porosity of about 120 lb/ft^3 and 0.29, respectively. At gravimetric moisture contents of 5% to 19%, the soil pore space would be 30% saturated to fully saturated with water. The soils laboratory data and additional supporting plots are included as Appendix B.5.

3.2 Bedrock Morphology

Information on bedrock morphology, including: depth to bedrock; bedrock surface topography; and rock lithology, bedding, and jointing has been derived from the bedrock fracture trace analysis and four phases of bedrock drilling and monitoring well installations and three phases of bedrock drilling and rock core sampling. Additional information on depth to refusal has been recorded in direct-push rock probing. The work and observations are discussed in more detail in Appendices B.3, C, and F.

The refusal depth of the direct-push probing was generally considered indicative of the top of bedrock; however, in several instances the direct-push probe recovered up to several feet of weathered rock. In a few other instances direct-push refusal was encountered on coarse gravel in the glacial till. These observations were considered in preparing the bedrock surface elevation contours depicted in orange on Figure 5. The contours indicate that the bedrock surface is a muted reflection of surface topography.

A depression in the bedrock surface has been identified extending southwesterly from just south of the former Burn Pit (at BP-6) toward the southern Gun Club property line (at BP-9A) as shown on Figure 5. This trough-like depression in the bedrock surface corresponds to the center of higher observed VOC concentrations in groundwater and rock core samples as outlined in

Section 5.1. The trough in the bedrock surface appears to coincide with historical transport of VOC-containing solvent and/or groundwater within or on top of bedrock.

In general accordance with the protocol described in Appendix B.3, the rock core retrieved during drilling was classified according to the observed hardness, degree of weathering, color, texture, and geologic type. In addition, the bedding thickness and angle, and the spacing and orientation of jointing, were systematically classified and logged. The depth and angle class of observed fracturing were logged into a spreadsheet for later analysis. Rock core exhibiting very close joints (i.e., where the individual fractures could not be resolved) were classified as extremely fractured intervals or zones, whereas intervals with more than 5 feet between joints were classified as "sound". The following sections describe in more detail the observations derived from logging of rock cores and geophysics.

3.2.1 Hardness, Weathering, Color, and Texture

The rock was generally found to be moderately hard, consistent with well-cemented, fine-grained sedimentary rock, principally sandy siltstone. Severely weathered shale typically encountered in the upper 5 feet of rock was typically classified as being soft; while unweathered, fresh shale was predominantly classified as being medium hard.

The top 5 feet of rock was found to be severely or very severely weathered, where all the rock appeared discolored or stained. The observed degree of weathering generally decreased with depth. Below the top 5 feet of rock, very slightly or moderately weathered rock was typically found at joints and fracture surfaces. At greater depth, weathering and discoloration typically extended only a few inches or less into the otherwise unweathered rock. Typically rock retrieved from below 40 ft below ground surface (bgs) was classified as "fresh" with no visible evidence of weathering.

The rock color ranged from light gray sandstone, gray for sandy siltstone, to dark gray for shale. Fracture surfaces exhibited hues of rust red, brown, gray, or black. The fracture surfaces at depth were more often gray to black, indicative of anoxic conditions, whereas the reddish or brown fracture surfaces indicative of oxic or suboxic groundwater conditions with precipitation of iron-oxides were more predominant in the upper 40 feet bgs.

The sandstone and sandy siltstone intervals were generally classified based on a fine-grained texture. The individual grains were typically visible and tactile for sandstone, whereas although not always visible in the sandy siltstone, a more granular texture could be felt by hand. Shale intervals exhibited an "aphanitic" texture, where the individual grains could not be seen or felt.

3.2.2 Lithology and Bedding

Rock described as sandy siltstone comprised approximately 81% of the over 2,600 feet of collected rock core, followed by sandstone (14%), and shale (5%). The relative proportion of sandy siltstone, sandstone, or shale does not appear to be correlated to elevation or depth below ground surface, and review of the cross sections provided as Figures 6 and 7 does not support correlation or tracing of lithology between boreholes.

A visual review of the lithology profiles shown on Figures 6 and 7 suggests the possibility of marginally greater proportion of shale in the upper 90 feet of subsurface and perhaps greater thicknesses of sandstone in the upper 60 feet of subsurface. Additionally, the profiles imply a greater proportion of sandstone in the historical boreholes and boreholes BP-12 and BP-13. However, the differences may reflect evolution in logging of subtle textural differences rather than true differences in lithology. Laboratory testing of samples of unfractured rock core indicate little variability in physical properties among the lithologies. Therefore, precise differentiation of the lithologies is not that important.

The lithology has been observed to range from fine-grained sandstone to shale, which represent end-members in a generally fine-grained textural continuum of well-cemented rock exhibiting little weathering and no readily visible primary porosity. For much of the core, the lithology is not distinct, typically exhibiting interbedding and gradational transitions in texture at different scales. Rock logged as ‘sandstone’ may actually be sandy siltstone, while rock logged as predominantly ‘siltstone’ may consist of thinly interbedded siltstone with shale.

Changes in lithology were generally observed to be gradual over a few inches to feet, and rock classified as sandy siltstone typically included intervals with a higher proportion of shale as well as more sandy (sandstone) intervals reflective of bedding. The bedding was generally found to be “very thin” (less than two inches thick) and horizontal.

3.2.3 Physical Property Testing of Rock Samples

The physical property testing of unfractured rock, which is documented in detail in Appendix F.5, revealed only subtle lithologic differences in properties, including matrix porosity (ϕ_m), dry and wet bulk density (ρ_{dry} and ρ_{wet}), and fraction of organic carbon (f_{oc}). In other words, few differences were noted among rock classified as sandstone, siltstone, and shale. The laboratory physical testing data are summarized in Exhibit 3.2 below.

Parameter	Matrix Porosity ϕ_m Unitless Fraction	Bulk Density		Fraction Organic carbon f_{oc} %
		Wet ρ_{wet} g/cm^3	Dry ρ_{dry} g/cm^3	
Number of Observations	9	19	19	19
Min	0.03	2.61	2.59	0.07
Max	0.07	2.72	2.68	0.31
Mean Value	0.05	2.67	2.65	0.18

Exhibit 3.2 Summary of Physical Properties Based on Laboratory Testing of Unfractured Bedrock Core Samples.

As discussed in Appendix F.2, 11 samples collected in the BPA primary source rock from borings BP-1 through BP-6 ranged from 0.15% to 0.31% with a mean of 0.22%. In contrast, f_{oc} values for rock samples collected further downslope on Country Club property outside the primary source rock (Appendix F.4.2) ranged from 0.07% to 0.24%, with a mean of 0.13%. As shown on Exhibit 3.3, the apparent higher f_{oc} in rock proximate to the BPA reflects the observed presence of petroleum hydrocarbons in the rock matrix as discussed in Section 5.1.3, and not differences in natural rock composition.

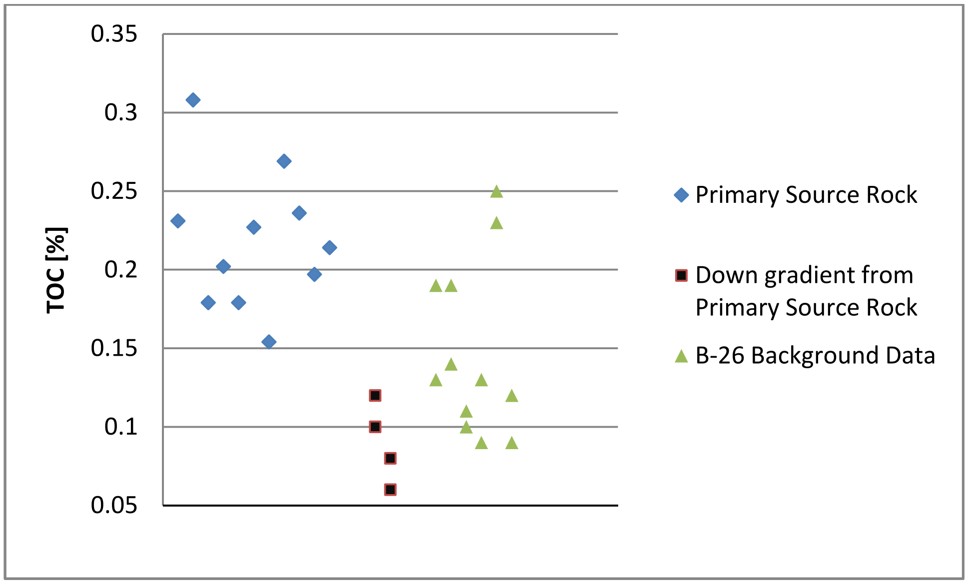

Exhibit 3.3 Scatterplot of Organic Carbon Content of Rock Samples from Within and Outside the Primary Source Rock.

The wet bulk density of the unfractured rock indicates field unit weights of in-place rock of about 2.2 to 2.9 tons per cubic yard (ton/yd^3). At the mean f_{oc} and dry bulk density, which is equivalent to a dry unit weight of 165 lb/ft^3, each cubic foot of rock would contain about 0.2 pounds (lbs) of organic carbon. This mass of carbon indicates the rock exhibits a considerable capacity to physically/chemically sorb volatile organic compounds. Where petroleum hydrocarbons are present in the rock, the sorptive capacity would be further increased as a result of the additional organic carbon content. At the upper limit of f_{oc} and dry bulk density, about 0.5 lbs of organic carbon would be contained in every cubic foot of rock.

3.3 Bedrock Fracturing

Recognizing that groundwater flow in well-cemented, fine-grained sedimentary rock is largely influenced by the presence of fractures, considerable effort was expended in characterizing the nature of in-situ fractures. Considering that site-specific testing has indicated that the permeability of the unfractured rock is typically five orders of magnitude lower than the bulk fractured rock, even thin bedding of intact, unfractured rock can serve as an aquitard that would largely limit the vertical flow of water. These intervals of unfractured rock were encountered at all depths in site borings and are referred to as "aquitard intervals" later in the text.

Characterization of fractures included hydrogeophysical logging of the existing and newly drilled bedrock boreholes and detailed logging of in-situ fractures observed in core. The fracture log data were compiled in graphical form on logs, histograms, and a variety of vertical profiles. The observed fractures were classified according to dip orientation, ranging from flat bedding-parallel to vertical or near vertical fractures. The hydrogeophysical logging included acoustic televiewer (ATV) and optical televiewer (OTV) geophysics which allowed for further assessment of the orientation, strike, and dip of linear features, including fractures and bedding planes. The ATV/OTV data were plotted in profile views and used to create rose diagrams and pole plots to assess for patterns of strike and dip as included in Appendices D and E.

The in situ fracturing inferred from logging of rock core is depicted on the geologic and hydrologic profiles included as Figures 6 and 7. The symbols differentiate among relative fracture orientations, including horizontal, dipping, and vertical. Appendix D presents the findings of hydrogeophysical logging of about 530 feet of the four open bedrock boreholes associated with monitoring and water supply wells that pre-dated SHA's work. Appendices E.1 and E.2 present the data, observations, and inference recorded in logging of rock core and hydrogeophysical logging of about 840 feet of new deep bedrock boreholes drilled at four additional locations.

Appendix B.6 presents estimates of fracture porosity (ϕ_f) and fracture aperture (e) derived from the detailed borehole logging and in-situ hydraulic properties testing in all bedrock boreholes completed as either monitoring wells or multilevel devices. Finally, the data recorded for fracture and hydraulic properties testing were assessed statistically to further examine spatial patterns of fracturing and hydraulic conductivity, and to establish statistical distributions of hydraulic properties that were then used to assess groundwater flux and advective seepage velocities. As the key hydraulic properties range over several orders of magnitude, cumulative frequency distributions and other statistical techniques were used to inform these analyses. The text to follow summarizes the data, observations, and inference derived from this body of work.

3.3.1 Fracture Density

A systematic review of in-situ fractures along the lengths of boreholes does not indicate a readily apparent correlation between lithology and fracture density. Based on logging of the existing bedrock boreholes, we had initially perceived the possibility of zones of marginally increased fracture density at certain elevation intervals across the site, but geostatistical analysis of the data as presented in Appendix H.1 does not support a correlation between increased fracture density and elevation. Rather, the analysis supports a stronger negative correlation of increased fracture density with depth below ground surface.

In other words, we have found no statistical correlation to suggest the presence of more highly fractured rock at consistent elevation horizons across the site. Instead, we have found that the density of fractures decreases with depth, supported by a statistical correlation indicating that the relationship between depth and fracture density is systematic, and that fracturing is not a random variable driven by chance alone. This finding is logical in that bedding-parallel fractures should decrease with depth and with increased normal stress associated with the weight of overlying rock and soil. The statistical analysis also indicated no material spatial difference in the density of fractures between the deep boreholes such that the density of fractures encountered in deep borings at different locations is statistically similar.

Detailed logging of rock core and borehole geophysics indicates that the majority of fractures are observed in the upper 40 feet of rock where mean fracture spacing has been shown to be on the order of a few tenths of feet, in contrast to mean fracture spacing on the order of several feet at greater depth. Fracture density per meter of borehole was used in quantitative analysis of hydrogeologic parameters as discussed further below.

The first 15 to 20 ft of rock above the first aquitard interval generally exhibits more than 10 fractures per meter and is referred to throughout this report as the *uppermost highly fractured rock*. Monitoring wells straddling the water table screened within this zone and above the first aquitard interval are referred to as *water table monitoring wells*. The first aquitard interval[9] forms the base of the uppermost highly fractured rock. The elevation of the first aquitard is depicted as the green line on the profiles included as Figures 6 and 7. As depicted in Exhibit 3.4, the distribution of fracture density above and below the first aquitard is markedly different.

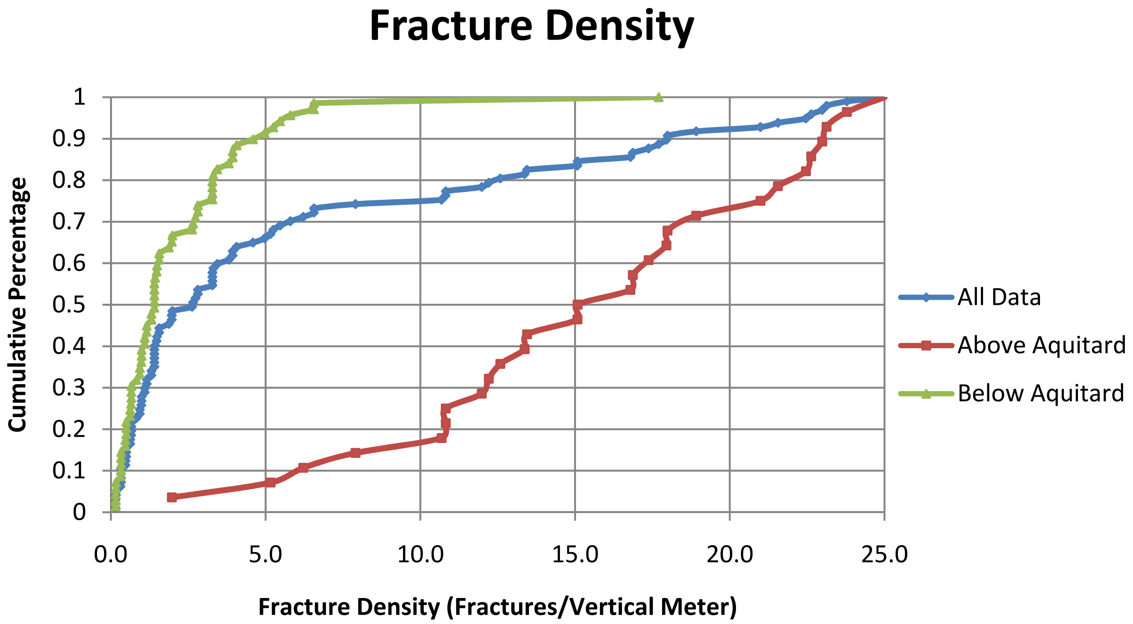

Exhibit 3.4 - Cumulative Frequency of Fracture Density Per Meter of Borehole for Bedrock Intervals Screened by Monitoring Intervals above the Aquitard, and Below the Aquitard.

The depth interval from approximately 15 to 40 ft bgs exhibits greater than 1 but less than 10 fractures per meter. Monitoring wells screening this interval below the first aquitard are referred to as intermediate depth wells. This density contrasts with that observed for the water table wells that almost always screen rock with more than 10 fractures per meter. Finally, the screened

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[9] *The first aquitard interval was inferred from multiple lines of evidence including a marked decrease in fracture density, no moderate to steeply dipping or vertical fractures, and a marked reduction in VOC concentrations in rock core samples, as discussed further in Section 5.1.3.*

intervals for multilevel systems generally at greater depth exhibit between 0.1 and 10 fractures per meter, typically about 1 fracture per meter. Deeper intervals characterized by borehole packer testing exhibit lower fracture densities approaching 0.1 fractures per meter.

3.3.2 Inferred Fracture Aperture and Porosity

Exhibit 3.5 depicts hydraulic conductivity estimates and estimated mean fracture aperture (e) based on a generally accepted relationship among fracture density, hydraulic conductivity, and fracture aperture. The estimated aperture for the interval screened represents the estimated mean width of fractures within the tested interval expressed in this case in micrometers, or microns (µm). Water table wells are shown as black squares, while intermediate depth wells are depicted by tan circular symbols.

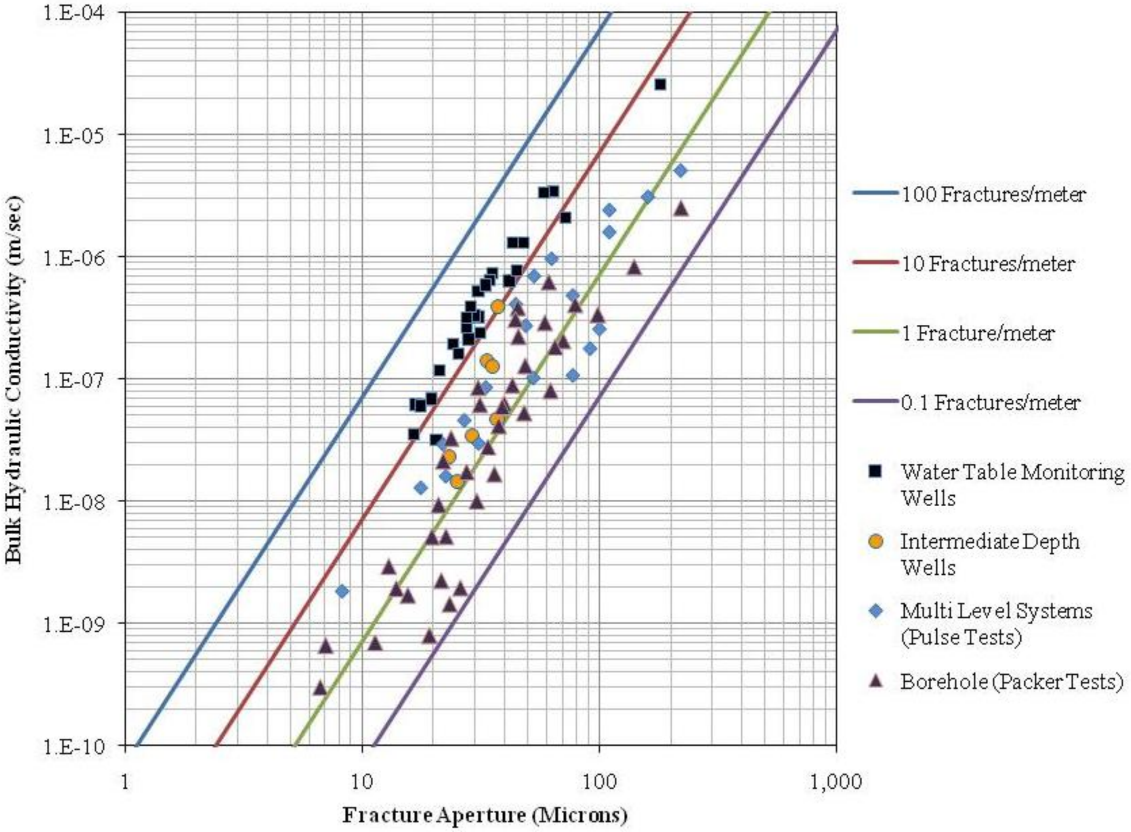

Exhibit 3.5 - Relationship among Hydraulic Conductivity, Fracture Density, and Fracture Aperture (e) - estimated for screened Intervals of monitoring wells and multilevel devices.

The estimated e values range over less than two orders of magnitude from 6.7 to 220 µm, with geometric means in the relative narrow range of 30 to 50 µm. For comparison, thin human hair is typically understood to be about 50 µm in diameter, while silt and clay particles are generally accepted to be about 75 µm or less in diameter. The particle size of fine sand, believed to be the parent sediment for the most granular segments of lithologies observed at the site, range from 75 to 450 µm. The upper bound of the e estimates corresponds to upper bound values published in the literature for sandstone and siltstone[10,11]; however, the lower end estimates are nearly an order of magnitude below the literature values. The lower bound e reflects findings of packer testing of 20 ft of borehole consisting of relatively sparsely fractured rock (<1 fracture per meter).

Exhibit 3.6 presents estimates of fracture porosity (ϕ_f) – the fraction of bulk rock volume occupied by fracture space – that were calculated for different screened intervals.

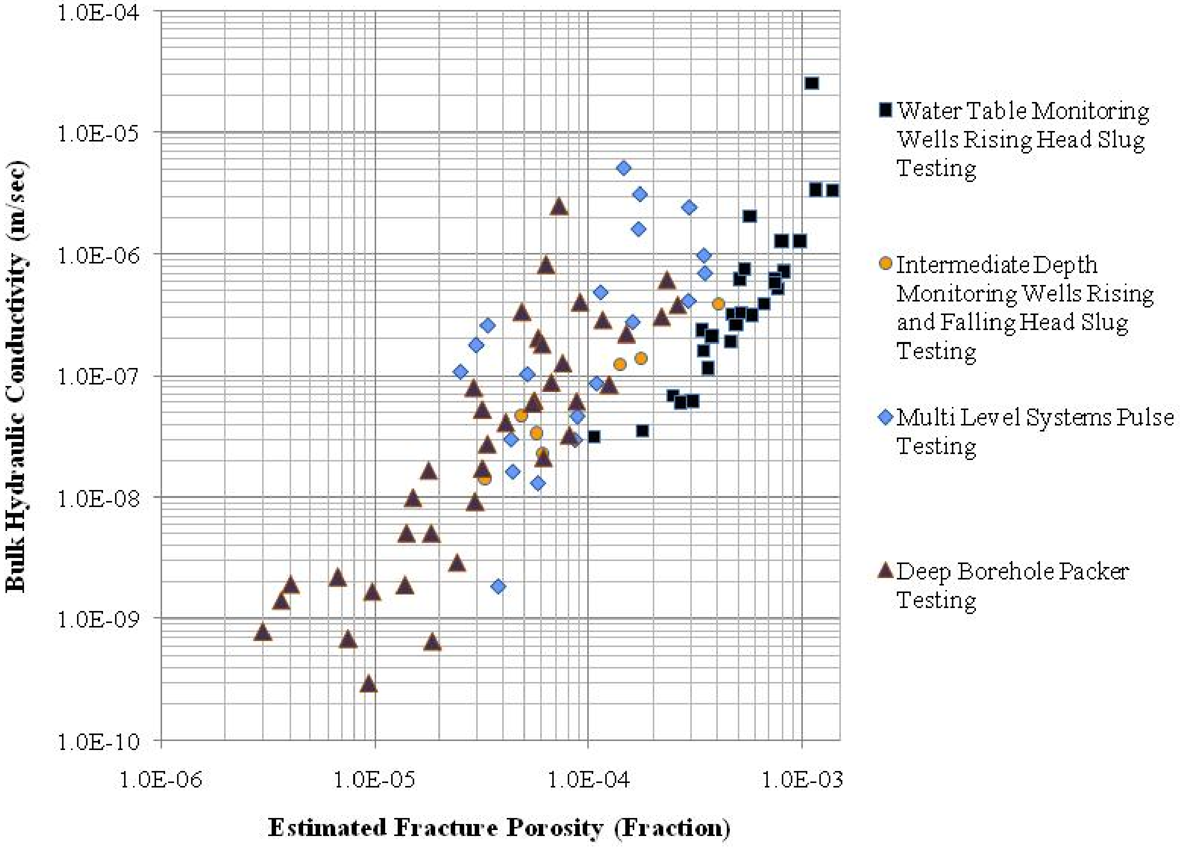

Exhibit 3.6 - Relationship between Hydraulic Conductivity and Fracture Porosity.

As shown in Exhibit 3.6, the estimated ϕ_f ranged from $3x10^{-6}$ to $2x10^{-3}$ decreasing with depth. A geometric mean of $5x10^{-4}$ was estimated for the saturated intervals of the water table wells screening the uppermost highly fractured rock, whereas the geometric mean for intermediate depth intervals in the upper 40 ft of highly fractured rock below the first aquitard is half an order of magnitude lower at approximately $9x10^{-5}$. The multilevel ports at greater depth exhibit a similar geometric mean ϕ_f of $9.5x10^{-5}$, supporting that the multilevel ports screen intervals with

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[10] David S. Lipson, Bernard H. Keuper, and Michael J. Gefell, 2005. Matrix Diffusion-Derived Plume Attenuation in Fractured Bedrock. *Groundwater, vol. 43, 30-39.*

[11] Ira S. Merin, 1992. Conceptual Model of Ground Water Flow in Fractured Siltstone Based on Analysis of Rockcores, Borehole, and Thin Sections. *Ground Water Monitoring Review, vol. 12, 118-125.*

increased fracture density. The low end of ϕ_f below $2.5x10^{-5}$, reflect estimates from packer testing of relatively unfractured borehole intervals.

Comparison of the field test estimates of ϕ_f and laboratory estimates of matrix porosity (ϕ_m) suggest ratios of ϕ_m to ϕ_f ranging from about 20:1 to 20,000:1. The ratio estimates of ϕ_m/ϕ_f are typically on the order of 20:1 to 300:1 for the uppermost highly fractured rock, and between 300:1 and 1,500:1 for fractured intervals screened by the multilevel systems at greater depth.

3.3.3 Fracture Orientation

The aggregate data recorded in assessment of bedrock fractures indicates that most fractures (greater than 80%) are horizontal, or near-horizontal, bedding-parallel joints, while less than 20% of the observed fractures are moderately and steeply dipping to near vertical. As discussed above, the upper 40 ft of highly fractured rock is characterized by a predominance of bedding-parallel jointing, with lower proportions of moderate to steeply dipping and near vertical fractures that cross bedding planes. The relative proportion of steeply dipping to vertical fractures appeared to increase with depth, with a decreasing frequency of near-horizontal fractures.

Based on observation of bedrock outcrops, and data from ATV and OTV logging of boreholes, a relatively small proportion (about 20% to 25%) of the moderately to steeply dipping fractures are oriented roughly within 20^o of north to south, or compass azimuths between 340^o and 20^o. These more prevalent orientations comport with regional mapping by Isachsen et al.[12]. However, it should be noted that the “more prevalent” north to south near vertical fractures represent about 25% of the non-horizontal fractures and thus 5% or less of the total fractures. The fracture orientation evidence supports that the systematic, near-horizontal planar jointing is more areal extensive, and influences groundwater flow and transport to a greater degree than vertical fractures.

Given that all of the boreholes are near vertical, the density of steep or vertical fracturing inferred from the data may underestimate the actual proportion of vertical fracturing. However, the borehole logging observations are consistent with observations of bedrock outcrops that indicated predominantly near-horizontal, bedding-parallel cleavage joints, rather than more steeply dipping, cross-bedding fractures.

4.0 GROUNDWATER HYDROLOGY

This section provides a summary of data and inference regarding groundwater hydrology as relevant to the RI goals. First, we discuss estimates of the potential magnitude of precipitation recharge that is expected to drive groundwater flow. Second, we discuss the findings of nearly three years of water level monitoring and estimates of hydraulic properties related to

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[12] Isachsen, Y.W., Landing, E., Lauber, J.M., Rickard, L.V., and Roger, WB. Editors, 2000, Geology of New York, A Simplified Account,. *New York State Museum educational Leaflet 28, Second Edition.*

groundwater flow. Finally, we discuss estimates of groundwater flow, advective seepage velocities, and transport times.

4.1 Water Budget and Groundwater Recharge

As the BPA is located on top of the hill, groundwater conditions are largely a function of precipitation recharge. Site-specific estimates of precipitation recharge derived using a widely accepted water budget technique indicates that of the average annual precipitation of 39 inches, about 7 inches may directly run off, and another 24 inches may be evapotranspired or remain stored in the soil column each year. The remainder constitutes an estimated groundwater recharge equivalent to about 8 inches per year, or about 0.41 gallons per minute per acre (gpm/acre). Assuming about an 8-acre acre encompassing the BPA and nearest monitoring wells (within the inferred 1,365 ft AMSL groundwater elevation contour depicted on Figure 5), the net recharge would be equivalent to about 3 gpm. Details regarding the water budget estimates are outlined in Appendix H.2.

4.2 Groundwater Levels and Flow Directions

The depth to the water table over the period of monitoring average about 10 to 11 ft bgs for monitoring wells screened across the water table in the uppermost highly fractured rock. The average depth to the first aquitard interval at these same locations is about 15.8 ft bgs, which results in an average saturated thickness above the first aquitard interval of about 5 ft. The average saturated thickness above the first aquitard ranges from about 3 feet or less near the BPA and about 7 feet further downgradient in areas on the Country Club property.

Water level elevations for monitoring wells screening the water table in the uppermost highly fractured rock ranged from about 1,350 to 1,235 feet AMSL. Potentiometric levels as low as 1,305 ft. AMSL were recorded for multilevel system ports at depth. The water table fluctuates seasonally, with the highs observed in November through March, and the lows observed July through September. The magnitude of water table fluctuations averages about 7 feet with the largest fluctuations observed in monitoring wells BP-12A (15’), BP-8A (12’) and BP-7A (10’). Water levels for wells within the BPA, including BP-2A, BP-4A, and BP-5A exhibited seasonal fluctuations of about 5’ over the history of monitoring.

As shown on Figure 5, groundwater at or near the water table in the uppermost highly fractured rock flows radially outward from the hill east of monitoring well BP-13. Accounting for seasonal variability, the estimated horizontal hydraulic gradients range from about 0.02 to 0.15 feet per foot (ft/ft). Hydraulic gradients increase beneath the steep slope from the edge of the BPA south into Country Club property.

Potentiometric levels recorded for monitoring wells and multilevel ports at depths between about 20 to 80 ft bgs in more highly fractured rock but below the first aquitard suggest a similar radial flow pattern and similar hydraulic gradients[13]. Hydraulic head conditions and groundwater flow directions vary considerably with depth. A plot of potentiometric head profiles prepared based

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[13] *A potentiometric contour plan for this depth in rock is included as Figure H.3.2 in Appendix H.3.*

on water level data from multilevel systems, included as Exhibit 4.1 below, shows how both vertical and horizontal hydraulic gradients vary with elevation.

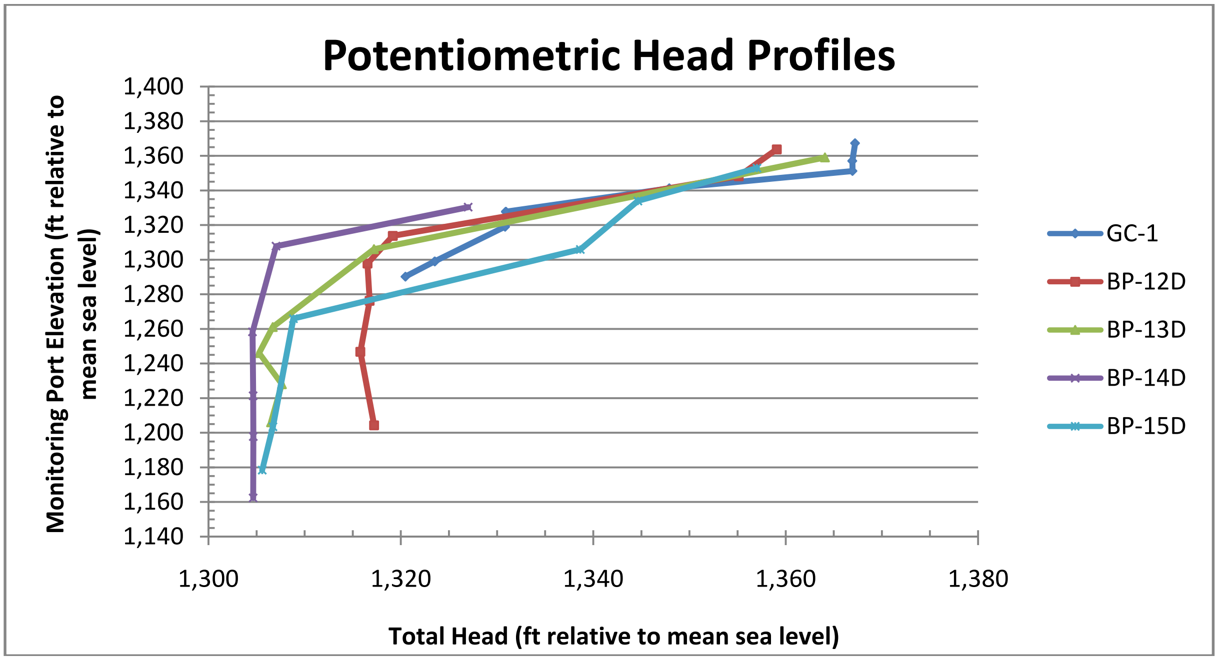

Exhibit 4.1 - Potentiometric Head Profiles, September 2008 Water Levels.

Consistent with the equipotentials depicted on Figures 6 and 7, the steepest vertical downward hydraulic gradients have been observed across the upper 70 to 110 feet of subsurface, down to about 1,260 feet AMSL. The vertical downward gradients as depicted on the Figures range from about 0.5 ft/ft at BP-15D to about 1.4 ft/ft at BP-14D.

Below about 1,330 to 1,260 ft AMSL, the vertical gradients drop by over an order of magnitude to about 0.04 ft/ft and approach the magnitude of horizontal hydraulic gradients, which range from about 0.004 to 0.03 ft/ft. Vertical upward gradients have been observed in the lower multilevel ports in BP-12D, BP-13D, and BP-14D.

Based on the aggregate site characterization data, the majority of water recharged at or within the BPA flows laterally and radially away in the top 40 feet or so of highly fractured rock along the predominantly horizontal bedding-parallel fractures. In places, this flow breaks out as seeps and springs along the hill slope. Seeps and springs have been observed at ground surface elevations between 1,300 and 1,310 feet AMSL, and higher elevations along the side-slopes of the hill northwest, south, and east of the BPA.

As shown on Figures 6 and 7, at depths below where the vertical downward hydraulic gradients decrease dramatically, groundwater flow is more horizontal to the east in the direction of Gray Creek, the lowest nearby topographic feature that is a groundwater discharge area. The decline in vertical gradients reflects a decreasing downward component of flow, as much of the water has been transmitted laterally and discharged to the seeps and springs. The equipotentials shown on Figure 6 in particular the 1,320 and 1,310 AMSL equipotentials indicate that groundwater flow converges on more highly fractured rock between about 1,260 and 1,310 ft AMSL and flows easterly toward Gray Creek. This elevation interval is monitored by thirteen multilevel ports in BP-13D through BP-15D. BP-13D and BP-15D are located directly beneath and downgradient of the BPA primary source zone in bedrock.

4.3 On-Site Open Borehole Water Supply Well GC-A

As shown on Figure 6, the 180-ft deep water supply well (GC-A) serving the B665 washroom is an open bedrock borehole cased down to about 20 ft bgs. Under non-pumping conditions, water is expected to enter the borehole at the top of the rock column and discharge out the bottom of the borehole into the formation. During pumping, water is withdrawn from the formation into the borehole. Hydrogeophysical logging of this borehole suggests the primary water bearing fracture zone is located near the bottom of the borehole about 159 to 169 ft bgs, or between 1,225 and 1,215 ft AMSL. A secondary water bearing zone may exist at about 110 ft bgs, or about 1,275 ft AMSL. The occupants of B665 report that the well runs dry if the toilet tank runs overnight.

Although the daily withdrawal from this well is believed to be small, on the order of about 40 to 60 gpd [14], to serve washroom needs, this withdrawal is not inconsequential given the overall low permeability of the bedrock and the small magnitude of groundwater recharge. Water level fluctuations that appear related to pumping of GC-A have been observed in continuous monitoring of multilevel monitoring ports that screen fractured zones generally below 1,300 ft AMSL at the following locations:

- GC-1 (Ports 7 and 8) located about 460 feet southwest;
- BP-12D (Ports 5 through 7) located about 170 feet southwest; and
- BP-15D (Ports 4 and 5) located about 450 feet to the southeast.

We believe that groundwater withdrawals from fracture zones in GC-A at or below 1,275 ft AMSL partially explain the pattern of converging groundwater flow depicted on Figure 6. Pumping-related water level fluctuations are not readily apparent in multilevel monitoring at BP-13D, which is within or just downgradient of the primary VOC source zone in rock, or in BP-14D, which is downgradient of the entire area to the east. Analysis of the water level fluctuation data indicates relatively low storage coefficient (S) on the order of 10^{-5} expressed as a unitless ratio representing the volume of water released by a column of porous media of unit volume per unit decline in head.

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[14] *Monitoring of water usage suggests that approximately 30 to 100 gallons per day, but typically between 40 and 60 gallons per day may be withdrawn from this well during a typical working day. This estimated daily withdrawal is equivalent to a few tenths of a gallon per minute (gpm) or less on an 8-hour basis, or a few hundredths of a gpm or less on a 24-hour basis.*

4.4 Hydraulic Conductivity

Field- and laboratory-derived estimates of the hydraulic properties of overburden and bedrock are discussed in Appendices B.6 and F.5, respectively. The field estimates were derived from slug testing of overburden and bedrock monitoring wells, pulse testing of multilevel system monitoring intervals, and packer testing of boreholes that typically included intervals of relatively unfractured rock. The laboratory testing included permeability testing of nine unfractured rock samples collected from rock borings in the BPA. Exhibits 4.2 and 4.3 provide graphic summaries of hydraulic conductivity (K) values derived from the field and laboratory testing in units of centimeters per second (cm/sec).

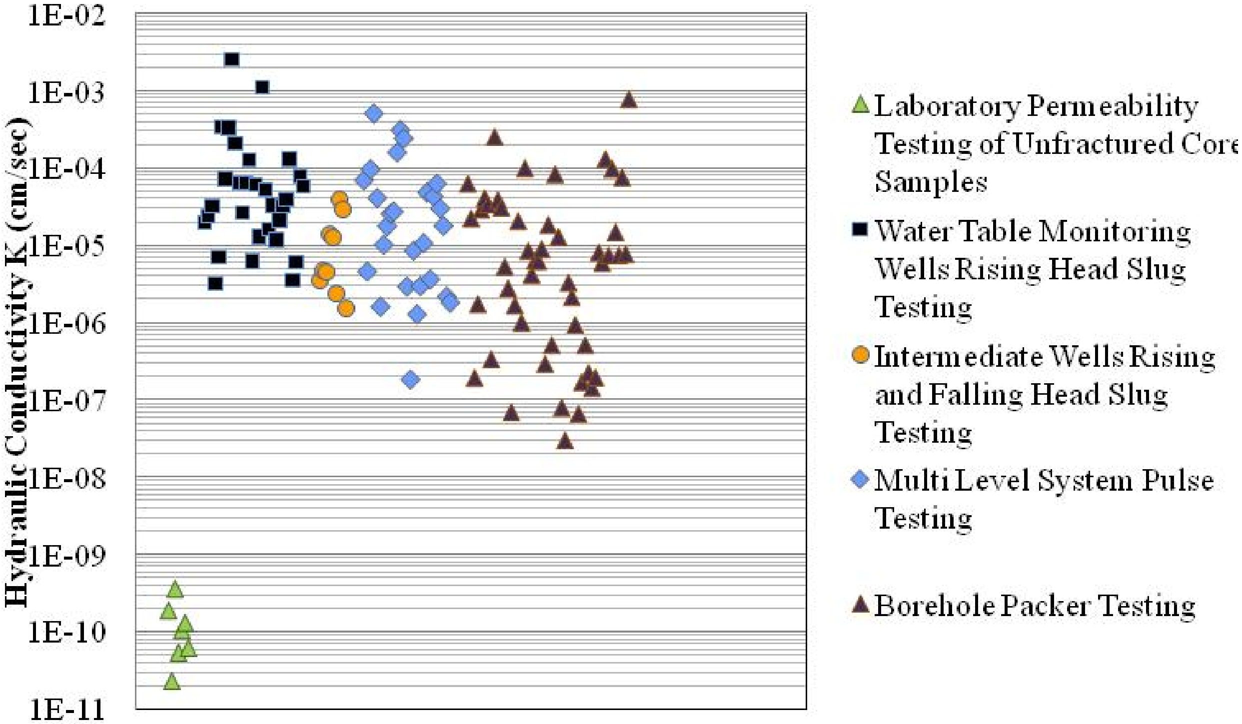

Exhibit 4.2 Scatter Plot of Field and Laboratory Estimates of Hydraulic Conductivity.

As shown in Exhibit 4.2, water table monitoring wells screening the highly fractured rock above the first aquitard exhibit the highest K values, and intermediate depth wells and multilevel monitoring ports exhibit intermediate values of K. The lowest K values were derived from packer testing of less fractured intervals of borehole. Given the predominance of horizontal fracturing the field estimates are believed to more reflect estimates of horizontal hydraulic conductivity (K_h).

The median K values determined for laboratory testing of unfractured rock core samples are about 5 orders of magnitude below the median observed for field intervals of fractured rock. The data also indicate vertical hydraulic conductivity (K_v) three to eight orders of magnitude below the K data recorded in field testing of fractured rock. Given the low permeability groundwater flow through the primary pore space of the unfractured rock is negligible and contaminant transport in the unfractured rock matrix is diffusion controlled.

The statistical analysis discussed in Appendix H.1 supports marked differences in hydraulic conductivity between the uppermost highly fractured rock and the rock found beneath the first inferred aquitard discussed in Section 3 of this report. Further analysis of the K datasets support that the multilevel system monitoring ports were successful in screening zones of higher K compared to the bulk testing of borehole intervals. The K data for multilevel monitoring intervals exhibiting greater fracture density were found to be statistically different at a 95% confidence level and exhibit mean K about one-half order of magnitude higher than data derived from packer testing of 20-foot long borehole intervals.

As shown on Exhibit 4.3, the cumulative density distributions of K estimates grouped by observations above and below the first aquitard interval, and all together, fit lognormal distributions.

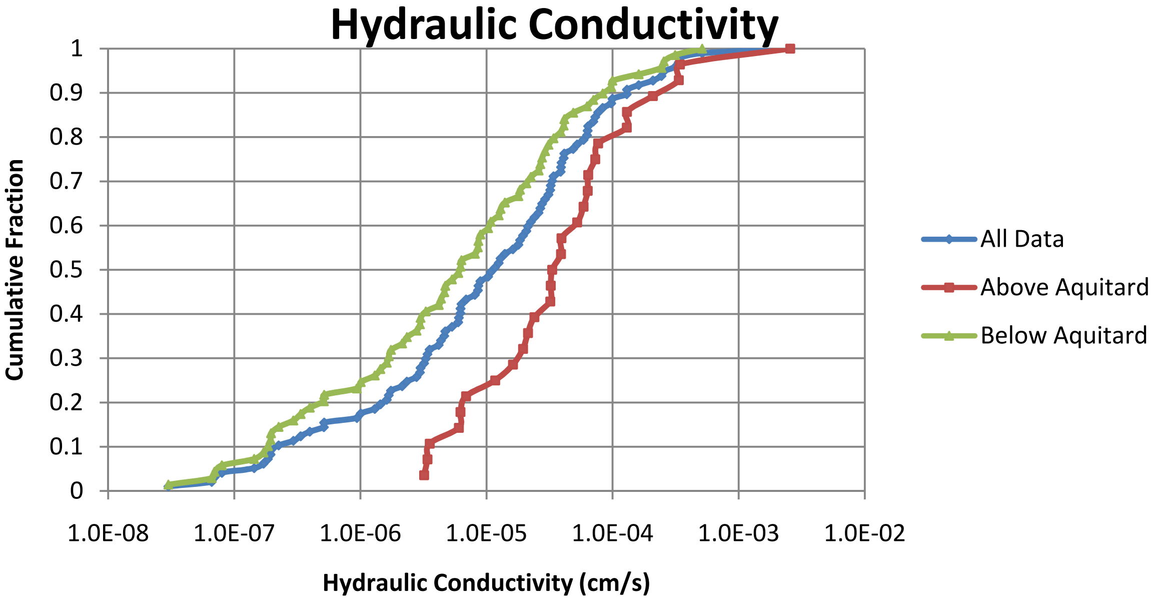

Exhibit 4.3 - Cumulative Distributions of Field Estimates of Hydraulic Conductivity.

As shown by the red line, for data recorded for 28 test intervals above the first aquitard in highly fractured rock about 90% of values fall within about two orders of magnitude, with about 60% between 1x10^{-5} and 1x10^{-4} cm/sec and a geometric mean of 4x10^{-5} cm/sec. In contrast, about 90% of the 69 observations below the first aquitard span three orders of magnitude between about 1x10^{-7} and 1x10^{-4} cm/sec, with a geometric mean over one order of magnitude lower at 6x10^{-6} cm/sec.

The data outlined above compare with the findings of historical short duration borehole pumping tests conducted by Dames & Moore in 1997 which yielded estimates of bulk K of 1x10^{-7}, 4x10^{-6}, and 2x10^{-4} cm/second for boreholes GC-1, GC-2, and water supply well GC-A, respectively. These historical values are within the range observed in SHA's field testing and roughly correspond to values at the lower 5%, lower 25th %, and 90th % of observations for intervals below the first aquitard.

Based on our water balance and quantitative analysis of groundwater flow, we believe that the vertical hydraulic conductivity (K_v) of the upper 70 to 80 feet of bedrock is likely less than $1x10^{-6}$ cm/sec ($1x10^{-3}$ feet per day) or at or below about 75% of the field K estimates.

The few field estimates of K for wells screened in the glacial till support the USDA mapping with values below $1x10^{-6}$ cm/sec. As such, the K of the glacial till is expected to be below the lowest 15% of values recorded for all bedrock intervals and much lower than the highly fractured rock above the first aquitard interval. Given the limited and temporally variable nature of the glacial till over most of the investigative area and the limited permeability, groundwater flow through the surficial soils is believed to be negligible.

4.5 Estimated Groundwater Flow and Seepage Velocities

Groundwater flow, seepage velocities, and advective travel times were estimated for certain flow paths using hydraulic properties derived from field observations and laboratory testing of bedrock samples. As detailed in Appendix H.3, reasonable statistical metrics of K and fracture porosity $\phi_{f,}$ along with the observed hydraulic gradients, were used to calculate the advective seepage velocity using a simplified form of Darcy's Law. The seepage velocity calculated herein represents the average linear rate of advective transport for a particle of water moving through the interconnected and saturated fractures in the bedrock.

Seepage velocities (V) were calculated for five flow lines through the uppermost highly fracture rock originating from the BPA and extending to the limit of the existing monitoring network (see Figure H.3.1). The calculations performed assuming K and ϕ_f values within the middle-half of their statistical distributions indicate V ranging from about 1 to nearly 100 feet per day (ft/day), yielding advective transport times on the order of:

- several weeks for transport from the primary source zone in rock along the shortest distance (250 feet) to BP-12A;
- about a month for transport from the BPA about 860 feet south and east to monitoring well BP-27A along Robinson Hill Road; and
- about 4 to 6 months for the longest distance of about 1,500 feet southwest past BP-20 to the man-made pond.

As noted in the discussion to follow, despite the rapid travel times the overall magnitude of groundwater flow and VOC mass transport potential is quite small. In terms of bulk volumetric flow in the saturated interval above the first inferred aquitard, we estimate that on the order of 0.5 gpm may flow radially outward from the BPA across the 1,365 ft. groundwater contour shown on Figure 5, and a little less than half of that, approximately 0.2 gpm, may flow southwesterly. Based on this estimated flow and the water quality data, we estimate the TCE mass flux in the southerly direction to be on the order of a few tenths of a pound per year (lb/yr), with the majority of mass transport occurring across a 200 foot width of flow centered on monitoring well BP-9A.

The upper bound of vertical groundwater flow across the first inferred bedrock aquitard over an approximately eight acre area within the 1,365 ft groundwater contour (Figure 5) is estimated to be on the order of a few gpm. As VOCs are found at intermediate depth over approximately a one acre area the magnitude of downward mass flux across the first aquitard, based on current TCE concentrations in groundwater, is estimated at a few thousandths of a pound per year.

It should be noted that transport of the principal contaminant VOCs is influenced by attenuation mechanisms, including but not limited to: diffusion, sorption, dilution, chemical transformation, and biochemical degradation. In particular, we believe that VOC concentrations in groundwater appear to be limited by matrix diffusion and sorption, and by biological degradation.

4.6 Effects of Matrix Diffusion and Sorption on Subsurface Transport

As alluded to in Section 4.4, contaminant transport into and out of the unfractured rock matrix is predominantly controlled by molecular diffusion through the primary pore space of the rock, a process referred to as matrix diffusion. Matrix diffusion, described by a form of Flick's law, is proportional to the concentration gradient and an effective diffusion coefficient (D_e). As shown in the diagram from Parker (1994)[15] below, matrix diffusion can account for the "disappearance" of separate-phase solvent liquid (referred to in the exhibits below as dense non-aqueous phase liquid, or DNAPL) from the fracture pore space by dissolution and diffusion into the matrix.

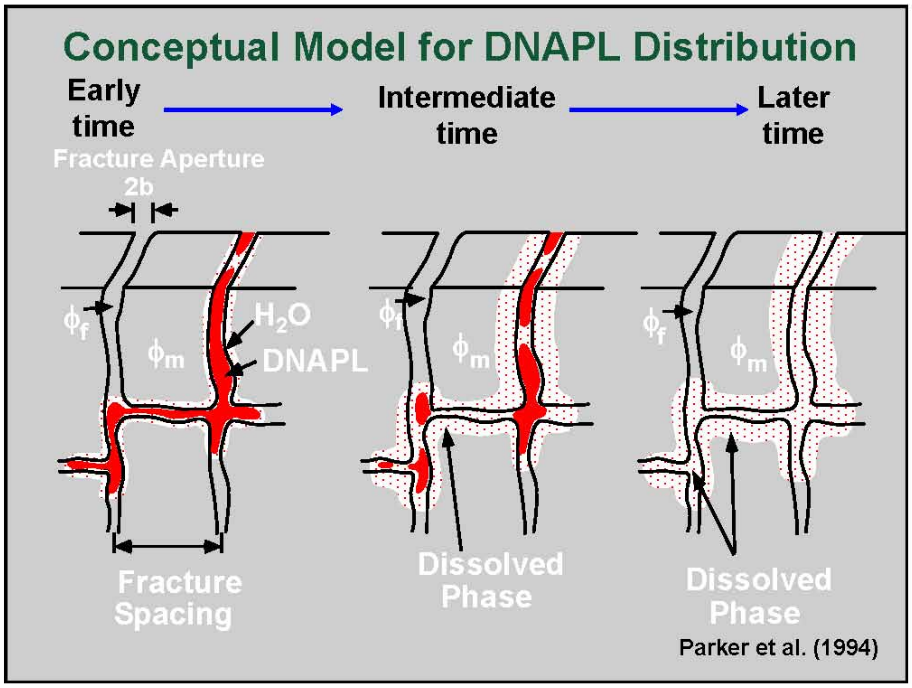

Exhibit 4.4 – DNAPL Disappearance by Matrix Diffusion.

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[15] Beth, L. Parker, R.W. Gillham, and J. A. Cherry, October 1994, Diffusive Disappearance of Immiscible-Phase Organic Liquids in Fractured Geologic Media. *Groundwater, September-October 1994 Volume 32, Number 5.*

As shown below in Exhibit 4.5, matrix diffusion also retards the transport of contaminant mass downgradient in fractures by loss of mass, particularly when the matrix contains organic carbon and the solute is a sorptive organic compound.

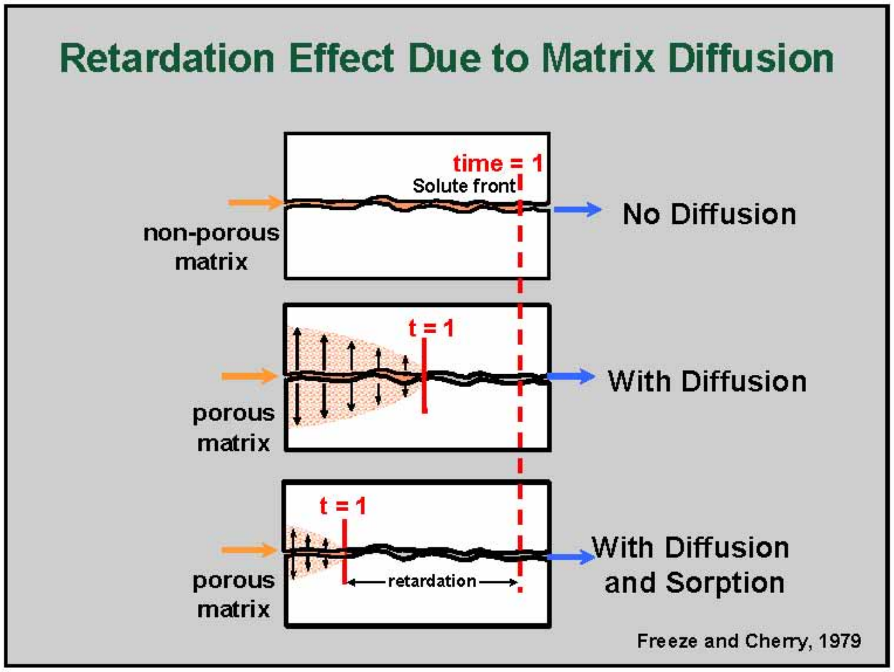

Exhibit 4.5 – Matrix Diffusion and Sorption Influence on Fracture Transport.

Laboratory testing of unfractured rock core for D_e indicated values ranging over about one order of magnitude, from $1x10^{-7}$ cm^2/sec to $2.5x10^{-6}$ cm^2/sec, with a geometric mean of $5x10^{-7}$ cm^2/sec. The testing indicated matrix tortuosity factors (τ) ranging from 0.01 to 0.15, averaging about 0.05, defined as the ratio of the actual diffusive length through matrix pore space to macroscopic distance. The values are in the same range of published values derived from laboratory testing of similar rock (shale, mudstone, sandstone) as reported by Parker (1994).

Diffusion modeling conducted by representatives of the University of Waterloo (described in Appendix H.4), based on the laboratory estimates of D_e indicates that complete transfer of separate-phase VOCs by diffusion from the fracture porosity to the rock matrix porosity is possible in a few years to a few decades. It should be noted that these estimates were derived based on core-scale D_e values that may underestimate D_e in the field[16]. As such, these calculations and the estimates of matrix diffusion influences on downgradient transport are likely conservative. As such, the time for NAPL disappearance and extent of down gradient transport as outlined above and below are likely to be smaller.

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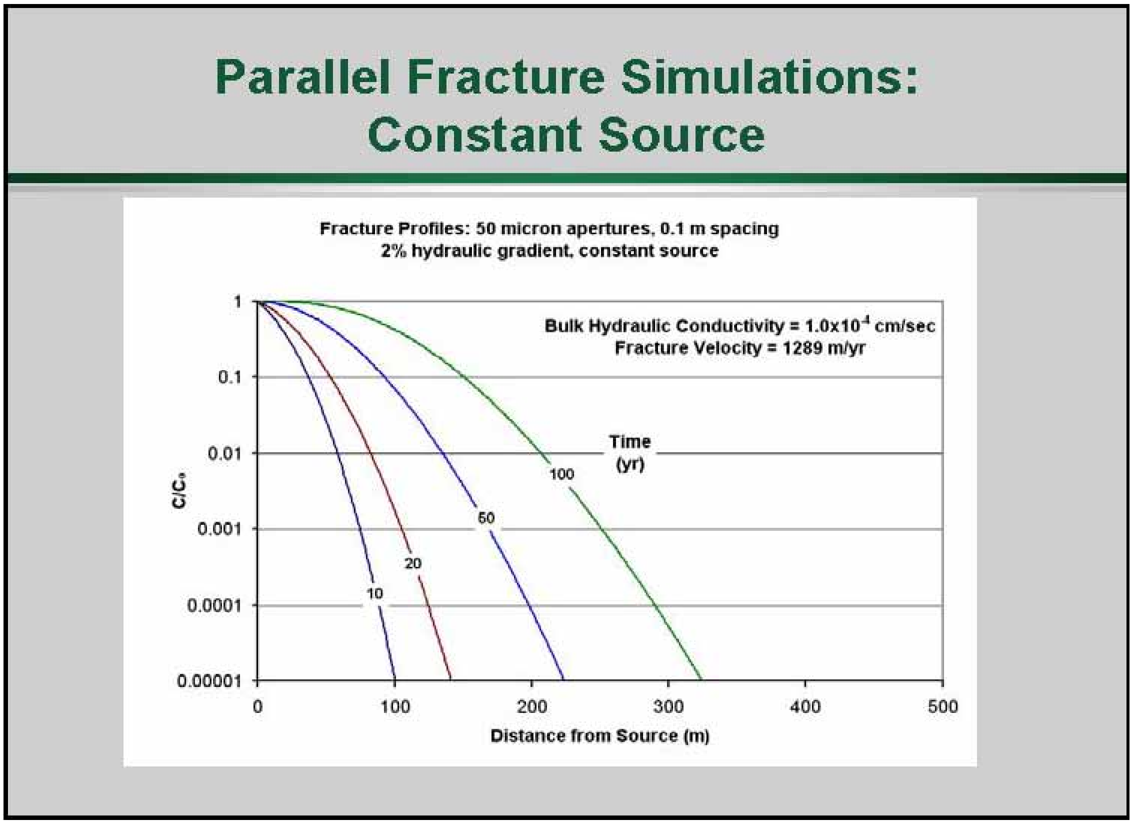
[16] Zhou, Quanlin et al. 2007, Field-Scale effective matrix diffusion coefficient for fractured rock: Results from literature survey. *Journal of Contaminant Hydrology, 93 (2007), 161-187.*

Matrix diffusion also limits downgradient VOC transport and partially explains the limited water quality degradation downgradient of the primary source zone in rock. As shown in Exhibit 4.6 below, VOC transport distance downgradient is a function of the relative concentration and time, where relative concentration is defined as the ratio of the downgradient concentration C to the source zone concentration C_o, or (C/C_o). Higher concentrations of solute tend to transport shorter distances because of the greater concentration gradient between the fracture and matrix, while lower concentrations may be transported longer distances. For a given concentration ratio and time, the ratio of the estimated travel distance relative to the distance predicted by advection alone could be considered a retardation ratio.



Parallel Fracture Simulations:
Constant Source

Exhibit 4.6 – Representative Parallel Fracture Simulations of Matrix Diffusion and Sorption.

For example, at a concentration ratio of 0.001 and a 50 year period, Exhibit 4.6 indicates a downgradient distance of about 170 meters or about 500 feet. In contrast, at the estimated groundwater seepage velocity in fractures, a solute transport distance of about 60,000 meters would be expected over 50 years. The difference in transport distance over the same period is equivalent to a retardation ratio of about $3x10^{-3}$. At the estimated seepage velocity, the observed extent of VOCs downgradient from the BPA suggests a retardation ratio of about $4x10^{-3}$.

Given the relatively short advective transport times and the relatively low VOC concentrations compared to source zone conditions, the extent of VOCs observed as discussed in Section 5.0 are believed to reflect a steady-state condition.

5.0 CONTAMINATION CHARACTERIZATION

This section presents the site characterization data consisting of environmental media testing results for VOCs and other hazardous substances. The media tested for hazardous substances included groundwater, surface water, soil, rock, and subsurface gas. Hazardous substances potentially related to the Burn Pit activities are identified in Table 2 of this report based on historical data and the data derived from the RI. They include VOCs detected in historical sampling of GC-1 and GC-2, and other compounds detected during the RI that have exceeded applicable standards or guidance values for soil or water quality. The principal site contaminants have been identified as halogenated VOCs, largely chlorinated ethenes, due to their prevalence, mobility, and toxicity. In the text and figures the principal site contaminants referred to as "Key VOCs including the suite of chlorinated ethenes 1,1,1-trichloroethane (TCA), carbon tetrachloride or perchloromethane (PCA), and chloroform. A few trace metals and polychlorinated biphenyls (PCBs) were also identified as site contaminants.

Table 2 lists 82 compounds or elements organized by analyte class and indicates which media the hazardous substances were detected in. A total of 22 individual VOCs have been identified as site contaminants believed to be related to former Burn Pit activities, including halogenated compounds, aromatics associated with petroleum, and ketones that are common industrial solvents. Eight inorganics, petroleum hydrocarbons, and two PCB isomers are also identified as site contaminants. The laboratory analytical data reports are included as Appendix K, and the data validation and usability assessments are included as Appendix J.

Data and observations regarding site contaminants are discussed in the following subsections. Section 5.1 discusses VOC data for water, soil, and rock. Sections 5.2 and 5.3 present data and observations for semi-volatile organic compound (SVOCs) and metals in groundwater samples. A discussion of groundwater geochemistry conditions relevant to the RI and remedial feasibility is included as Section 5.4. Section 5.5 provides an overview of data for soil sampling conducted in and around the BPA. Section 5.6 summarizes an assessment of data quality. These sections are supported by Appendices as referenced later in the text. Additional data for VOCs in subsurface gas, surface water, and sediments are presented in Appendix F.

5.1 Volatile Organic Compounds

5.1.1 Overview of VOC Speciation and Distribution

As inferred based on historical data, chlorinated VOCs, principally TCE and biochemical breakdown products, have been confirmed to be the primary constituents of interest. RI data has been consistent with the historical data in that chlorinated ethenes are the most prevalent class of VOCs detected in environmental media, including groundwater and rock matrix. Also consistent with historical data, the RI has identified the presence of ketones, aromatics often associated with petroleum, chlorinated methanes, and chlorinated ethanes. However, these other classes of VOCs have been detected less frequently, at lower concentrations relative to applicable standards, and generally in the presence of chlorinated ethenes at equal or higher concentrations. The chlorinated ethenes have also been identified over a larger geographic area.

Table 3 provides a statistical overview of data for the 22 VOCs that were identified as site contaminants. The table lists descriptive statistics, including the number of detections, minimum and maximum concentrations, and the median and arithmetic mean values. The arithmetic mean values were compared against the potentially applicable groundwater or drinking water quality standards, including New York State Part 703 Ambient Groundwater Quality Standards and Standards for Drinking Water Supplies (Subpart 5-1), and United States Environmental Protection Agency (USEPA) Primary or Secondary Drinking Water standards Maximum Contaminant Levels (MCLs). In the five broad VOC constituent groups, the compounds that were most frequently detected at the site, and/or were detected at concentrations exceeding applicable water quality standards include:

- Chlorinated ethenes: TCE and principal daughter products, including cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC). Other chlorinated ethenes detected that are not directly related to TCE include tetrachloroethene (PCE) and DCE isomers trans-1,2-,DCE (tDCE) and 1,1-dichloroethene (1,1-DCE);

- Chlorinated methanes: Carbon tetrachloride, also known as perchloromethane (PCM), and daughter products chloroform (CF), methylene chloride, and chloromethane (CM);

- Chlorinated ethanes: Trichloroethane (1,1,1-, and 1,1,2-TCA), 1,2-Dichloroethane;

- Ketones: Acetone, 2-butanone (MEK), and 4-methyl-2-pentanone; and

- Petroleum hydrocarbons: primarily aromatic compounds benzene, toluene, ethyl benzene, xylenes (isomers o-, m- and p-), and other alicyclic, and aliphatic compounds.

The distribution of these five groups of VOCs in groundwater generally follows a similar spatial pattern. The highest concentrations have been typically detected in samples from wells near or within the BPA that are screened in the primary source zone in rock. The concentrations in groundwater decrease two to three orders of magnitude toward the east, north and west within the BPA, and southwest of BP-9A. Figure 8 shows this overall pattern of arithmetic means for the four key VOCs: TCE, cDCE, VC, and PCM. The overall pattern is consistent with a similar figure posting maximum observed TCE concentrations as provided in Appendix G.4. As shown on Figure 9, the concentrations generally decline markedly below the uppermost aquitard found at about 15 ft bgs.

5.1.2 VOCs in Groundwater Samples

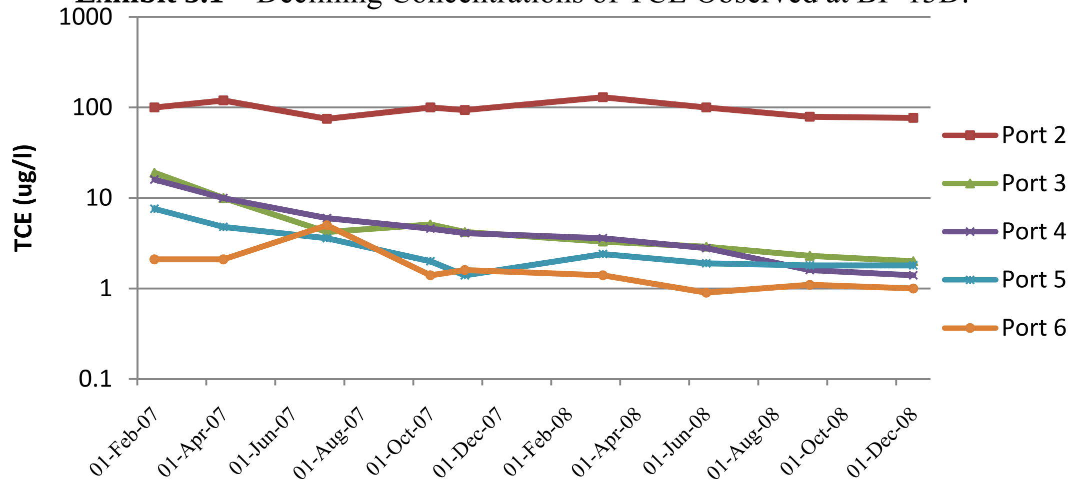
Of the 55 VOC compounds listed in Table 2 that have been routinely analyzed for, 21 have been detected at one or more monitoring locations at concentrations exceeding applicable water quality standards (Table 3). TCE exceeded 5 µg/L at the largest number of locations. As shown by the green contouring on Figure 8, TCE is present in groundwater at 5 µg/L or greater in a narrow band extending southwesterly from the BPA, which then bifurcates around topographically high wooded ground at the north end of the golf course. One fork extends southeast to Robinson Hill Road, and the other fork extends southwest to the man-made pond. At both locations, groundwater discharges to the ground surface in seeps or springs.

The presence of other VOCs at concentrations exceeding groundwater quality standards almost always occurs where TCE exceeds groundwater standards, with a few exceptions noted below. Groundwater standard exceedances for other VOCs were typically found in monitoring of locations within the BPA that screen the water table within the primary source rock (BP-1A, BP-2A, and BP-4A), and intermediate depth wells just below the first inferred aquitard (BP-3 and BP-6). VOC concentrations exceeding applicable standards for TCE, cDCE and 1,2-dichloroethane, acetone, MEK, and toluene were observed in samples from one or more multilevel system ports installed at depth within BP-13D and GC-1.

GC-1 had been an open borehole for 27 years before installation of a multilevel device. Geophysical logging of this borehole documented flow into the top of the borehole and flow out the bottom of the borehole allowing for VOCs in the uppermost fracture zone to be drawn to the well and carried downward and discharged to deeper fracture zones. Borehole cross connection of fractured zones creating unnatural flow and contaminant transport conditions has been documented by others[17] and shown to produce persistent changes to water quality[18]. Supporting this concept, over nearly two years since installation of the multilevel device, concentrations in samples from the deeper ports declined about an order of magnitude.

Similar conditions are believed to be reflected in water quality at depth in BP-13D. As shown in Exhibit 5.1, while TCE concentrations in Port 2, screened within or just below the primary source rock, have remained relatively constant at near 100 µg/L over two years of monitoring, the concentrations of TCE in ports 3 through 6 have generally decreased.

Exhibit 5.1 – Declining Concentrations of TCE Observed at BP-13D.



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[17] Price, M. and A. Williams, 1993. The Influence of Unlined Boreholes on Groundwater Chemistry: A Comparative Study Using Pore-water Extraction and Packer Sampling. *Journal of the Institute of Water and Environmental Management. 7(6):pgs 651 to 659.*

[18] Sterling, S.N., B.L. Parker, J.A. Cherry, J.H. Williams, J.W. Lane Jr., and F.P. Haeni, 2005, Vertical Cross Contamination of Trichloroethylene in a Borehole in Fractured Sandstone. *Groundwater, 43(4): pgs 557 to 573.*

We believe that the initial concentration recorded in sampling of port 3 (31 μg/L) reflects VOC mass transferred down the borehole in the period between drilling of the borehole and installation of the multilevel device. The TCE concentrations recorded in sampling of ports 3 through 6 have subsequently declined to between 3 and 0.6 μg/L as shown on Figure 9. The data posted for multilevel systems BP-13D and GC-1 on Figure 9 reflect the findings of monitoring over the last year from November 2007 through 2008.

5.1.2.1 Chlorinated Ethenes

The predominant chlorinated ethene, TCE, was detected in 23 monitoring well locations or multilevel ports at concentrations exceeding the applicable groundwater standard (19 locations on Gun Club property and 4 locations on Country Club property) (see Figure 8 and Table 3). The highest arithmetic mean concentration of TCE was observed for monitoring well BP-9A which is screened in primary source rock on Gun Club property (2,800 μg/L).

Mean concentrations of 5 VOCs that are common breakdown (daughter) products of TCE also exceeded groundwater standards at between 2 and 15 sample locations. Specific observations include the following:

- cDCE was detected at more than 36 monitoring locations, 5 of which were located on Country Club property but at concentrations below potentially applicable standards. The highest mean concentration of cDCE (6,000 μg/L) was observed in monitoring well BP-2A, which screens the uppermost highly fractured zone proximate to the Burn Pit.

- Concentrations of cDCE were generally correlated to locations where elevated TCE concentrations and chemically-reducing conditions were observed in groundwater. The presence and ratio of cDCE to parent compound TCE at these locations is consistent with studies documenting stepwise reductive dehalogenation processes occurring as a result of available organic carbon and biochemically-reducing conditions[19].

- VC a tertiary breakdown product of TCE and was found at six monitoring locations exhibiting mean concentrations above applicable standards within the BPA and mostly where cDCE exceedances were also observed. Similar to cDCE, concentrations of VC were found to be particularly elevated where chemically-reducing conditions combined with excess available carbon materials have been documented.

- tDCE, 1,1-DCE, and 1,2-Dichloroethane are breakdown products of TCE under certain anaerobic conditions. These compounds are typically produced in smaller ratios than cDCE. The mean concentrations exceeded groundwater standards at 2, 2, and 11 monitoring locations, respectively within BPA. Mean concentrations of 1,2-DCA exceeded applicable standards for samples from multilevel system GC-1 Ports 1 through 3 and Port 8.

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[19] Lee, M.D., Odom, J.M., Buchanan Jr., R.J. (1998). New Perspectives on Microbial Dehalogenation of Chlorinated Solvents: Insights from the field., *Annual Reviews in Microbiology,* 52, 423-452.

Additional discussion regarding TCE biochemical degradation is presented in Appendix G and report Section 5.4.4 and 5.4.5.

5.1.2.2 Chlorinated Methanes

PCM was detected in samples from 26 monitoring wells and multilevel system intervals, including 6 locations on the Country Club. PCM has historically been detected in sampling of monitoring wells GC-1 and GC-2. Mean concentrations of PCM exceeded applicable groundwater standards at only one location, GC-2A. GC-2A is a shallow water table monitoring well installed in place of the open borehole monitoring location GC-2 in Spring 2007.

Chloroform was detected at 45 monitoring locations beneath Gun Club property and 15 locations beneath Country Club property. Despite its widespread detection, chloroform concentrations exceeded the applicable standard at only 3 monitoring locations on IBM property. Mean concentrations of chloromethane and methylene chloride (dichloromethane) were also observed exceeding standards in samples from two monitoring locations.

All three chlorinated methanes are known breakdown products of PCM under chemically-reduced conditions. Detections of chloroform in samples from GC-1 and BP-13D multilevel systems appear to be correlated to detections of carbon tetrachloride, suggesting that chloroform is present in part as a result of PCM degradation. Chloroform is also a trihalomethane resulting from use of chlorine as a disinfection agent in municipal water supplies. We believe the presence of chloroform may also be related to potable water used in drilling. As discussed in Appendix G.1 residual chlorine was also detected in groundwater samples.

5.1.2.3 Other Chlorinated VOCs

Isolated detections of tetrachloroethene (PCE) and two isomers of tetrachloroethane (1,1,1- and 1,1,2-PCA) were identified for samples from between 1 and 5 monitoring locations. 1,1,2-PCA has historically been detected at monitoring locations GC-1 and GC-2. Detections of PCE and TCA were recorded for monitoring locations on Country Club property, but were not consistent with observations and patterns of these compounds on Gun Club property. Concentrations of PCE and 1,1,2-PCA were below their applicable standards for all locations, except at BP-2A located in the BPA.

5.1.2.4 Petroleum Hydrocarbons

Aliphatic and unsubstituted aromatic hydrocarbons associated with petroleum have been observed in the groundwater and rock core samples. The aromatics have included benzene, ethyl benzene, toluene, and xylene (BTEX) in the presence other tentatively identified alicyclic and aliphatic hydrocarbons.

Groundwater samples collected from five wells screening within or just beneath the primary source rock were analyzed for Diesel Range Organics (DRO) and Gasoline Range Organics

(GRO)[20]. GRO and DRO were detected in samples from four of the five wells with DRO ranging from 51 to 430 µg/L and GRO at concentrations ranging from 48 to 7,100 µg/L. GRO concentrations over 1,000 µg/L a common action threshold for groundwater were reported for samples from the two wells screened directly in primary source rock. These include BP-2A which is located beneath the BPA and BP-9A which is located about 300 feet south of the Burn Pit. These data are consistent with petroleum sheens noted on rock core samples and indicate a substantial presence of petroleum.

BTEX compounds were detected in samples from 52 monitoring locations. Mean concentrations of benzene, ethyl benzene, *m,p*-xylenes and *o*-xylene exceeded applicable groundwater standards at two locations within or near the BPA. Benzene concentrations also exceeded the groundwater standard for samples from BP-9A and BP-13D Port 6.

Toluene has been detected in samples from 49 monitoring locations, including all 35 multilevel system ports. Concentrations of toluene greater than applicable standards were recorded for samples from 26 locations, including those within primary source rock beneath the BPA and from 24 of 35 multilevel system ports. With the exception of the multilevel ports, the spatial distribution of toluene is similar to that of other BTEX compounds.

The toluene concentrations observed in sampling of multilevel systems reflect materials used during manufacturing of FLUTe™ liners (see letter from FLUTe™, dated Sept. 23, 2003 in Appendix G.2). FLUTe™ liner systems have been reported to leach toluene at near 70 µg/L, and then these concentrations typically dissipate over several months to years. As a result, the toluene data in samples from multilevel system ports are not expected to reflect field conditions and are biased high.

5.1.2.5 Ketones

Three ketones, including acetone, MEK, and 4-methyl-2-pentanone were detected at levels greater than applicable water quality standards within the BPA. Acetone was also detected in excess of applicable standards in samples from four multilevel system ports from BP-14D and GC-1. All three compounds were detected in many of the multilevel system ports at the site, but at levels below applicable standards. The ketones are miscible in water and are readily consumed by microorganisms present in the subsurface under both aerobic and anaerobic conditions, and were typically not detected in monitoring wells screening the uppermost highly fractured rock. Although acetone is a site contaminant the data for the multilevel devices is suspect. Acetone may also be a contaminant related to materials present in the liner systems.

5.1.3 VOCs in Rock Core Samples

Three phases of bedrock coring and analysis of whole rock core samples were completed to define the presence and distribution of VOCs in the rock matrix. Over 700 samples of rock were collected at roughly one-foot intervals from 33 borehole locations on Gun Club and Country

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[20] Wells sampled for DRO and GRO included BP-2, BP-3 and BP-6 screened below primary source rock and BP-2A and BP-9A screened within source rock.

Club property. The samples were prepared for VOC analysis using a microwave extraction technique developed by the University of Waterloo and analyzed for nine chlorinated VOCs. Extractions from about 20% of the samples (130 samples) were sent to a commercial lab where they were analyzed for an expanded list of site-specific VOCs. The lab also reported tentatively identified compounds (TICs). Further details on bedrock core sampling and laboratory analysis can be found in Appendix F. Photos of rock core sampling are included as Exhibit 5.2.


Rock Core Sampling

Exhibit 5.2 – Photos of Rock Core Sampling- depicting counterclockwise from upper left, photo documentation of a 4-foot core run, a close-up of a segment of core with a stained vertical fracture and oily sheen, and weighing crushed rock sample in vials of methanol.

The rock core sampling data define the horizontal and vertical extent of the VOC source in bedrock. This degree of source delineation would not have been achieved without this technology. The data indicate that the majority of chlorinated VOC (CVOC) mass is present in the primary pore space of the rock at depths less than 15 feet below ground. The VOC mass in rock extends south to southwesterly direction from the former Burn Pit in the uppermost highly fractured rock as shown on Figure 10. The VOC mass found in rock includes the key CVOCs, ketones, and constituents of petroleum. As such, we believe that the data indicate the past release of mixed solvents and petroleum. The presence of lighter than water petroleum with this mixture may explain why the VOC mass has not penetrated the rock to depths greater than about 10 to 15 feet below ground.

5.1.3.1 Key Chlorinated VOCs

TCE was detected in over half of the rock core samples. Other VOCs, including the primary breakdown product cDCE, 1,1-DCE, chlorinated methanes, 1,1,1-TCA, and PCE were detected in about 5% to 40% of the samples. TCE and cDCE were typically found at one to two orders of magnitude higher than concentrations of the other chlorinated VOCs. TCE concentrations approached 100 micrograms per gram of wet field weight (µg/g) near the Burn Pit a concentration estimated to be equivalent to around 340 milligrams per liter (mg/L) or about 30 percent of the theoretical TCE aqueous solubility. Estimated pore water concentrations within 0.5 to 2 orders of magnitude of aqueous solubility are believed to be indicative of the dissolution of non-aqueous phase liquids that may have penetrated adjacent fracture pore space, particularly in the presence of other compounds.

As shown below in Exhibit 5.3, VOC presence in rock is correlated to a higher density of fracturing, specifically in the top 12 feet below ground. At boring BP-2, the first aquitard interval was observed about 11 feet below ground. Intervals exhibiting a lower density of bedding-parallel fractures only, or no fracturing, that are also considered aquitard intervals were found from about 12 to 16 ft bgs, 16.5 to 24 ft bgs, and about 25 to 30 ft bgs etc.

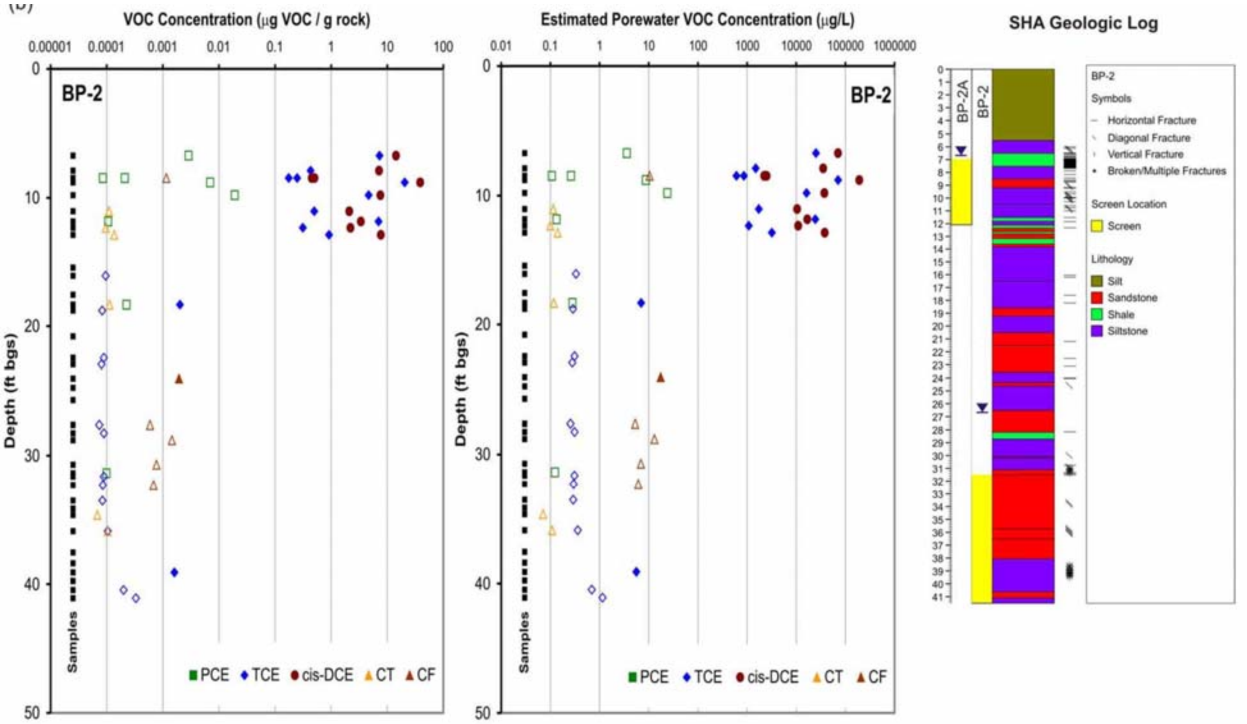

Exhibit 5.3 – Graphical Summary of Rock Core Analytical Results and Log for Boring BP-2.

While TCE and cDCE concentrations in the rock core in tens of µg/g are believed to reflect pore water concentrations on the order of 100 mg/L, the median TCE and cDCE concentrations recorded for water withdrawn from the uppermost fractured zone at BP-2A are 1.1 and 5.5 mg/L, respectively, or about two orders of magnitude lower than expected pore water concentrations, reflective of water in the fractures fed by diffusion from the matrix without sufficient time to reach equilibrium with the pore water. Exhibit 6.2 in Section 6.0 demonstrates the observed relationship among estimated pore water concentrations and groundwater data for nearby wells.

In contrast to the rock core samples collected above the first inferred aquitard, a sample collected at BP-2, an intermediate depth well screened within an extremely fractured zone at about 39 ft bgs, exhibited TCE only, at a concentration of 1.6×10^{-3} µg/g. This concentration, equivalent to about 5 µg/L in pore water, is believed to reflect past and on-going transport of VOC mass in groundwater through the fractures, and not historical presence or contact with separate phase liquids. Although TCE has been detected in sampling of BP-2, the median of the observations is below 0.9 µg/L. The modest presence of TCE in groundwater about 18 feet below the primary source rock is evidence of how aquitard intervals and retardation due to matrix diffusion and sorption can limit vertical transport of VOCs.

As shown by the red shading depicted on the three dimensional representation of the rock core data included as Figure 10, the sum of key VOCs totaling over 1 gram per cubic foot of bulk rock volume (g/ft^3) extends southerly from the Burn Pit along an apparent trough in the bedrock surface past B-10 about 320 feet to the vicinity of well BP-9A. The red shaded area encompasses about 0.6-acres of land and is estimated to contain over one-half of the key VOC mass. Source mass in rock at concentrations of about 0.1 g/ft^3, as shown by orange shading on Figure 10, underlies about 1.6-acres and is believed to encompass the probable limit of historical separate-phase liquid penetration into fractures.

The sum of the red and orange shaded rock volume on Figure 10 is estimated to contain over 90% of the VOC mass in rock and therefore is considered to be the “primary source” of the on-going VOC presence in groundwater (Primary Source Rock). Based on equilibrium partitioning relationships, we estimate that over 90% of the key VOC mass is sorbed to the rock matrix with the majority of the remainder dissolved in the pore water.

The yellow and green shading on Figure 10 reflects total chlorinated VOCs in rock core at concentrations one to three orders of magnitude lower 0.01 and 0.001 g/ft^3. These concentrations reflect diffusion of VOCs into the rock from VOCs in groundwater passing through fractures over the history of subsurface transport.

We estimate that the total key VOC mass residing in the primary source rock may be on the order of 1,000 pounds. Assuming an equal proportion of PHCs and ketones the total VOC mass may be about double the key CVOCs. More than 95% of the total is estimated to be located beneath lands owned by IBM, with about 80% within the upper 10 feet below ground and about 99% within the top 15 feet below ground. Although there is likely a large error band associated with the estimate of total VOC mass, and also some degree of uncertainty regarding the partitioning of mass, these estimates were prepared to support the conceptual model of site conditions.

5.1.3.2 Other VOCs and Petroleum Constituents

Analysis by a commercial laboratory of 130 samples of methanol extract from the rock core suggests that TCE may represent less than one-half of the VOC mass on a molar basis. Analysis of the methanol for a wider suite of VOCs using method EPA 8260B confirmed the presence of 30 other “non key” VOCs and unknown or TICs. These TICs included unsubstituted alicyclic, aliphatic, and aromatics typical of petroleum hydrocarbons. Unknowns and unknown alkanes were detected in about 58% and 51% of the samples comparable to the detection frequency for TCE at 55%. Methylcyclohexane and methyl acetate both common industrial solvent were detected in about 30% and 24% of the sample extract splits, respectively.

The next most commonly detected class of VOCs were ketones (acetone and MEK), which were detected in more than 40% of the extract splits. The presence and concentration of these two compounds were positively correlated to each other and may comprise about one-quarter the mass of TCE detected in the same samples.

The unsubstituted aromatics including BTEX, were detected in extract samples at frequencies ranging from 5% to 25%. Unknown aromatics were detected in about the same frequency. Certain TICs including aliphatic hydrocarbons were present at concentrations within the same order of magnitude as that of TCE.

A limited analysis of this data suggests that key halogenated VOCs may represent on the order of 36 to 50% of the total VOC mass, with aliphatics at 16 to 47%, ketones at about 7 to 26%, aromatics at 6 to 9%, and 1 to 2% other compounds. The actual proportioning varies greatly by sample and spatially. In general, fewer non-key VOCs were detected with distance away from the Burn Pit. Although what is observed in sampling nearly 50 to 60 years after beginning BPA operations, the data support the historical release of a mixture of halogenated solvents and petroleum which is consistent with operations of the time which include heat treating and machining operations using petroleum oils.

5.2 Other Hazardous Substance List Analytes

Water samples from a subset of monitoring wells screened beneath the BPA, including those exhibiting the highest VOC concentrations, were tested for the presence of other hazardous substances, including SVOCs, PCBs, pesticides and herbicides, and cyanide. PCBs, pesticides and herbicides were not detected. Two semi-volatile chlorinated benzenes were detected in 1 and 4 samples at concentrations less than 2 µg/L, orders of magnitude below applicable water quality standards. Total cyanide was detected in three samples from BP-2 and BP-4 at concentrations of equal to or less than 0.067 µg/L; well below the 200 µg/L. NYS Part 703 water quality standard for cyanide.

5.3 Metals

Samples from a subset of monitoring locations within the BPA were analyzed for metals identified in the Work Plan Target Analyte List (TAL). The wells included those screened in the uppermost highly fractured bedrock above and below the first inferred aquitard. Of the 23 analytes, 10 metals, including arsenic, barium, calcium, chromium (total and hexavalent), cobalt, magnesium, nickel, potassium, and selenium were detected in samples from one or more wells, but at concentrations below applicable ambient groundwater or drinking water standards (see Table G.2.1 in Appendix G.2). An additional 10 metals were not detected. Four other metals, including aluminum, iron, manganese, and sodium were detected at concentrations that exceeded applicable water quality standards (Table G.2.1). Aluminum was recorded at concentrations above applicable water quality standards in samples collected from BP-2, BP-2A, and BP-8A.

The aggregate data for metals in the BPA indicates the following:

- Certain metals found in sediments in the BPA do not appear to be mobile in groundwater under the geochemical conditions present at the site.
- Metals that have previously been detected in surficial soils as a result of former skeet activity, including lead and zinc were not detected in groundwater.
- Elevated dissolved iron and manganese is consistent with geochemical reducing conditions observed in the vicinity of the BPA.

Iron was detected at concentrations greater than the Secondary Drinking Water Standard Maximum Contaminant Level (SMCL) in samples from eight monitoring locations at concentrations ranging from 0.31 to 28 mg/L. Six of these locations were monitoring wells screened in the uppermost highly fractured zone or in fractured rock below the first inferred aquitard in the BPA, and two samples were from monitoring wells located on Country Club property, BP-19A and BP-25A. Manganese was found at concentration above the SMCL in samples from fifteen monitoring locations at concentrations ranging from 6 to 28 mg/L.

5.4 Groundwater Geochemistry

This section provides an overview of an assessment of groundwater geochemistry. The assessment was focused on geochemistry as it may be relevant to:

- lines of evidence regarding groundwater flow patterns and chemical transport;
- conditions influencing abiotic and biotic cycling of chemical compounds in the subsurface;
- insights into the potential for biochemical degradation, including conditions which may be limiting the natural attenuation of VOCs; and
- identification of geochemical conditions that could be relevant to suitability and performance of remedial technologies.

The assessment included review of water quality data documenting concentrations of major anion and cations, nutrients, and organics in groundwater samples collected from monitoring locations near the BPA source zone and locations further afield. Additionally, the observed concentrations of dissolved gasses that may be related to microbiological activity or the degradation of chlorinated VOCs are discussed.

This section also summarizes the particularly relevant data, observations, and findings of an analysis provided in Appendix G, which includes further details on biochemical degradation along selected apparent groundwater flow paths beginning in the BPA source zone and extending downgradient. A tabular presentation of water quality data is also provided in Appendix G.

5.4.1 Specific Conductance and Major Cations & Anions

Specific conductance, or the ability of the groundwater to conduct an electrical current, is proportional to the ionic content of the water. The major cations and anions that contribute the most to conductivity include: calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. These are discussed in more detail below.

Measurements of specific conductance and other parameters recorded during low-flow sampling have been compiled into a table of descriptive statistics for each monitoring location; including mean, median, and ranges (minimum, maximum) (see Table G.2.2 in Appendix G.2). The highest median value of specific conductance was observed for samples from BP-3, which is screened in fractured rock below the first inferred aquitard beneath the Burn Pit. Samples from other monitoring locations screened in fractured rock below the first aquitard beneath the BPA exhibit median values of specific conductance 3 to 10 times higher than other monitoring locations.

The elevated specific conductance is believed to reflect the influence of both historical burning activities and the geochemical influence of VOC sourcing in the BPA. Combustion and biological degradation of chlorinated solvents would be expected to release carbon dioxide and chloride ions. The excess chloride ions would be expected to result in an ionic imbalance that would drive exchange of minerals with the soil and rock.

Data for monitoring locations remote from the BPA indicate patterns of conductivity likely related to the degree of groundwater recharge and residence time. Data for multilevel system ports indicate an increase of 200 microsiemens per centimeter (µS/cm) at depths of 120 to 190 feet below ground. This increase in conductance at elevations of between about 1,200 and 1,250 ft AMSL corresponds to where both horizontal and vertical gradients decrease by more than an order of magnitude.

The patterns of conductivity are consistent with concentration of individual cations and anions including:

- One to two orders of magnitude greater concentrations of four major cations (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) in water samples from intermediate depth wells than from water table wells in the vicinity of the BPA.

- Similarly, three major anions, including chloride, carbonate alkalinity, and phosphate, were typically one order of magnitude greater in samples from intermediate depth as compared to samples from water table depth.

- The highest chloride, carbonate alkalinity, and orthophosphate were observed in BP-3 and BP-6. Orthophosphates, nitrates, and other cations (Al^{3+}, Ca^{2+}, Mn^{2+}, $Fe^{2+, 3+}$) are common salt or inorganic additives in both gasoline and diesel fuels, residuals of which have been detected in groundwater and rock core samples here within the BPA.

In units of milliequivalents per liter (meq/L), the total ionic strength of groundwater increases from less than 5 meq/L at the water table to around 20 meq/L at the depth of multilevel system ports, with monitoring wells screened in fractured rock beneath the inferred aquitard within the BPA at almost 100 meq/L.

The species composition also changes with depth. Sodium and potassium carbonates are the predominant ion pairs in water from water table depth that is characterized as relatively soft to moderately hard. Water samples from wells screened in fractured rock below the first inferred aquitard and from multilevel system port depths exhibit an excess of chloride, with calcium chlorides and sodium and magnesium chlorides as the primary ion pairs. The water would be considered hard to extremely hard in the range from 1,000 mg/L to more than 5,000 mg/L as calcium carbonate.

5.4.2 pH values

Descriptive statistics for pH data recorded during low-flow sampling are presented in Table G.2.2 in Appendix G.2. The observed range of pH could be generally described as circumneutral, with typical pH values ranging from 6.5 to 7.5. The pH values and other geochemical data indicate that the surficial soils and bedrock are fairly well buffered.

5.4.3 Total Organic Carbon

As discussed in more detail in Appendix G.1, the total organic carbon (TOC) concentrations appear to be related to petroleum-derived VOCs observed in groundwater and rock core samples. Gasoline and diesel range organics were detected at concentrations between 50 μg/L and 7,000 μg/L in samples from wells screened in primary source rock. As discussed under Section 5.3.6, evidence of biochemical degradation of key chlorinated VOCs, including TCE, are associated with locations where TOC concentrations are greater than 8 mg/L. Outside the BPA, TOC concentrations were observed to be 2 mg/L or less.

5.4.4 Oxidation-Reduction Potential (ORP) and Electron Accepting Processes

Oxidation-reduction potential is a general measure of electron activity of a solution. It is an indication of the tendency of the groundwater to gain or lose electrons. Positive ORP values indicate that greater potential for oxidation or gain in electrons, whereas negative ORP values indicate greater potential for reduction or losing electrons. ORP data combined with geochemical evidence were used to infer primary electron accepting processes in certain areas of the site. The major terminal electron accepting process (TEAP) is relevant to assessing the abiotic and biotic electron transfer mechanisms and the potential for biochemical degradation of chlorinated VOCs.

Patterns of colored shading on Figure 11 support that groundwater above the first inferred aquitard is more strongly reducing near the Burn Pit where sulfate reducing and methanogenic conditions are inferred and less so with distance from the Burn Pit. Chemical and biological oxygen demands in the form of reduced metals and VOCs (petroleum hydrocarbons, alcohols) within the primary source rock have resulted in more reduced conditions.

In the vertical direction, the redox conditions progress to more strongly reduced conditions. Observations of ORP values and other geochemical data discussed in more detail in Appendices G.1 and G.2 indicate the following with regard to terminal electron accepting processes:

- Within the green shaded area other indicators of natural biochemical degradation include elevated concentrations of reduced iron and manganese [Fe(II) and Mn(II)], detectable sulfides, dissolved methane concentrations several orders of magnitude larger than elsewhere, and increased concentrations of chlorinated VOC daughter products cDCE, VC, and ethene. The presence of reducing conditions and chlorinated VOC daughter products beneath the BPA support that microbes capable of degrading chlorinated VOCs are already present and are active in certain areas of the subsurface.

- Samples from monitoring locations within the yellow shaded area within or near the BPA exhibit median ORP values less than 100 mV, which are generally associated with iron and manganese reducing conditions. Lower molar ratios of chlorinated daughter products relative to the TCE parent compound observed in this area indicate that biochemical degradation of chlorinated VOCs may be limited by the availability of organic carbon.

- Monitoring wells screened at the water table in locations outside the primary VOC source rock, as shown in grey shading, more commonly exhibit detectable dissolved oxygen and ORP in a range indicative of nitrate-reducing or more oxygenated electron accepting processes.

- The data from monitoring locations screened in fractured rock down to 41 ft bgs within the BPA typically exhibit median ORP values less than zero, including BP-2A, BP-3, and BP-6. This moderately negative ORP is consistent with an increased level of microbial activity that is probably related to greater available organic carbon.

- Median ORP values recorded in samples collected from multilevel ports 3 and below in borings BP-12D, BP-13D, and BP-14D were typically below -100 mV. These ORP values are consistent with highly reducing conditions and the occurrence of sulfate reduction and/or methanogenesis[21]. Chemically reduced conditions in the deep bedrock are believed to be

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[21] *Methanogenesis is the production of CH_4 and CO_2 by biological processes that are carried out by methanogens.*

reflective of oxygen depleted conditions not readily replenished by recharge of water containing atmospheric oxygen. Lesser reducing conditions were observed for samples collected from BP-15D multilevel ports; with median values typically between -10 and -70 mV. These ORPs would generally be associated with iron- or sulfate-reducing electron accepting processes.

5.4.5 Evidence of Biochemical Degradation of Chlorinated VOCs

The pie diagrams depicted on Figure 11 illustrate the relative proportion of chlorinated ethenes on a molar basis in shades of blue with TCE as the parent product in the darkest coloration and primary, secondary, and the terminal breakdown products in successively lighter coloration.
The diagrams show a higher degree of biochemical degradation within the green shaded area surrounding the Burn Pit where the concentrations on a molar basis of chlorinated daughter products (cDCE, VC) and ethene were equivalent to or larger than TCE concentrations. As an example based on median values recorded in sampling the relative ratios of TCE:cDCE:VC: ethene in BP-3 samples from were approximately 1:5:1:2. These ratios are consistent with step-wise reductive dehalogenation processes.

Ethene has been found at concentrations up to 510 μg/L within the green shaded areas area, roughly correlated to dissolved methane concentrations exceeding 10 μg/L. The upper bound ethene concentrations are more than two orders of magnitude greater than those recorded for samples from other monitoring wells within the BPA where nitrate/manganese/iron-reducing conditions are indicated, and more than four orders of magnitude greater than ethane concentrations detected where suboxic or nitrate-reducing conditions are inferred.

Monitoring locations outside or on the border of the green shaded area exhibit a lower proportion of breakdown products and complete microbial degradation is not readily apparent. The data for well BP-9A, for example, indicates parent to daughter product ratios of 12:1 for TCE:cDCE, and ethene has been detected at lower concentrations (0.1 to 18 μg/L).

Biochemical degradation of CVOCs is dependent in part upon the availability of excess organic carbon which may not be present with distance away from the Burn Pit. More limited biochemical degradation may reflect dissolved oxygen, nitrates, and metals (iron, manganese). Microorganisms known to be responsible for complete dechlorination of TCE to ethene are only able to compete with other microbes in highly chemically reduced environments, such as sulfate-reducing and methanogenic conditions.

5.5 Summary of Soil Characterization Data

Direct-push and test pit soil samples were collected within the initial investigative area depicted on Figure 2. The samples were analyzed for VOCs, SVOCs, pesticides, herbicides, PCBs, cyanide, and trace metals. In addition, samples from temporary soil vapor implants were analyzed for VOCs. The work and results are further detailed in Appendices C.1 and C.2.

All sampled soils met unrestricted use soil cleanup objectives[22] (SCOs) for VOCs, SVOCs, pesticides, herbicides, and cyanide; however, certain trace metals and PCBs were found at concentrations above unrestricted use SCOs. The SCOs are risk-based default soil cleanup objectives established under NYCRR Part 375 for specific site-use categories. The unrestricted use SCOs are defined by NY State as "a concentration of a contaminant in the soil which, when achieved at a site will require no use restrictions on the site for protection of public health, groundwater and ecological resources." Exceedence of an SCO does not indicate unacceptable risk to human health or the environment, but the potential to do so under certain site uses. The actual health risk would depend on site-specific exposure conditions as discussed in Section 7.0.

PCBs and metals found at concentrations above unrestricted use SCOs within the BPA included PCB-1254, Arsenic (As), cadmium (Cd), hexavalent chromium (CrVI), trivalent chromium (CrIII), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). However, the geometric and arithmetic mean and median values derived from the testing were below the unrestricted use SCOs, except for As, CrVI, CrIII, Ni, and PCB-1254.

Soil laboratory data from an area that appears not to have been affected by the former burn pit activities and the 1980 soil excavation, indicate that As and Ni concentrations greater than unrestricted use SCOs represents a natural background condition. The figure provided as Appendix C.3 summarizes the locations where one or more metal or PCB exceeds either unrestricted, residential or commercial SCOs at any depth or in the case of arsenic and nickel, the upper bound of observed background concentrations. The overall pattern of the observed concentrations of certain metals and PCBs in comparison to background samples and unrestricted use SCOs, suggest some residual effects of BPA disposal.

5.6 Data Validation and Usability

The Data Quality Objectives (DQOs) for the RI were developed consistent with process described in USEPA (2000)[23] and Exhibit E of the New York State Analytical Services Protocol (NYSASP)[24] . The DQOs are summarized in the RI Work Plan. The objectives were to:

- Identify the presence and concentration or absence of target VOCs in groundwater, surface water, soil gas, soil, and bedrock; and

- Provide organic and inorganic data for the different mediums of sufficient accuracy, precision, representativeness, and sensitivity to adequately assess the extent of potential

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[22] Department of Environmental Conservation, Subpart 375-6: Remedial Soil Cleanup Objectives. Effective December 14, 2006.

[23] United States Environmental Protection Agency. Data Quality Objectives, Process for Hazardous Waste Site Investigations, Final, January 2000.

[24] New York State Department of Environmental Conservation. Analytical Services Protocol, Exhibit E-Quality Assurance Quality Control Requirements, June 2000.

organic and inorganic contaminants in the different mediums to adequately understand the site conditions, and if necessary, support screening of potential remedial alternatives.

Two general types of laboratory data were collected during the RI, including:

- Mobile laboratory VOC analysis of samples of soil gas and the headspace of soil and rock core samples. The mobile analytical laboratory analysis data were not used to quantify the extent and concentrations of site contamination, but rather to qualitatively assess for the presence or absence of contamination at certain locations and aid in the siting of rock core borings and permanent monitoring wells; and

- Fixed laboratory analysis of samples of soil, bedrock and groundwater for organic and inorganic contaminants. Data were used to quantify the extent and magnitude of site conditions, and the Section 7.0 Qualitative Exposure Assessment is based on fixed laboratory data.

The analytical data from the Environmental Laboratory Accreditation Program (ELAP)-certified fixed laboratory were validated by New Environmental Horizons (NEH), Inc. of Skillman, NJ, except for the quarterly groundwater monitoring data collected September and December 2008, which underwent data usability review (DUSR)[25] by SHA personnel. NEH evaluated the data against project-specific measurement performance criteria for usability, precision, accuracy/bias, representativeness, comparability, sensitivity, and completeness. The data validation and DUSR reports are included in Appendix J, which is organized according to sampled medium and date.

QA/QC protocol for the project included 10% field duplicates, 5% matrix spike/matrix spike duplicates (for VOC samples), daily field blank, and 10% equipment blanks when using non-dedicated equipment. Each cooler shipped with VOC samples included one trip blank and one temperature blank. Additional laboratory QA/QC program included method blanks, laboratory control samples, and surrogates.

In summary, all fixed laboratory data that were evaluated under a data usability review are usable for their intended purpose, and no laboratory results were rejected or qualified as non-usable for remedial investigation purposes. Additional data usability comments include:

- Precision – Data for less than 1% of the samples were qualified during validation and the data are all usable for project objectives as qualified. Acetone, a common laboratory contaminant, was the compound that most often did not meet the MS/MSD and field duplicate precision.

- Accuracy/Bias – DQOs were met for more than 90% of the samples. The majority of the identified bias address tentatively identified compounds.

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[25] New York State Department of Environmental Conservation, DER-10 Technical Guidance for Site Investigation and Remediation, December 2002.

- Representativeness – DQOs were met for more than 99% of the laboratory results. Approximately 50% of the exceedances were noted for acetone, a frequent laboratory contaminant.

- Comparability – DQOs for comparability were met.

- Sensitivity – DQOs for sensitivity were met for more than 99% of the results.

- Completeness – DQOs were met for all laboratory results.

The data usability review did not identify laboratory issues for the two most prevalent site contaminants, TCE and cDCE. Most data review actions were related to known laboratory contaminants, including acetone, toluene, carbon disulfide, methylene chloride, and chloroform, as well as for tentatively identified compounds.

6.0 CONCEPTUAL MODEL OF SITE CONDITIONS AND IMPLICATIONS FOR REMEDIAL FEASIBILITY

The scope of RI investigations and testing was developed with an initial conceptual model of site conditions in mind, i.e., that migration of VOCs dissolved in groundwater within fractured bedrock represented the potential migration pathway of primary interest. The on-going VOC presence in groundwater was likely attributable to VOC mass residing in the primary porosity, or matrix, of the sedimentary rock. Chlorinated VOCs, principally TCE and biochemical breakdown products, were believed to be the VOCs of primary interest. This initial conceptual model was largely validated by the subsequent site investigations and testing. Although certain metals and semi-volatile organics have been detected in samples of soil remaining at the site following the 1980 soil removal, surficial soils no longer are a significant source of VOCs and the residual metals and organics do not appear to be mobile in groundwater.

This section provides a broad overview of the present conceptual model of site conditions considered in assessment of routes of human exposure and the establishment of remedial goals. The quantitative aspects of the conceptual model as outlined below are not intended as an absolute determination of site conditions but an illustration of relevant concepts.

6.1 VOC Sources

Data from multiple rock core sampling events has confirmed the presence of VOC residuals in the unfractured rock matrix. VOC species found in the rock include not only TCE and related chlorinated ethenes, but also include a variety of aromatic and aliphatic hydrocarbons that are components of petroleum, ketones such as acetone, and lower concentrations of other halogenated compounds. The majority of the VOC mass is found in the uppermost highly fractured rock beneath the BPA and extending mostly in a southerly direction from the BPA in the upper 10 feet of the subsurface.

The data indicate that a mixture of non-aqueous phase oils and solvents spread mostly laterally beneath about a 1.6-acre area from the presumed point of release at the Burn Pit, and to a more limited degree downward. This finding is contrary to conditions at many sites where vertically downward transport of dense chlorinated solvents is more significant.

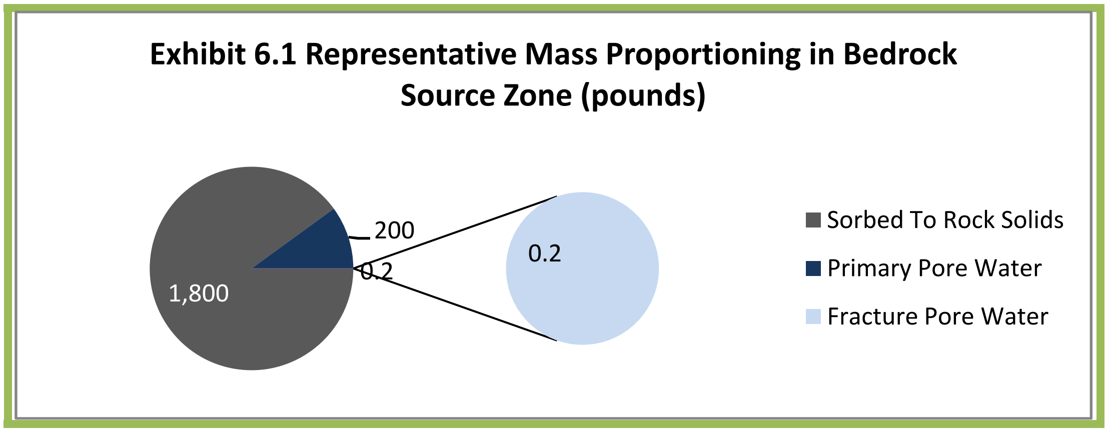
The apparent distribution of mass is believed be attributable to the predominance of near-horizontal, bedding-parallel fractures, and the lower density and higher viscosity of the mixture of solvents and oils. The finding that the highest proportion of VOC mass is between 5 and 10 feet below ground near the observed water table supports the idea that the contamination is a result of a liquid mixture that was lighter than water.

The amount of key CVOC mass present in the rock matrix is estimated to be on the order of about 1,000 lbs. Conservatively assuming that the total VOC mass, including unsubstituted aliphatic and aromatic hydrocarbons, and ketones may be about twice the total mass of key halogenated VOCs, the total mass would be equivalent to several hundred gallons of petroleum mixed with solvents.

The conditions inferred to be present today could be explained by the migration of several hundred gallons of a liquid mixture of petroleum oils and solvents into fracture spaces in the rock. Yet, the site investigations to date have not identified the presence of recoverable liquid solvents or oils.

Diffusive transport modeling supports that sufficient time has likely elapsed since the releases for the liquids to dissolve and largely disappear into the unfractured rock matrix through diffusion. At the expected ratios of matrix porosity to fracture porosity (ϕ_m to ϕ_f) for even the most fractured intervals, the matrix pore space offers one to two orders of magnitude greater volume for mass storage. The majority of the VOC mass residing in the rock matrix is believed to be sorbed to the rock solids.

The chart provided as Exhibit 6.1 illustrates the hypothetical relative proportioning of mass in the primary source rock assuming 2,000 pounds of total mass.



Aqueous concentrations of individual key VOCs in the matrix pore water within the primary rock source zone are estimated to be on the order of 10,000s to 100,000s of µg/L.

Conservatively assuming a 10 foot thickness and average matrix pore water VOC concentration of 100,000 µg/L over the one acre area, about 200 lbs or 10 percent of the mass would be in aqueous phase.

In contrast, at a median fracture porosity of $5\text{x}10^{-4}$ and an average aqueous concentration of 1,000 µg/L, the mass residing in the fractures if fully saturated with water would be on the order of 0.2 lbs in a few thousand gallons of liquid. Although these estimates are simplified approximations of the total mass that may be present, they provide an illustration of a quantitative conceptual model to be considered against apparent transport mechanisms and remedial feasibility.

Given the low matrix permeability, the VOC-containing water present in the pore space is not expected to be mobile under field hydraulic gradients and hence transfer of VOC mass back from the matrix to groundwater flowing in the fractures is limited by the rate of diffusion.

A very small proportion of the total mass in the subsurface is mobile within the fractures while the vast majority resides in the rock matrix where the mobility is limited by sorption and diffusion mechanisms. Back diffusion out of the matrix into water transmissive fractures is the mechanism for VOC mass contribution to groundwater flowing through the fractures. The lower concentrations of VOCs found in rock core samples outside and downgradient of where non-aqueous liquid likely has penetrated fractures are believed to reflect VOCs diffused into the rock matrix from historical dissolved-phase downgradient transport.

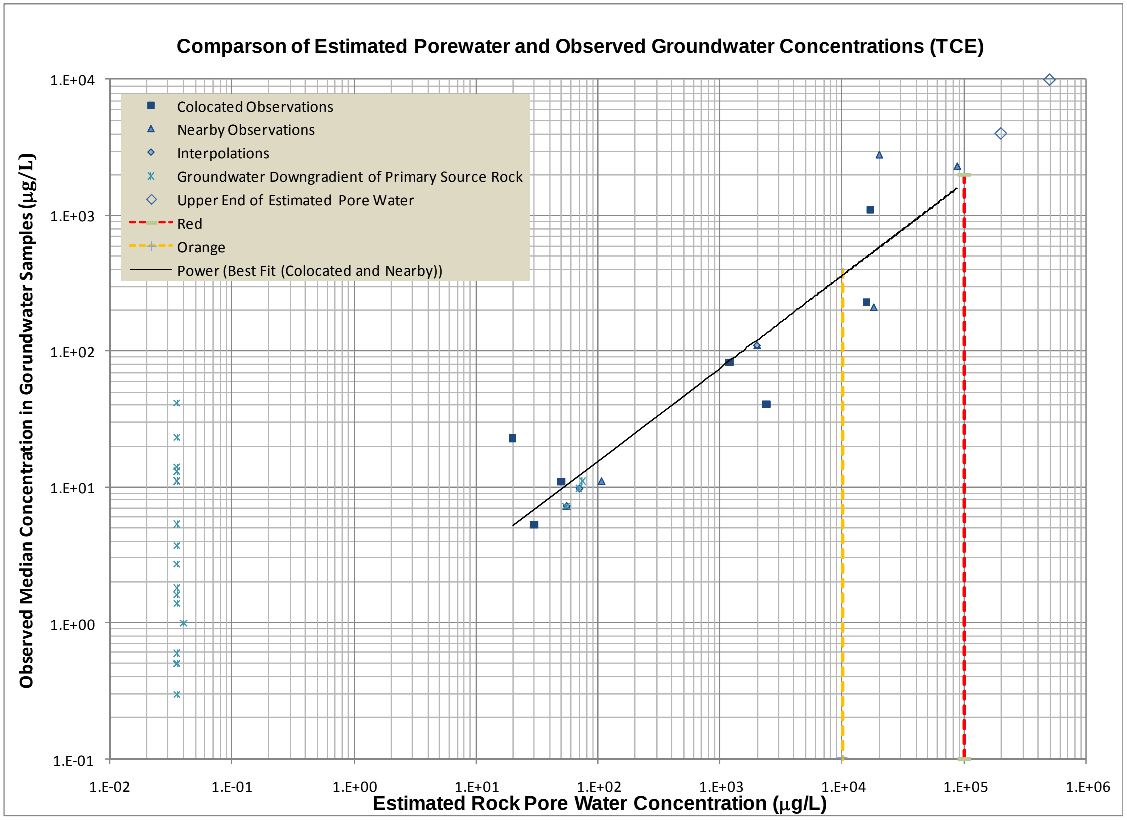


Exhibit 6.2 - Estimated Soil Pore Water Concentrations vs Water Quality Samples

Exhibit 6.2 illustrates the correlation between matrix pore water concentrations estimated based on the rock core data and actual observations of water quality recorded in sampling of monitoring wells withdrawing water from fractures. As shown in the legend of Exhibit 6.2, the "data" points included estimated matrix pore water concentrations for borehole intervals screened by monitoring wells (co-located observations), comparison of nearby observations, and pore water estimates interpolated between well and rock core boring locations. Two points also depict the upper end of estimated pore water concentrations and assumed groundwater concentrations. The data exhibit correlation for the co-located and nearby observations with correlation coefficients (R^2) above 0.85. The data also suggest the following:

- Typically between one to two orders of magnitude differential is observed between the estimated pore water concentration and water derived from fractures intercepted from the adjacent or nearby screened interval.

- Removal or hydrologic isolation of source rock with estimated matrix pore water concentrations greater than 10,000 μg/L may be expected to reduce concentrations in the fractures in the primary source zone to 2,000 μg/L or less. Based on our preliminary calculations, on the order of 6,000 cubic yards of in-place rock volume may encompass matrix pore water concentrations at or greater than 10,000 μg/L.

- Removal or isolation of source rock with estimated matrix pore water concentrations an order of magnitude lower may result in reducing concentrations in the fracture pore water in the primary source zone to 400 μg/L or less. However, the volume of rock to be addressed may be up to three times larger.

Although these are approximations, and the downgradient effects are uncertain, this analysis provides an initial conceptual framework to assessing practicability, effort, cost, and benefit of remedial options.

6.2 Fate and Transport

The overall volumetric flux of water through the source rock is believed to be small. The total groundwater flow through a roughly 8-acre area around the BPA, where the higher VOC concentrations are found in groundwater, was estimated to be on the order of a few gpm. At the estimated rates of recharge and groundwater flux, the volume of water in fracture pore space within the source rock may be exchanged about 100 times per year. The primary direction of transport is lateral along bedding-parallel fractures in the uppermost highly fractured rock. The data suggest greater VOC transport downslope to the south, likely reflecting bedrock surface topography, the surface of the first aquitard interval, and rock fracture patterns.

Despite the rate of fracture pore volume exchanges, the net rate of mass export by groundwater flow through the fractures from the source rock is small, probably on the order of tenths of pounds per year (lbs/year) with a reasonable upper bound below 1 lb/year. This modest mass export is reflected in the low concentrations of VOCs over a limited geographical extent downgradient of the source despite rapid groundwater advective velocities. The observed downgradient conditions are a manifestation of attenuation mechanisms including dilution, uptake and removal by plants, downgradient matrix diffusion, sorption, and biochemical degradation processes.

The observed distribution of VOCs in groundwater is believed to represent a dynamic equilibrium condition. Although we may expect to observe marginal increases and decreases in VOC concentrations with seasonal changes in water level and groundwater flow, the overall extent and concentration is not expected to materially change over time.

Given that VOCs may have first entered the ground 50 to 60 years ago, and given estimated groundwater seepage velocities on the order of 4,000 to 7,000 feet per year, without substantial attenuation the extent of VOCs in groundwater would be far greater than observed, i.e., a few hundred feet to just over 1,000 feet from the BPA as shown on Figures 8 and 9. The present extent of key VOCs in groundwater is supported by the findings of fracture transport model simulations conducted by representatives of the University of Waterloo (Appendix H.4), which predict transport distances of about 600 to 900 feet over a 60 year period[26].

An assessment of aqueous geochemical data supports that biochemical degradation of TCE and related compounds is occurring in the subsurface near the Burn Pit correlated to the presence of petroleum hydrocarbon components and ketones in the rock and groundwater. The geochemical data confirm methane generating conditions that are conducive to reductive dechlorination, and intermediate and terminal breakdown products have been found. Elsewhere further downgradient there is little evidence of biochemical degradation, and we believe biochemical activity is likely limited by lower organic carbon content in the water.

6.3 Implications for Remedial Goals and Feasibility

While destruction or elimination of the source of on-going groundwater contamination would be desirable, given the nature of the VOC source, we know of no proven technology to achieve this in-situ. Given the relatively shallow depth where the majority of contaminant mass resides, excavation and off-site treatment and disposal of rock with the goal of partial source removal remains a possibility. However, the feasibility of excavation without causing potential adverse effects and undue disruption of the neighboring community is not certain. The effectiveness of in-situ technologies that rely on the delivery of heat, biological, and/or chemical agents to achieve source reduction are likely limited by the low permeability and porosity of the unfractured rock.

The downgradient effects on groundwater quality of present source conditions are not substantial. If practicable it would be IBM's goal to further limit VOC transport in groundwater and/or reduce concentrations where water has been found to seasonally discharge to the ground surface. Given the relatively modest magnitude of groundwater flow, treatment of groundwater ex-situ would not be difficult; however, any extraction based technology would only address a

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[26] *Transport distances for a 5*μ*g/L TCE concentration assuming a steady source concentration of about 1,000* μ*g/L and a bulk retardation coefficient (*$R=V_{solute}/V$*) of* $4x10^5$ *which was computed assuming a 50 micron fracture aperture and mean fracture spacing of about 0.1 meters.*

minute portion of the total mass in the source zone, and such action would only be marginally useful in intercepting VOC transport downgradient.

Extraction of water from a thin zone of modest permeability rock would be ineffective with drilled vertical wells, whereas extraction from some sort of trench may be more effective. Given that VOC mass is diffused into rock downgradient of the original source area, substantial capture of groundwater flowing from the original source zone and/or removal or reduction of the source zone offers potential to only marginally improve downgradient water quality.

7.0 QUALITATIVE EXPOSURE ASSESSMENT

A qualitative assessment was performed to identify and screen potential pathways for human and biotic exposure to constituents present in surface water, groundwater, soil, bedrock, and soil vapor associated with the BPA at the Gun Club. The assessment was performed in consideration of available information regarding the nature and extent of contamination and the present understanding of human activity within and near the site. The assessment was conducted in accordance with the requirements for a Qualitative Exposure Assessment as outlined under CMR375 Part 3.6 and ECL 27-1415.

7.1 Background and Methodology

Our work included an enumeration of potential pathways for human exposure, followed by systematic assessment of the relative likelihood of pathway completion. A complete pathway of exposure requires the following:

- A contaminant source – a source of release to the environment;

- A contaminant release and transport mechanism – to carry contaminants from the source to points where humans or biota may be exposed;

- A point of exposure – a location where actual or potential human contact with contaminated media may occur;

- A route of exposure – the manner in which a contaminant may enter the body; and

- A receptor population – humans or biota that are, or may be exposed to contaminants at a point of exposure.

If any one component of the pathway of exposure is missing, then the pathway is not complete and exposure cannot occur. An exposure pathway may be eliminated from further evaluation when any one of the five above elements that comprise an exposure pathway has not existed in the past, does not exist in the present, and will never exist in the future.

In this assessment, release-source mechanisms for soil, groundwater, surface water, and subsurface vapors were tabulated against primary hazardous constituents, potential receptors and exposure points, and routes of exposure. This assessment was performed in consideration of the hazardous constituents believed related to the BPA as summarized in Table 4. In the "discussion" column of Table 4, pertinent facts, inference, and opinions regarding our present understanding of conditions were compiled to support a qualitative assessment of the likelihood of pathway completion. Finally, additional information and action that would clarify or support the probability of pathway completion are listed in the last column of the table.

The primary focus of our assessment was potential pathways of human exposure. We understand that the NYSDEC Natural Heritage program has determined that there are no known occurrences of significant biota, natural communities, or habitats at the site [27].

7.2 Pathways Believed Incomplete

As presented in Table 4, given the data collected to date, human exposure to site-related contaminants is not occurring through drinking water or soil vapor under present site use conditions. Engineered controls and access to public water would limit future exposure in the event of future development on Gun Club or Country Club property.

7.3 Pathways with Limited Potential for Completion

There is marginal potential for exposure of trespassers to metal- and PCB-containing soils that are outside the fenced area on the Gun Club property. As there is no apparent reason/attraction for trespass on this area of the property, we believe that the potential for realizing incidental, non-systematic human exposure is limited. Furthermore, with the exception of arsenic attributed to naturally occurring conditions, the samples collected outside the secure fenced area met the NYSDEC residential soil cleanup objectives.

At least traces of site-related VOCs were found in water samples collected from three wet areas; typically small areas of seeps and/or springs believed to be related to groundwater discharge to the ground surface. The areas include: 1) a limited area of the Gun Club property south of the BPA fenced area and north of the property boundary centered on BP-9A, 2) the surface drainage associated with the man-made pond on the Country Club, and 3) what is believed to be a drainage feature along Robinson Hill Road. The locations are shown on Figure 4 and photo documentation of the surface water sampling points is included in Appendix B.1.

Human contact is possible in that access is not restricted to each of the three areas. Our observations of site conditions indicate no regular systematic use of the specific areas that would result in regular, direct human contact. In each of the three cases, the observed part per billion (ppb)-level concentrations of VOCs are orders of magnitude below levels that would pose a risk

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[27] Omega Environmental Management, Inc., Newtown, PA Fish & Wildlife Resource Impact Analysis – Resource Characterization, IBM Gun Club, Former Shooting Range Area, Town of Union, Broome Country, New York, submitted to NYDEC Spring 2008. "*We have no records of known occurrences of rare or state-listed animals or plants, significant natural communities, or other significant habitats, on or in the immediate vicinity of your site.*" "*No Federal or State rare, threatened, endangered, or species of some regulatory concern were observed on the Site or in the Study Area. No unique or regulatory significant habitats were mapped or identified by the visual survey within the Site or in the Study Area*".

of acute, short-term health effects. Additionally, at the observed concentrations, these VOCs pose little concern for incidental, non-systematic chronic exposure via direct dermal contact, inhalation, or incidental ingestion. The concentrations range from less than, to about 8 times, standards set for public drinking water supplies and NYSDEC Part 703 Surface Water Quality Standards, which are based on daily lifetime exposure. Facts supporting the qualitative exposure assessment for each of the three areas are further discussed below.

7.3.1 Wet Areas on Gun Club Property

The wet surficial soil conditions, with TCE concentrations exceeding 1 µg/L, have been detected in rock probe explorations within an approximately 0.6-acre area between the BPA fenced area and the southern Gun Club property boundary centered on monitoring well BP-9A. The wet soil conditions have been observed to be seasonal, and related to snowmelt and times of increased precipitation, such as in the spring and fall. The area where TCE concentrations have exceeded 10 µg/L in rock probe explorations is approximately 0.2 acres and encompasses surface water sampling locations Seep-1, Seep-2, and SWA discussed in Appendix F.3.1.

The perimeter road passes through the wet area and there are seasonal puddles and rivulets of water on the road. The VOCs detected at one or more of the three surface water sample locations included TCE, cDCE, tDCE, and chloroform. TCE and cDCE concentrations ranged from 1.5 µg/L to 38 µg/L, and 0.7 µg/L to 19 µg/L, respectively. The tDCE and chloroform concentrations were less than 0.4 µg/L. In general, the higher end concentrations were observed for SEEP-1 adjacent to the BPA fencing, and lower end concentrations were observed in water seasonally running across the road.

As discussed in Section 2.1, the road is primarily used for access to the water tower located just west of the southwest corner of the Gun Club property. As the service personnel typically would be traveling in a vehicle, direct human contact with the water would be limited. The perimeter road, however, is accessible to trespassers and has been observed to be occasionally used for recreational walking. The recreational use of the perimeter road could potentially lead to human contact with water present either as puddles on the road or as wet soil next to the road. The exposure pathway completion, however, would be incidental, short duration, and dermal in nature. The potential for exposure could be mitigated in the short term by extending fencing south to the Gun Club property boundary and/or placement of a culvert to direct water under the roadway.

7.3.2 Man-Made Pond Drainage

The wet area is located in a wooded section of the Country Club property, downgradient from monitoring well BP-20A associated with the man-made pond. Surface water monitoring locations included two seeps/springs upstream of the pond (112 and 113), the man-made pond denoted as location 115, and three downstream sample locations (locations 111, 110, and 109). While the pond contains standing water throughout the year, the upstream and downstream locations flow seasonally.

VOCs observed in water samples from this area included TCE and chloroform. The concentrations were in all cases below applicable drinking water MCLs and Part 703 Surface Water Quality Standards. TCE has been detected in samples from 6 of the 7 sample locations at 0.1 µg/L to 4.1 µg/L; with the highest concentrations observed at the two upstream locations 112 and 113. The concentrations decrease to 0.1 µg/L downstream of the pond at location 110. Chloroform (0.1 µg/L) has only been observed at location 112. No VOCs were detected in sampling of water at the most downstream location 109.

The exposure pathway could only be completed in the event that Country Club recreational users or employees ventured off the golf course into the wooded section surrounding the man-made pond. The wooded area is not accessible to the vehicles used by employees and golfers. Furthermore; the high season for golfing is during the months of early May to early October, periods typically associated with less precipitation, and therefore dryer ground conditions. A potential exposure would be incidental, short duration, and most likely dermal.

7.3.3 Robinson Hill Road Drainage Feature

The drainage feature 116 at BP-27A is a less than 1-ft deep and 2-ft wide depression oriented from west to east that drains into a culvert (sampling point 118) that runs under Robinson Hill Road and eventually flows into Gray Creek. The drainage feature where water was observed exiting the ground appears to be man-made as it is lined with gravel. A narrow depression, approximately 1-ft wide, can be traced on the ground surface from 116 toward monitoring well BP-24A. It appears to drain the easterly section of the fairway number 9. Free water capable of being sampled has only been observed at location 116 under seasonal wet conditions in early spring. The highest observed flow at 116 was estimated to be less than 0.5 liters/minute during the March 2008 snowmelt. The flow from 116 converges with a drainage ditch running north to south along Robinson Hill Road before discharging under the road in a culvert at location 118 approximately 20 feet from location 116.

The compounds detected in samples from location 116 include TCE, cDCE, carbon tetrachloride, and chloroform. Observed TCE and cDCE concentrations ranged from 9.5 µg/L to 12 µg/L, and 3.4 µg/L to 5.2 µg/L, respectively. Chloroform and carbon tetrachloride have been observed at trace concentrations of 0.2 µg/L or less. Chloroform and carbon tetrachloride have not been detected in sampling of location 118, and the TCE and cDCE concentrations have been detected only at concentrations less than the MCLs, at 2 µg/L and 0.7 µg/L, respectively. Human exposure in this area would require direct contact with the small area of exposed water. The potential exposure would be incidental, of a short duration, and most likely dermal.

7.4 Exposure Assessment Conclusions and Implications for Remedial Goals

We conclude that potential for human exposure is low as to be practically negligible under the present use of the Gun Club and adjacent properties. Although we acknowledge the potential for human exposure to VOCs, the data support no possibility of acute health risk, and low potential of chronic health risk given the low concentrations and incidental short duration nature of possible contact through a primarily dermal route of exposure. We draw similar conclusions in regards to the limited potential for exposure to soils exceeding SCOs for metals and PCBs in the vicinity of the former BPA.

Regardless of the perceived level of potential exposure, we propose taking steps to further limit exposure potential where practicable. It is in this light that short-term measures, such as extending fencing to cover areas of soil or seepage, may be considered. In the longer term, remedial measures that appear to offer potential to limit VOC migration in groundwater, and thereby reduce future concentrations at potential points of exposure, would be preferred if found to be practicable. Given the relatively short advective travel times from the primary source zone in rock to points of observed discharge, it is possible that at least marginal improvements in water quality and exposure point concentrations may be achievable if either the source or the transport mechanism can be meaningfully disrupted.

Given the fractured bedrock setting many of the technologies will require pilot testing to support full scale design, demonstrate performance, or better assess unit costs for implementation. Such pilot testing is recommended for the alternatives analysis phase to support a realistic assessment of remedial alternatives.

8.0 POTENTIAL REMEDIAL GOALS AND PRELIMINARY ASSESSMENT OF TECHNOLOGIES

This section presents the potential remedial goals and systematic screening of potential remedial technologies that may be appropriate for the BPA. Potential remedial goals have been developed in consideration of BPA conditions and the findings of the exposure assessment described in Section 7.0. The remedial goals are focused on removing, reducing, and/or containing contaminants observed in soil, bedrock, and groundwater. Given these potential remedial goals and understanding of BPA conditions, the objective of the screening process was to review potential remedial technologies and identify those that might be suited, either alone or in combination, to meet the remedial goals.

The overall outcome of this process was to assemble a group of remedial alternatives from retained technologies that will be subject to a detailed "Alternatives Analysis" in accordance with the New York State Brownfield Regulations 6 NYCRR Part 375-3.2. In the "Alternatives Analysis", remedial alternatives will be evaluated against the selection criteria outlined in 6 NYCRR Part 375-1.8 (f). These criteria include, but are not limited to: overall protectiveness; conformance to applicable standards and guidance; reduction of toxicity, volume, and/or mobility; short and long term effectiveness; implementability; safety; and cost.

This section concludes with a recommended list of remedial alternatives for more detailed evaluation in the "Alternative Analysis". These alternatives are composed of the technologies that appear to be favorable to the remedial goals and site conditions based on the screening evaluation.

8.1 Potential Remedial Goals and Visions of Success

The remedial goals developed in consideration of site conditions and the findings of the exposure assessment are listed in Exhibit 8.1.

Exhibit 8.1- Preliminary Remedial Goals:

1. **Reduce the downgradient VOC mass flux from the BPA primary source zone –** Success would mean realizing a material reduction in VOC concentrations in groundwater outside the source zone and in water reaching seeps and springs.
2. **Reduce VOC Source Mass –** To the extent practicable, reduce the mass of VOCs in source zone bedrock. Success in meeting this goal would mean realizing a reduction in the time, effort, and/or cost to establish and maintain goal No. 1.
3. **Limit potential for direct contact with PCB - and metals-containing soils in the vicinity of the BPA** – Success would mean that soil contaminants would be effectively precluded from potential human or ecological receptors.

The above goals and visions of success have informed the remedial technology screening process summarized below.

8.2 Identification and Screening of Remedial Technologies

To identify potential remedial technologies for review, we relied on several resources, including NYSDEC guidance[28] on presumptive or proven technologies for treatment of certain VOCs, review of literature/guidance pertaining to contaminated site remediation[29], and our own experience with remediation of contaminated sites in diverse hydrogeologic settings. We compiled a range of technologies, from conventional to those still in development, but based on the available literature, offer some field-based evidence that supports remediation of chlorinated VOCs in subsurface environments.

The remedial technologies included in this screening assessment are presented in Table 5 and are grouped into the following general categories:

- **Containment:** three technologies for capture/control of groundwater flow to limit contaminant migration, including vertical extraction wells, collection trenches in bedrock, and capping.

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[28] New York Department of Environmental Conservation DEC Program Policy, DER-15: Presumptive/Proven Remedial Technologies, February 27, 2007.

[29] Available from several internet sources, including USEPA’s website on hazardous waste clean-up information at http://www.clu-in.org, and the website of the Interstate Technology & Regulatory Council at http://www.itrcweb.org

- **In situ control:** four technologies to control/limit contaminant migration using in situ treatment methods, including phytoremediation, permeable reactive barriers (PRBs), electrochemical barriers, and monitored natural attenuation.

- **Source mass removal with ex situ treatment:** four technologies to actively remove contaminant mass from the source zone in combination with ex situ treatment methods. These technologies include source zone excavation, soil vapor extraction, dual-phase extraction, and thermally enhanced extraction.

- **Source mass removal with in situ treatment:** three technologies to reduce source zone contaminant mass using in situ treatment methods, including chemical oxidation, chemical reduction, and enhanced biochemical degradation (i.e., biostimulation/bioaugmentation).

Table 5 also includes a review of technologies that could be considered for ex situ treatment of VOCs, and technologies that might be used in several different remedial applications for improving performance by enhancing permeability (e.g., hydraulic, pneumatic, or explosive fracturing).

A general process description of each technology and a general vision of how it might be applicable to the site are provided in Table 5. Further, the table documents the technology evaluation process against the potential remedial goals using various screening criteria, which include site characteristics, contaminant characteristics, and technology limitations. The outcome of the screening process is noted in the table for each technology as either “retain” or “eliminate”, along with a summary of the outcome rationale.

8.2.1 Screening Criteria for Potential Remedial Technologies

As documented in Table 5, in evaluating the potential for a given remedial technology to meet one or more of the potential remedial goals, the screening criteria included consideration of site characteristics, contaminant characteristics, and technology development/limitations. Key considerations for these evaluation criteria included the following:

- Groundwater flow through and downgradient from the contaminant source zone is relatively small – on the order of a few gallons per minute. This relatively low volumetric rate is generally favorable to hydraulic containment and migration control technologies.

- The depth of the primary source zone in bedrock is relatively shallow, with most of the mass located 15 feet or less below ground surface. This depth is generally favorable to containment or direct removal technologies (e.g., excavation for a groundwater collection trench or to remove source mass in rock).

- The confirmed presence of the majority of the source mass in the rock matrix means that mass transfer out of the rock will be limited by the rate of diffusion. This condition is generally unfavorable to in situ mass removal technologies (e.g., in situ chemical oxidation, in situ chemical reduction) and those that are based on contaminant extraction and ex situ treatment (e.g., dual-phase extraction, thermally enhanced extraction).

- The primary site contaminants, which consist principally of TCE and its daughter products, are generally amenable to a wide range of in situ and ex situ remedial technologies. However, the presence of other compounds and contaminants (e.g., alcohols, hydrocarbons) may make certain technologies less favorable because of their relatively narrower scope of applicability.

- Many of the developing technologies lack a proven track record for application to chlorinated VOCs in sedimentary bedrock media.

While several of the technologies have been identified by NYSDEC as “proven” or presumptive, this characterization generally applies to CVOCs in saturated and unsaturated soils, not to VOC source mass present in a rock setting. We are not aware of a technology that has been proven for remediation of chlorinated VOCs in a fractured sedimentary bedrock system or offers the potential to completely restore this site. This statement is made based on a review of the current peer-reviewed literature, observed presentations at recent technical conferences, and EPA, DOE, and DOD documentation of case studies for remedial technological merit. In this context, our assessment broadly considered these technological limitations with respect to remediation of a fractured bedrock system, and we have retained technologies that we believe are reasonably worthy of further assessment as part of the alternatives analysis.

8.2.2 Preliminary Cost Assessment for Remedial Technologies

The preparation of detailed capital and operations and maintenance (O&M) costs for remedial technologies would be premature without more specific details on remedial goals, design criteria, and performance metrics. This development of details to support remedial cost analysis will be conducted as part of the alternatives analysis. However, we have ranked the technologies in Table 5 by their relative capital cost potential. The relative cost for each technology is outlined in Exhibit 8.2.

Technologies classified as “Low” cost are believed to carry potential capital costs less than $100,000. Those categorized as “Intermediate-Low” would be expected to carry capital costs in the range of $100,000 to $500,000, while “Intermediate-High” would be expected carry capital costs in the range of $500,000 to $1 million. Capital costs for remedial technologies greater than $1 million are categorized as “High”.

8.3 Outcome of Technology Screening

Exhibit 8.2 below presents the outcome of the remedial technology screening process documented in Table 5. As shown in Exhibit 8.2 of the 14 technologies included in this assessment, 9 were retained for the Alternatives Analysis in consideration of potential to address one or more of the remedial goals in part or in full (Exhibit 8.1). Among the 9 technologies, only 5 were identified by NYSDEC as proven technologies for remediation of chlorinated VOCs or metals in surficial soils or groundwater. These "proven" technologies include vertical extraction wells, collection trenches, capping, and source zone excavation. These technologies carry screening-level capital costs ranging from Intermediate-Low to High.

Exhibit 8.2 - Outcome of Preliminary Screening of Remedial Technologies

Technology	Screening Outcome	New York DER-15 Proven Remedial Technology		Potential Remedial Goal Addressed	Relative Cost Category
		Soil	Groundwater		
Vertical Extraction Wells	Retain	-	X	1	Intermediate-Low
Collection Trench	Retain	-	X	1	Intermediate-High to High
Capping	Retain	X	-	1, 3	Intermediate-Low
Phytoremediation	Retain	-	-	1	Intermediate-Low
Permeable Reactive Barrier (PRB)	Retain	-	-	1	High
Electrode Barrier	Eliminate	-	-	1	High
Monitored Natural Attenuation	Retain	-	-	1	Low
Source Zone Excavation	Retain	X	-	2	High
Subsurface Vapor Extraction	Eliminate	X	-	1, 2	Intermediate-High
Dual-Phase Extraction	Eliminate	X	X	1, 2	Intermediate-High
Thermally Enhanced Extraction	Retain	X	-	1, 2	High
***In Situ* Chemical Oxidation**	Eliminate	-	X	2	High
***In Situ* Chemical Reduction**	Eliminate	-	X	2	High
Enhanced Biochemical Degradation	Retain	-	-	1, 2	Intermediate-High

While not currently listed as proven technologies by NYSDEC, four other remedial technologies have been retained as potentially feasible for the Gun Club BPA. These include phytoremediation, permeable reactive barrier, monitored natural attenuation, and enhanced biochemical degradation. These technologies carry capital costs ranging from Low to High. The first three of these were retained as worthy of further evaluation toward meeting Goal 1. The fourth, enhanced biochemical degradation, was retained because of its potential to achieve Goal 1, and to a lesser degree Goal 2, by treating contaminant source mass *in situ* and reducing mass transport. Along with a documented track record of success in soil and bedrock media for CVOCs, it carries intermediate-high cost.

In situ thermal treatment/thermally enhanced extraction has been retained for consideration after discussions with IBM and NYSDEC representatives. Although we know of no successful implementation of this technology in a fractured rock setting and its' application would bring high cost and large energy usage, it is retained for further screening including discussions with USEPA technology researchers and vendors.

Technologies that have been eliminated are those that offer low potential for success in meeting any of the remedial goals and/or because of their lack of a track record of performance in a bedrock setting. Soil vapor extraction, dual-phase extraction, and *in situ* chemical oxidation have been eliminated primarily because they offer little potential to address mass in the rock matrix. Electrode barriers, and *in situ* chemical reduction, have been eliminated primarily because in addition to the challenges of addressing contaminant mass in bedrock, they lack a track record in similar settings that could provide a basis for evaluation.

8.4 Recommendations for Alternative Analysis

The remedial technologies retained from the screening process have been assembled in Exhibit 8.3 below to form remedial alternatives. They include three alternatives categorized as Containment/Migration Control alternatives, and one alternative categorized as a Source Reduction alternative. These alternatives will be subject to an Alternatives Analysis to be submitted separately. Other alternatives may also be developed and evaluated depending on further detailed review of the retained technologies as part of the Alternatives Analysis.

Exhibit 8.3 – Technology Combinations Identified for Alternatives Analysis

Containment/Migration Control – Alternatives to intercept and treat, either *in situ* or *ex situ*, VOC-containing groundwater flowing laterally away from the source zone in the uppermost highly fractured rock.

- **Enhanced Biochemical Degradation –** Expansion and enhancement of existing in situ biochemical degradation within and proximate to the source zone by injection of amendments and/or microorganisms into the subsurface coupled with downgradient groundwater extraction and recirculation to create a subsurface mixing zone. Hydraulic or pneumatic fracturing could be used to enhance/improve the permeability and effectiveness of the treatment zone.

- **Groundwater Extraction and Treatment –** Extraction using drilled wells or a collection trench coupled with *ex situ* treatment. Our current vision for the extraction system includes creating a zone of enhanced permeability using hydraulic or pneumatic fracturing and extraction from larger diameter borehole.

- **Permeable Reactive Barrier –** Treatment of VOC-containing groundwater *in situ* by constructing a trench containing a reducing agent, such as zero-valent iron, across the path of lateral groundwater flow away from the source zone.

Source Reduction – Alternatives to reduce the amount of VOC mass in the rock matrix that currently provides an on-going source for groundwater contamination.

- **Excavation and Ex Situ Treatment/Disposal of Source Zone Rock –** Partial removal of bulk rock containing the majority of VOC mass by excavation and treatment/disposal on or off-site.
- **In Situ Thermal Treatment/Thermally Enhanced Extraction –** Application of in situ thermal heating of rock and vacuum extraction to remove VOC mass from primary source rock.

By convention, in addition to the above, the alternatives analysis will consider no further action and monitored natural attenuation, and an unrestricted remedy for soils.

Capping and phytoremediation were retained for consideration as possible components of one or more of the alternatives. For example, capping could supplement groundwater extraction by reducing the volume of water requiring capture and treatment. Phytoremediation may supplement one or more of the alternatives. Capping and fencing have been retained along with excavation and offsite disposal have been retained to address PCB and metals containing surface soils.

Three of the five alternatives identified in Exhibit 8.3 will require pilot testing or performance testing. Enhanced biochemical degradation would require pilot testing to confirm short term effectiveness, assess for long term viability and the potential for negative outcomes such as accumulation of vinyl chloride, and to develop data to support full scale application. Test excavation and testing of rock is necessary to better understand the potential effort and cost for excavation and "treatability" of the excavated materials. In situ thermally enhanced extraction would require treatability testing and/or extensive pilot testing to demonstrate feasibility. Given the apparent stability of site conditions, questions about the practicability of these technologies, and the high range of potential costs, IBM intends to complete treatability and pilot testing as a part of the Alternatives Analysis.

9.0 SUMMARY OF FINDINGS AND CONCLUSIONS

This section provides a summary of findings and conclusions based on the Remedial Investigation at the IBM Gun Club – BPA from April 2006 to December 2008. The investigation included sampling and laboratory analysis of soils, soil vapor, surface water, groundwater, and rock core samples. The findings and conclusions are additionally summarized on Figure 12 of this report. Consistent with our initial understanding, TCE was identified as the principal contaminant in terms of mass and distribution, with lesser concentrations of the breakdown products cDCE and VC, as well as a limited presence of carbon tetrachloride, petroleum hydrocarbons, and ketones.

Soil vapor and soil sampling within the 1980 soil excavation in the BPA has confirmed that soils with residual petroleum and solvents were successfully removed. Although evidence of former Burn Pit activities remains in the surficial soil in the form of certain trace metals and PCBs. The observed concentrations that cannot be attributable to natural background conditions

substantially meet the NYS default cleanup objectives for commercial site use. We infer that residuals from as little as a few hundred gallons of mixed non-aqueous phase petroleum oils, ketones and chlorinated solvents can explain the observed presence of VOCs in the unfractured rock matrix that is an on-going source of VOCs in groundwater flowing in fractures. The mixture of non-aqueous phase oils and solvents had spread mostly laterally from the Burn Pit southwest beneath an approximately 1.6 acre area principally beneath IBM property.

In contrast with other sites where dense non-aqueous phase liquids were released in a bedrock setting, the vertical extent of primary sourcing in rock is limited largely to the top 15 ft below ground surface and has not penetrated to depth. This finding attributed to the predominance of near-horizontal, bedding-parallel fracturing and historical release of a mixture of petroleum oil and mixed solvents. Nearly all of the primary source rock was found beneath IBM property. A very small proportion of the total mass is mobile in groundwater flowing in the fractures while the vast majority resides in the rock matrix where the mobility is limited by sorption and diffusion.

TCE concentrations in groundwater samples in the 100s to 1,000s of μg/L were only observed in wells screening fractures in the top 15 feet of subsurface directly within the primary source rock beneath IBM property. The VOC presence in groundwater outside and downgradient of the primary source rock is one to two orders of magnitude lower reflecting limited mass export from the primary source rock. The extent of VOCs in groundwater has been defined vertically and horizontally based on data from monitoring wells, rock probes, and surface water sampling. The presence of VOCs including TCE at concentrations above ambient groundwater quality and drinking water standards is largely limited to the upper 15 ft of bedrock and is believed to reflect a condition that will not worsen with time and is more likely to marginally improve even with no action.

The key conclusions of the Remedial Investigation include:

1. Considering that VOCs may have first entered the ground 50 to 60 years ago, and considering that the estimated advective groundwater seepage velocities are on the order of thousands of feet per year, we believe that the documented limited lateral and vertical extent of VOCs in groundwater represents a steady-state condition that is not expected to change with time. This condition s largely attributed to diffusion of VOC mass into the rock matrix and retardation by organic carbon present in rock, and to a lesser extent, by natural biological attenuation processes.

2. No private or public water supplies are affected by the conditions attributed to the BPA, including well GC-A, the on-site water supply well located adjacent to the BPA, that supplies water for non-potable use Building 665 and . Private and public water supplies are not at risk including the public water supply used by the Binghamton Country Club for all its operations including irrigation.

3. Given the data collected to date, human exposure to site-related contaminants is not occurring through drinking water or soil vapor under the present use conditions. Engineered

controls and access to public water would limit future exposure in the event of future development on the Country Club property. There is marginal potential for exposure of trespassers to metal- and PCB-containing soils that are outside the fenced area on the Gun Club property. As there is no apparent reason or attraction for trespass on this area of the property, we believe that the potential for realizing incidental, non-systematic human exposure is negligible.

4. Low concentrations of BPA-related VOCs were found in water samples collected from three wet areas believed to be related to groundwater discharge to the ground surface. The areas include: 1) a limited area of the Gun Club property south of the BPA fenced area and the property boundary centered on BP-9A, 2) the surface drainage associated with the man-made pond, and 3) what is believed to be a man-made drainage feature along Robinson Hill Road. Human contact is possible in that access is not restricted to each of the three areas. Our observations of site conditions indicate no regular systematic use of the specific areas that would result in regular direct human contact. We estimate that any potential exposure related to the wet areas would be incidental, short duration, and dermal in nature.

Nine remedial technologies are to be evaluated as part of an Alternative Analysis against remedial goals of reducing the downgradient mass flux of VOCs, reducing the identified source mass in bedrock, and achieving the appropriate soil cleanup objectives. The Alternative Analysis will be summarized in a separate report to follow.

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TABLES

FIGURES

EXHIBITS

APPENDICES

EXECUTIVE SUMMARY

This report presents the findings of Remedial Investigations (RI) associated with the former Burn Pit Area of the IBM Gun Club Property (BPA). The work was conducted by Sanborn, Head & Associates, Inc. (SHA) under contract with the International Business Machines Corporation (IBM) under the New York State Brownfield Cleanup Program (BCP) administered by the New York State Department of Environmental Conservation (NYSDEC). The project was led by IBM Corporate Environmental Affairs under BCP Agreement No. C704044 executed by IBM and NYSDEC on August 22, 2005.

The IBM Gun Club property is a 53.4-acre parcel of land located on top of a hill west of Robinson Hill Road in the Town of Union in Broome County, New York. The focus of this work was to investigate environmental conditions that could be remaining from a historical disposal practice where solvents and oils were burned in an excavated pit. The primary incentive for this RI was the apparent on-going presence of certain volatile organic compounds (VOCs) in groundwater samples withdrawn from several bedrock monitoring wells. The wells were located in the vicinity of the BPA where IBM had voluntarily conducted removal of VOC-containing soils in the early 1980s.

This report communicates the data, inference, and conclusions derived from the RI. It also presents an assessment of the need and possible goals for remediation, and the identification and screening of potentially applicable remedial technologies. An analysis of remedial alternatives, referred to in the Brownfields Rules as an "Alternatives Analysis", is being conducted and will be submitted under separate cover.

The RI work included intensive investigation of subsurface conditions using a combination of technologies focused on characterizing suspected sourcing of VOCs from solvent mass diffused into extremely low permeability sedimentary bedrock. The work was also focused on characterizing bedrock fracturing that represents the primary migration pathway for VOCs in groundwater. The investigation included the sampling and analysis of groundwater, surface water, soil, subsurface vapors and rock. The primary findings are reviewed on the attached Executive Summary Figure.

Using innovative rock core analysis (CORE™) technology, the RI has confirmed and defined that the primary source of on-going groundwater contamination is VOC mass residing in the matrix of rock beneath about a 1.6 acre area, extending from the BPA in a southerly direction. Nearly all of the VOC mass resides in the rock matrix within the upper 15 ft of subsurface. The unfractured rock matrix is essentially impermeable to water flow and VOCs are physically and chemically sorbed to the rock solids. A minute fraction of the total mass resides in groundwater flowing through fractures in the rock fed by diffusion from the rock matrix. The overall volumetric and VOC mass flux in groundwater through this primary source rock is small, on the order of a few gallons per minute and tenths of a pound per year, respectively.

Detailed characterization of bedrock fracturing successfully identified zones of higher permeability where the majority of the groundwater flow occurs. The data document that groundwater breaks out as seeps and springs along the hill slope south of the BPA.

The extent of VOC contamination in groundwater exceeding relevant water quality standards is limited to the top 40 feet or less of the subsurface beneath IBM property and found within 1,000 feet downgradient beneath an undeveloped wooded area and a small portion of a golf course on property adjacent to IBM's Gun Club property. The limited extent is consistent with what is estimated based on transport modeling and not expected to expand with time.

Given the data collected to date, human exposure to site-related contaminants is not occurring through private or public water supplies or soil vapor under present site use conditions. There is limited potential for human exposure to IBM site trespassers to metal and polychlorinated biphenyl (PCB) containing soils. Human exposure to low levels of VOCs found in three areas of seeps and/or springs is possible. Although access is not restricted to these areas, we have observed no evidence of systematic use of these limited areas that would result in regular human contact which, if at all, would be incidental and primarily dermal in nature.

Although there is no proven technology to completely restore the BPA and its relevant vicinity, the Alternatives Analysis to follow this RI report will evaluate potential combinations of remedial technologies to reduce the downgradient VOC mass flux from the source zone, and reduce VOC source mass, and limit potential for human contact with soil and groundwater seepage. Pilot testing will be required to demonstrate the effectiveness of some of the alternatives, and/or to support full scale design, and better assess potential level of effort and cost.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

1,1,1-TCA	1,1,1-Trichloroethane
1,1,2-PCA	Tetrachloroethane
1,1,2-TCA	1,1,1-Trichloroethane
1,1-DCE	1,1-dichloroethene
340°	azimuth range of 340°
Agreement	BCP Agreement No. C704044
Al	aluminum
AMSL	above mean sea level
As	arsenic
ATV/OTV	acoustic and optical televiewer geophysics
B665	Building 665 facility
bgs	below ground surface
BCA	Brownfield Cleanup Agreement
BCDOH	Broome County Department of Health
BCP	Brownfield Cleanup Program
BPA	Burn Pit Area including the Burn Pit and the Historical Excavation of Soil and Rock
BTEX	benzene, toluene, ethyl benzene, xylenes
C/C_O	concentration ratio
Ca	calcium
Cd	cadmium
cDCE	cis-1,2-dichloroethene
CF	chloroform
cm	centimeters
cm/sec	centimeters per second
cm^2/sec	square centimeters per second
CM	chloromethane
conjugate	secondary joint sets
Consortium	University Research Consortium
Country Club	Binghamton Country Club
Core™	Rock VOC Analysis
CPP	Citizen Participation Plan
Cr	chromium
Cr (III)	reduced species of chromium, trivalent chromium
Cr(VI)	oxidized species of chromium, hexavalent chromium
PCM	Carbon tetrachloride/Perchloromethane
Cu	copper
CVOC	chlorinated volatile organic compound
D_e	diffusion coefficient
DFN	Discrete fracture network
DQO	Data Quality Objective
DOE	Department of Energy
DOD	Department of Defense
DRO	diesel range orgnaics

substantially meet the NYS default cleanup objectives for commercial site use. We infer that residuals from as little as a few hundred gallons of mixed non-aqueous phase petroleum oils, ketones and chlorinated solvents can explain the observed presence of VOCs in the unfractured rock matrix that is an on-going source of VOCs in groundwater flowing in fractures. The mixture of non-aqueous phase oils and solvents had spread mostly laterally from the Burn Pit southwest beneath an approximately 1.6 acre area principally beneath IBM property.

In contrast with other sites where dense non-aqueous phase liquids were released in a bedrock setting, the vertical extent of primary sourcing in rock is limited largely to the top 15 ft below ground surface and has not penetrated to depth. This finding attributed to the predominance of near-horizontal, bedding-parallel fracturing and historical release of a mixture of petroleum oil and mixed solvents. Nearly all of the primary source rock was found beneath IBM property. A very small proportion of the total mass is mobile in groundwater flowing in the fractures while the vast majority resides in the rock matrix where the mobility is limited by sorption and diffusion.

TCE concentrations in groundwater samples in the 100s to 1,000s of μg/L were only observed in wells screening fractures in the top 15 feet of subsurface directly within the primary source rock beneath IBM property. The VOC presence in groundwater outside and downgradient of the primary source rock is one to two orders of magnitude lower reflecting limited mass export from the primary source rock. The extent of VOCs in groundwater has been defined vertically and horizontally based on data from monitoring wells, rock probes, and surface water sampling. The presence of VOCs including TCE at concentrations above ambient groundwater quality and drinking water standards is largely limited to the upper 15 ft of bedrock and is believed to reflect a condition that will not worsen with time and is more likely to marginally improve even with no action.

The key conclusions of the Remedial Investigation include:

1. Considering that VOCs may have first entered the ground 50 to 60 years ago, and considering that the estimated advective groundwater seepage velocities are on the order of thousands of feet per year, we believe that the documented limited lateral and vertical extent of VOCs in groundwater represents a steady-state condition that is not expected to change with time. This condition s largely attributed to diffusion of VOC mass into the rock matrix and retardation by organic carbon present in rock, and to a lesser extent, by natural biological attenuation processes.

2. No private or public water supplies are affected by the conditions attributed to the BPA, including well GC-A, the on-site water supply well located adjacent to the BPA, that supplies water for non-potable use Building 665 and . Private and public water supplies are not at risk including the public water supply used by the Binghamton Country Club for all its operations including irrigation.

3. Given the data collected to date, human exposure to site-related contaminants is not occurring through drinking water or soil vapor under the present use conditions. Engineered

controls and access to public water would limit future exposure in the event of future development on the Country Club property. There is marginal potential for exposure of trespassers to metal- and PCB-containing soils that are outside the fenced area on the Gun Club property. As there is no apparent reason or attraction for trespass on this area of the property, we believe that the potential for realizing incidental, non-systematic human exposure is negligible.

4. Low concentrations of BPA-related VOCs were found in water samples collected from three wet areas believed to be related to groundwater discharge to the ground surface. The areas include: 1) a limited area of the Gun Club property south of the BPA fenced area and the property boundary centered on BP-9A, 2) the surface drainage associated with the man-made pond, and 3) what is believed to be a man-made drainage feature along Robinson Hill Road. Human contact is possible in that access is not restricted to each of the three areas. Our observations of site conditions indicate no regular systematic use of the specific areas that would result in regular direct human contact. We estimate that any potential exposure related to the wet areas would be incidental, short duration, and dermal in nature.

Nine remedial technologies are to be evaluated as part of an Alternative Analysis against remedial goals of reducing the downgradient mass flux of VOCs, reducing the identified source mass in bedrock, and achieving the appropriate soil cleanup objectives. The Alternative Analysis will be summarized in a separate report to follow.

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substantially meet the NYS default cleanup objectives for commercial site use. We infer that residuals from as little as a few hundred gallons of mixed non-aqueous phase petroleum oils, ketones and chlorinated solvents can explain the observed presence of VOCs in the unfractured rock matrix that is an on-going source of VOCs in groundwater flowing in fractures. The mixture of non-aqueous phase oils and solvents had spread mostly laterally from the Burn Pit southwest beneath an approximately 1.6 acre area principally beneath IBM property.

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2. No private or public water supplies are affected by the conditions attributed to the BPA, including well GC-A, the on-site water supply well located adjacent to the BPA, that supplies water for non-potable use Building 665 and . Private and public water supplies are not at risk including the public water supply used by the Binghamton Country Club for all its operations including irrigation.

3. Given the data collected to date, human exposure to site-related contaminants is not occurring through drinking water or soil vapor under the present use conditions. Engineered

controls and access to public water would limit future exposure in the event of future development on the Country Club property. There is marginal potential for exposure of trespassers to metal- and PCB-containing soils that are outside the fenced area on the Gun Club property. As there is no apparent reason or attraction for trespass on this area of the property, we believe that the potential for realizing incidental, non-systematic human exposure is negligible.

4. Low concentrations of BPA-related VOCs were found in water samples collected from three wet areas believed to be related to groundwater discharge to the ground surface. The areas include: 1) a limited area of the Gun Club property south of the BPA fenced area and the property boundary centered on BP-9A, 2) the surface drainage associated with the man-made pond, and 3) what is believed to be a man-made drainage feature along Robinson Hill Road. Human contact is possible in that access is not restricted to each of the three areas. Our observations of site conditions indicate no regular systematic use of the specific areas that would result in regular direct human contact. We estimate that any potential exposure related to the wet areas would be incidental, short duration, and dermal in nature.

Nine remedial technologies are to be evaluated as part of an Alternative Analysis against remedial goals of reducing the downgradient mass flux of VOCs, reducing the identified source mass in bedrock, and achieving the appropriate soil cleanup objectives. The Alternative Analysis will be summarized in a separate report to follow.

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TABLES

Table 1

Chronological Summary of Remedial Investigations and Testing

Remedial Investigation

IBM Gun Club - Former Burn Pit Area, Union, New York

DATE	EVENT	DISCUSSION	DOCUMENTATION
April/May 2006	Soil vapor survey, Initial Soil Sampling and Analysis, Burn Pit and Vicinity	The purpose of this work was to assess the presence of VOCs in soil vapor and soil within and in the vicinity of the former BPA. A subset of the soil samples were analyzed for trace metals cyanide, SVOCs, herbicides, pesticides, TPH and PCBs. Results of this testing were used to assess the soil conditions at the site and aid in selection of locations for subsequent rock core drilling and monitoring well installations.	Appendix C.1, C.3
April/May 2006	Geophysical Logging and Testing of Existing Bedrock Boreholes.	The purpose of the logging and testing was to better understand site bedrock stratigraphy and fracturing, groundwater levels, and hydraulic properties of the bedrock before installing additional monitoring wells. The data were also used to design a multilevel groundwater monitoring system to be installed in well GC-1.	Appendix D
July 2006	Rock coring and sampling. Installation of initial shallow and intermediate bedrock monitoring wells. Initial FLUTe installation in existing bedrock borehole GC-1.	The initial event of rock core drilling and sampling of rock matrix. The work was conducted cooperatively with representatives of the University of Waterloo (UW). Drilling and rock sampling was conducted at six locations in the vicinity of the BPA (BP-1 through BP-6). Rock samples from the six rock coring locations were analyzed for VOCs by UW and LLI. A subset of samples were submitted Golder, Inc. for physical parameter testing.	Appendix F.2 Appendix F.5- physical properties testing
		Monitoring wells were installed at locations BP-1 to BP-6, and a shallow companion well was installed at location BP-2A.	Appendix B.2 Logs in Appendix B.3.1
		A multi-level monitoring system (manufactured by Flexible Liner Underground Technologies, LLC) was installed in the existing 97 ft deep bedrock well (GC-1) on July 25, 2006. The multi-level system has eight monitoring ports.	Appendix D
July 2006	First Water Quality Monitoring Event	The monitoring wells and multi-level systems were sampled on a quarterly basis after development. The first water quality monitoring event occurred in July 2006. Beginning in June 2008, a subset of surface water locations, first sampled in February 2008, were also included in the quarterly water quality monitoring program.	Appendix I
October through December 2006	Initial phase of drilling observation and logging of bedrock boreholes and the design and installation of monitoring wells and multilevel monitoring devices.	The initial drilling of deep bedrock boreholes and multi-level monitoring devices (BP-12D and BP-13D) were intended to further characterize bedrock conditions and establish monitoring intervals at depth between the known area of contamination and surface drainage courses to the east and west that are likely points of groundwater discharge. The intent was to identify and monitor zones of apparent fracture concentration that may be more conducive to groundwater flow and VOC migration compared to unfractured rock. The elevations of the monitoring intervals were chosen to complement existing monitoring well screen intervals and multi-level devices, allowing for further assessment of both vertical and horizontal hydraulic gradients and water quality patterns.	Appendix E.1
		Drilling of bedrock borings and installation of groundwater monitoring wells were intended to provide data for better characterization of the near-surface bedrock morphology, and establish monitoring points in the uppermost more highly fractured bedrock where the majority of the VOC mass is believed to reside. A total of 9 monitoring wells screening the water table were installed in the vicinity of the former BPA (BP-1A, -4A, -5A, -7A, -11A, -12A, and 13A) and along the southern IBM Gun Club property line (BP-8A, - 9A, and -10A).	Appendix B.2 Logs in Appendix B.3.2
April 2007	Initial phase of Direct Push Rock Probe Borings and wet area sampling on the Gun Club Property.	The work was completed to further assess subsurface conditions near the southern IBM Gun Club property boundary as needed to support siting of bedrock rock core sampling locations for a second rock matrix testing event. Groundwater samples from 26 temporary rock probe wells installed to bedrock refusal depth and surface water samples from three wet areas were analyzed for VOCs in a mobile laboratory at the site.	Appendix F.3.1

Notes:

1. This table is intended to provide an overview of the overall scope and sequence of work associated with the remedial investigation of the IBM Gun Club fomer Burn Pit Area as coordinated, observed and logged by Sanborn, Head & Associates, Inc. (SHA) personnel. The table is also intended to serve as an index to documentation of these activities in the Appendices of this report. Please refer to the report text and appendices for additional detail.

2. The following abbreviations are used in the table:
BPA = Burn Pit Area; VOCs = Volatile Organic Compounds; SVOCs = Semivolatile Organic Compounds; TPH = Total Petroleum Hydrocarbons; PCBs = Polychlorinated Biphenyls; UW = University of Waterloo; UG = University of Guelph; LLI = Lancaster Laboratories.

Table 1
Chronological Summary of Remedial Investigations and Testing
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

DATE	EVENT	DISCUSSION	DOCUMENTATION
April/May 2007	Second Phase of Bedrock Field Investigations and Testing	Rock core sampling was conducted with UW at fourteen locations in the vicinity of the former BPA and on a southerly section of the IBM Gun Club property. The work was performed to further assess potential VOC sourcing in rock related to the former burn pit activities.	Appendix F.3.2
		Rock core drilling and installation of monitoring wells screening the water table in the upper most highly fractured zone of bedrock were performed in areas north (BP-16A) and east (BP-15A) of the former BPA, and along the southerly property boundary (BP-14A and BP-17A). Additionally the open borehole GC-2 was partly filled with grout completed as a shallow monitoring well GC-2A. The objective of this work was to further characterize the presence of VOCs in groundwater in areas periphial to the former BPA.	Appendix B.2 Logs in Appendix B.3.3
		Rock core drilling of two deep borings, BP-14D located at the southerly property boundary, and BP-15D located east of the former BPA was performed. Hydrogeophysical logging was performed on the open boreholes. The findings of this work were used to design FLUTe multilevel devices for these boreholes.	Appendix E.2
June/July/August 2007	Competing BP-14D and BP-15D with multi-level devices.	A seven port multi-level system equipped with Level Troll 300 pressure and temperature transducers was installed in BP-15D during the week of June 25, 2007. A 6 port multi-level system with Level Troll 300 pressure and temperature transducers was installed in BP-14D the week of July 30, 2007.	Appendix E.2
January/February 2008	Visual reconnaissance of the Binghamton Country Club and ajacent properties and sampling of wet areas.	With the approval of the Binghamton Country Club, SHA personnel conducted a visual reconnaissance of a portion of the northern most Country Club property with a particular focus on identification and mapping of geologic and hydrologic features such as man-made and natural drainages, and other wet areas indicative of groundwater discharge. Samples of water and "stream sediments" were collected at the locations where sufficient water was available to support the sampling. Observations of reconnaissance and wet area sampling were used to develop an initial plan for direct push rock probe exploration locations.	Appendix F.4.1
February/March 2008	Direct Push Rock Probe Installation and Sampling on the Binghamton Country Club property.	The work included sampling of groundwater from 101 temporary monitoring wells installed in "rock probe boreholes" drilled by the direct push method to refusal depth on top of bedrock. Samples were analyzed for VOCs in both mobile and fixed based laboratories. Analytical results were used to assess the presence and extent of VOCs on the County Club property and to site locations for the final phase of rock core samplinlg and monitoring well installation.	Appendix F.4.1
April/May 2008	Final phase of rock core drilling and installing monitoring wells on IBM Gun Club and Binghamton Country Club Properties.	One shallow monitoring well (BP-18A) and fourteen (14) shallow and intermediate depth monitoring wells were drilled and installed on IBM Gun Club and Binghamton Country Club properties, respectively.	Appendix B.2 Logs in Appendix B.3.4.
May 2008	Robinson Hill Road private water supply sampling.	Sampling of five residential water supply wells located southeast of the former BPA and east of Robinson Hill Road. The sampling was offered to the homeowners to confirm previous sampling in 2003.	Confidential Reports Submitted to Agencies June 9 and August 5, 2008.

Notes:

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2. The following abbreviations are used in the table:
BPA = Burn Pit Area; VOCs = Volatile Organic Compounds; SVOCs = Semivolatile Organic Compounds; TPH = Total Petroleum Hydrocarbons; PCBs = Polychlorinated Biphenyls; UW = University of Waterloo; UG = University of Guelph; LLI = Lancaster Laboratories.

Table 1
Chronological Summary of Remedial Investigations and Testing
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

DATE	EVENT	DISCUSSION	DOCUMENTATION
June 2008	Robinson Hill Road indoor air residential sampling.	Four homeowners accepted IBM's offer to sample indoor air in residences located southeast of the former BPA and east of Robinson Hill Road. The sampling included indoor air, subslab soil vapor and ambient air.	Confidential Reports Submitted to Agencies July 23, 2008.
June 2008	Final phase of rock core matrix sampling on the IBM Gun Club and Binghamton Country Club property.	Rock core drilling and sampling was completed at 12 locations on Binghamton Country Club property and one location on the IBM Gun Club property. The work was conducted cooperatively with UG personnel to assess potential sourcing in rock from cores extracted from a southeasterly section of the IBM Gun Club propertya and areas on Binghamton Country Club property. Two rock coring locations (BP-30A and BP-31A) were completed as monitoring wells screening the water table in the uppermost highly fractured portion of rock.	Appendix F.4.2 Logs in Appendix B.3.4
July and September 2008	Supplemental Soil Sampling in the vicinity of the former BPA and in an area east of the former BPA.	Soil samples were collected using the direct push technique in an area east of the former BPA. This area is understood to be unaffected by former burn pit activities, and represents "background" soil conditions at the site. The samples were analyzed for a range of inorganic analytes.	Appendix C.2
		Soil samples were collected by the direct push techniques and from pit excavations in the vicinity of the former BPA. The objective was to further assess the soil conditions and to confirm findings of the May 2006 soil sampling. Samples were analyzed for PCBs and certain metals.	Appendix C.2, C.3
December 2006 through September 2008	Hydraulic property testing of monitoring wells and boreholes	Rising and falling head (slug) tests, borehole packer tests, and pulse recovery tests were conducted in monitoring wells, borings, and multilevel systems at the site to assess hydraulic properies related to storage, phase transfer, and transport in fractured bedrock systems.	Appendix B.6
September 2008	Preliminary Assessment of Groundwater Geochemistry	Groundwater samples along select transects from the former BPA to Binghamton Country Club property were analyzed for selected organic and inorganic compounds to better characterize site geochemical conditions and assess relevant biochemical degradation processes that are already occurring on site.	Appendix G
December 2008	Quarterly Water Level and Water Quality Sampling Event	The December 2008 quarterly sampling event was the last round of water quality monitoring included in the Remedial Investigatin Report. IBM intends to continue water quality monitoring on a biannual basis. The first water quality monitoring event is planned for April 2009.	Appendix I

Notes:

1. This table is intended to provide an overview of the overall scope and sequence of work associated with the remedial investigation of the IBM Gun Club fomer Burn Pit Area as coordinated, observed and logged by Sanborn, Head & Associates, Inc. (SHA) personnel. The table is also intended to serve as an index to documentation of these activities in the Appendices of this report. Please refer to the report text and appendices for additional detail.

2. The following abbreviations are used in the table:
BPA = Burn Pit Area; VOCs = Volatile Organic Compounds; SVOCs = Semivolatile Organic Compounds; TPH = Total Petroleum Hydrocarbons; PCBs = Polychlorinated Biphenyls; UW = University of Waterloo; UG = University of Guelph; LLI = Lancaster Laboratories.

Table 2
Summary of Organic Compounds and Metals Found in Samples
Remedial Investigation, IBM Gun Club
Former Burn Pit Area, Union, New York

COMPOUND/ ELEMENT	GROUNDWATER	SURFACE WATER	ROCK MATRIX	SOIL	SOIL VAPOR	SITE CONTAMINTNT?	COMMENTS
VOCs							
1-Hexanol, 2-ethyl	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected in a total of four groundwater samples at trace concentrations as a tentatively identified compound.
Acetone	X	X	X	X	--	Yes	Acetone has been detected in groundwater, surface water, rock matrix and soil samples. The compound is a frequent laboratory contaminant. Acetone is above groundwater standards in two locations near the former BPA and three ports from multilevel system BP-14D. The compound has historically been detected in GC-1 and GC-2.
Benzene	X		X			Yes	Benzene has frequently been detected at trace concentrations in groundwater in the vicinity of the former BPA, however, typically in tenths of a micrograms per liter. It was also detected in rock core samples from the uppermost 15 ft of bedrock. Five monitoring wells in the vicinity of the former BPA and one multilevel system interval exceeded the groundwater standard for benzene. Low benzene concentrations (few tenths of a microgram per liter) were detected in 4 out of 110 rock probe locations.
Bromodichloromethane	X				--	No	Bromodichloromethane is not a contaminant with a known historical presence at the site. It is a disinfection by-product commonly produced during the chlorination of municipal water supplies. Its isolated presence at the site in trace concentrations is probably related to investigations activities where large quantities of municipal water were used during rock core drilling. Another possible source is from irrigation of the golf courses with municipal water.
Bromoform	X				--	No	Bromoform is not a contaminant with a known historical presence at the site. It is a disinfection by-product commonly produced during the chlorination of municipal water supplies. Its isolated presence at the site in trace concentrations is probably related to investigations activities where large quantities of municipal water were used during rock core drilling. Another possible source is from irrigation of the golf courses with municipal water.
Bromomethane					--	No	Bromomethane is a disinfection by-product commonly produced during the chlorination of municipal water supplies. It was regularly tested but not detected in groundwater samples during the investigation period.
Butanone (2-)	X		X		--	Yes	Butanone(2-) has been detected at the site, but generally below the applicable groundwater standards and was detected in rock core samples from the uppermost 20 ft of bedrock. While certain groundwater detections are uncertain because of sample dilution, only BP-3 had concentrations that appear to be exceeding the groundwater standard.
Caprolactam	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected in one groundwater sample at a trace concentration as a tentative identified compound.
Carbon disulfide	X		X		--	No	Not a compound with a known historical presence at the site. It was detected at trace concentrations in groundwater and rock core samples near the former BPA.
Carbon tetrachloride	X	X	X		X	Yes	Carbon tetrachloride has historically been detected in GC-1 and GC-2.
Chlorobenzene	X				--	No	Not a compound with a known historical presence at the site. Chlorobenzene has been detected at trace concentrations the groundwater at four monitoring locations.
Chloroethane	X				--	No	Not a compound with a known historical presence at the site, but can be produced as a breakdown product of TCA. Chloroethane has only been infrequently detected at trace concentrations in groundwater at the site.
Chloroform	X	X	X	X	X	Yes	Chloroform has been detected in groundwater, surface water, and soil, and rock core samples collected at the site.
Chloromethane	X	X			--	Yes	Chloromethane has been infrequently been detected in groundwater samples. Chloromethane is a breakdown product of carbon tetrachloride, chloroform, and methylene chloride.
Cyclohexane	X		X		--	No	Cyclohexane is not a compound with a known historical presence at the site. It was infrequently detected at trace concentrations in groundwater, soil, and sediments.
Dibromo-3-chloropropane (1,2-)					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in samples collected at the site.
Dibromochloromethane	X				--	No	It is not a compound with a known historical presence at the site, but a known disinfection by-product. Analyzed for routinely, but infrequently detected at trace concentrations in the groundwater.
Dibromoethane (1,2-)					--	No	It is not a compound with a known historical presence at the site; developed for use as a pesticide/fumigant. Analyzed for routinely, but not detected in samples collected at the site.
Dichlorodifluoromethane					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in samples collected at the site.
Dichloroethane (1,1-)	X					No	Breakdown product of TCA. Analyzed for routinely, but infrequently detected in two samples at concentrations below the groundwater standard.
Dichloroethane (1,2-)	X		X		X	Yes	Breakdown product of TCE. Has frequently been detected in groundwater samples collected in the vicinity of the former BPA.
Dichloroethene (1,1-)	X		X		X	Yes	Breakdown product of TCE. Has been detected in groundwater samples collected in the vicinity of the former BPA.
Dichloroethene (cis-1,2-)	X	X	X	X	X	Yes	The primary breakdown product of TCE. It has frequently been detected in groundwater, surface water, soil, and rock core samples on site.
Dichloroethene (trans-1,2-)	X	X				Yes	Breakdown product of TCE. Detected at one surface water seep and in the groundwater at several locations on site, typically at trace concentrations.
Dichloropropane (1,2-)	X				--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but infrequently detected. Detected in one groundwater sample at a concentration below the groundwater standard.
Dichloropropene (cis-1,3-)					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in samples collected at the site.
Dichloropropene (trans-1,3-)					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in samples collected at the site.
Diethyl ether	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound in three locations near the former BPA.

Notes:

1. The table consists of validated and unvalidated laboratory analysis of samples collected in the period April 2006 to December 2008 on IBM Gun Club and Binghamton Country Club property. The water, soil, rock, and soil vapor samples were analyzed by Microseeps Laboratory of Pittsburgh, PA, Lancaster Laboratory of Lancaster, PA, University of Waterloo, Ontario, Canada, Guelph University, Ontario, Canada, or Stone Environmental, Inc. Montpelier, VT. The samples were analyzed using appropriate analytical techniques as discussed in the March 2006 Remedial Investigation Work Plan for the IBM Gun Club.

2. "Groundwater" indicates samples collected in monitoring wells, water supply well, or multi-level system. "Surface Water" indicate grab water sample collected from spring, seep, drainage or pond. "Rock Matrix" indicate analytical results of rock core samples. "Soil" indicate samples collected from test pits, drill cuttings, or surface sediment grab samples. "Soil Vapor" samples were collected from temporary monitoring points installed April 2006.

3. An "X" indicate that the compound or element has been detected in the indicated matrix. A blank indicate that the compound/element was not detected by the laboratory analysis. "--" indicate that the matrix was not analyzed for the compound/element.

4. Determination if compound/element is a site contamination is made based on review of pre 2006 data and data collected April 2006 to December 2008. A "(Yes)" indicates that the compound/element has not historically been considered a site contaminant, but that the RI investigation has found evidence of elevated concentrations.

5. VOCs are volatile organic compounds, SVOCs are semi-volatile organic compounds, THMs are trihalomethanes, MCLs are maximum contamination levels, SCOs are soil cleanup objectives and ug/L is micrograms per liter.

6. Please refer to Remedial Investigation Report text for further discussion.

Table 2
Summary of Organic Compounds and Metals Found in Samples
Remedial Investigation, IBM Gun Club
Former Burn Pit Area, Union, New York

COMPOUND/ ELEMENT	GROUNDWATER	SURFACE WATER	ROCK MATRIX	SOIL	SOIL VAPOR	SITE CONTAMINTNT?	COMMENTS
Ethylbenzene	X		X			Yes	Ethylbenzene has been detected in groundwater in the vicinity of the former burn pit and in rock core samples from the uppermost 10 ft of bedrock.
Heptanal	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound at one location near the former BPA.
Hexanal, 2-ethyl-	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound at one location near the former BPA.
Hexanone (2-)					--	No	Not a compound with a known historic use at the site. Analyzed for routinely, but not detected in samples collected at the site.
Isopropylbenzene	X		X		--	Yes	Not a compound with a known historic use at the site. Analyzed for routinely, but detected in a limited number of groundwater and rock core samples.
Methyl Acetate	X		X		--	No	Methyl Acetate was detected in rock core samples from the uppermost 30 ft of bedrock, but has only been infrequently detected at trace levels in groundwater samples collected in the vicinity of the former BPA.
Methyl mercaptan	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected as a tentatively identified compound at trace concentrations in a limited number of samples.
Methyl-2-pentanone (4-)	X		X		--	Yes	Methyl-2-pentanone(4-) was detected in rock core samples from the uppermost 15 ft of bedrock, and has also been detected in groundwater samples and multilevel system ports on the site.
Methylcyclohexane	X		X		--	No	Methylcyclohexane was detected in rock core samples from the uppermost 30 ft of bedrock, but has been infrequently detected at trace levels in groundwater samples collected in the vicinity of the former BPA.
Methylene chloride	X		X		--	Yes	Methylene Chloride was detected in rock core samples from the uppermost 20 ft of bedrock, but has been infrequently detected in groundwater and surface water samples at the site.
Methyl-tert Butyl Ether					--	No	Not a compound with a known historic use at the site. Analyzed for routinely, but not detected in samples collected at the site.
Nonanal	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound in a limited number of groundwater samples.
Octanal	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound in two locations near the former BPA.
Propylbenzene (n-)	X	--	X	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound in one locations near the former BPA.
Propylene	X	--	--	--	--	No	Not frequently tested or detected at the site. Detected at trace concentrations as a tentatively identified compound in a limited number of groundwater samples.
Styrene					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in samples collected at the site.
Tetrachloroethane (1,1,2,2-)					X	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in groundwater samples collected at the site.
Tetrachloroethene	X		X	X	X	Yes	Analyzed for routinely, but infrequently detected in groundwater, soil, and rock core samples.
Toluene	X		X			Yes	Toluene has been detected in groundwater and rock core samples. Elevated toluene concentrations in groundwater associated with FLUTe$^{\text{TM}}$ liners has been reported at concentrations similar to what has been observed multilevel systems at the Gun Club.
Trichloro-1,1,2-trifluoroethane-1,2,2						No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in groundwater samples collected at the site.
Trichloroethane (1,1,1-)	X				X	Yes	Detected infrequently at the site, in soil vapors within the vicinity of the former burn pit area and in one groundwater monitoring well.
Trichloroethane (1,1,2-)	X				--	Yes	Detected in soils in the vicinity of the former burn pit area at levels below SCO guidelines. 1,1,2-TCA has infrequently been detected in groundwater samples near the former BPA, at concentrations above applicable groundwater quality standards at one location. The compound has historically been sporadic detected in GC-1 and GC-2.
Trichloroethene	X	X	X	X	X	Yes	The principal compound at the site that has been detected in groundwater, surface water, soil, and rock core samples.
Trichlorofluoromethane					--	No	It is not a compound with a known historical presence at the site. Analyzed for routinely, but not detected in groundwater samples collected at the site.
Vinyl chloride	X		X			Yes	The primary breakdown product of cDCE and TCE. It has been detected in groundwater and rock core samples on site.
Xylene (m,p-)	X		X			Yes	Xylenes have been detected in groundwater and rock matrix samples.
Xylene (o-)	X		X	X		Yes	Xylenes have been detected in groundwater and rock matrix samples.
PCBs							
Aroclor-1254		--	--	X	--	Yes	PCBs were detected in soils in the vicinity of the former burn pit area, but not in groundwater. The soil concentrations met the residential SCO.
Aroclor-1260		--	--	X	--		

Notes:

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2. "Groundwater" indicates samples collected in monitoring wells, water supply well, or multi-level system. "Surface Water" indicate grab water sample collected from spring, seep, drainage or pond. "Rock Matrix" indicate analytical results of rock core samples. "Soil" indicate samples collected from test pits, drill cuttings, or surface sediment grab samples. "Soil Vapor" samples were collected from temporary monitoring points installed April 2006.

3. An "X" indicate that the compound or element has been detected in the indicated matrix. A blank indicate that the compound/element was not detected by the laboratory analysis. "--" indicate that the matrix was not analyzed for the compound/element.

4. Determination if compound/element is a site contamination is made based on review of pre 2006 data and data collected April 2006 to December 2008. A "(Yes)" indicates that the compound/element has not historically been considered a site contaminant, but that the RI investigation has found evidence of elevated concentrations.

5. VOCs are volatile organic compounds, SVOCs are semi-volatile organic compounds, THMs are trihalomethanes, MCLs are maximum contamination levels, SCOs are soil cleanup objectives and ug/L is micrograms per liter.

6. Please refer to Remedial Investigation Report text for further discussion.

Table 2
Summary of Organic Compounds and Metals Found in Samples
Remedial Investigation, IBM Gun Club
Former Burn Pit Area, Union, New York

COMPOUND/ ELEMENT	GROUNDWATER	SURFACE WATER	ROCK MATRIX	SOIL	SOIL VAPOR	SITE CONTAMINTNT?	COMMENTS
SVOCs							
Acetophenone	--	--	--	X	--	No	SVOCs have been infrequently tested and were not typically detected in samples at the sites. If present, concentrations have been below applicable groundwater quality standards or soil cleanup objectives.
Aniline	X	--	--	--	--	No	
Dichlorobenzene (1,2-)	X	--	X		--	No	
Dichlorobenzene (1,3-)		--			--	No	
Dichlorobenzene (1,4-)		--	X		--	No	
Ethanol, 2-(2-ethoxyethoxy)	--	--	--	X	--	No	
Pentanone,4-hydroxy-4-methyl		--	--	X	--	No	
Trichlorobenzene (1,2,4-)	X				--	No	
Pesticides							
Endrin		--	--	X	--	No	Pesticides have only been detected at low concentrations in soil, typically below the lowest quantifiable limit for the analytical techniques and the concentrations have therefore typically been estimated.
Endrin aldehyde		--	--	X	--	No	
Herbicides							
Dinoseb	--	--	--	X	--	No	Herbicides have been detected in soil at low concentrations in the vicinity of the former burn pit area. The detections were in all cases below the lowest quantifiable limit for the analytical methods and are therefore estimated.
MCPA	--	--	--	X	--	No	
MCPP (Mecoprop)	--	--	--	X	--	No	
Total Petroleum Hydrocarbons (including diesel and gasoline range)							
Petroleum related Hydrocarbons	X	--	--	X	--	Yes	Petroleum related hydrocarbons have been detected in soils in the vicinity of the former burn pit area. Gasoline or diesel range organics detected in groundwater are found in the vicinity of the former burn pit area. The presence of petroleum hydrocarbons appears to be limited to groundwater with significant concentrations of VOCs (>1000 ug/L; BP-2A, BP-3 and BP-9A).
METALS							
Aluminum	X	--	--	X	--	Yes	Groundwater samples collected from five locations near the former BPA exceeded EPA secondary MCL guidance values for aluminum. This is likely due to chemically-reducing conditions that exists in the former BPA promoting dissolution of naturally occuring aluminum. All analyzed soil sample met the unrestricted use and protection groundwater soil cleanup objectives.
Antimony		--	--	X	--	No	Antimony was not detected in groundwater samples collected at the site. Soil samples meet the unrestricted use SCO guidance values.
Arsenic	X	--	--	X	--	No	Arsenic was detected in the groundwater at two monitoring locations near the former BPA at concentrations that met the applicable groundwater quality standards. Review of soil "background" analytical results indicated that soils in the area are naturally elevated in arsenic.
Barium	X	--	--	X	--	No	Barium was detected in the groundwater at the Gun Club at concentrations that met the applicable groundwater quality standards. Soil samples met the unrestricted use SCOs.
Beryllium		--	--	X	--	No	Berylium was not detected in groundwater samples collected at the site. Soil samples meet the unrestricted use SCO guidance values.
Cadmium		--	--	X	--	(Yes)	Cadmium was not detected in groundwater samples collected at the site. Several soil samples exhibited cadmium concentrations exceeding the unrestricted SCO.
Chromium (Total)	X	--	--	X	--	(Yes)	Hexavalent chromium was not detected in groundwater samples at the site. Chromium was detected in one monitoring location near the former BPA at a concentration that met applicable water quality standards. All analyzed soil samples generally met the restricted residential or commercial SCOs.
Hexavalent Chromium		--	--	X	--		
Trivalent Chromium	--	--	--	X	--		
Copper		--	--	X	--	(Yes)	Copper was not detected in groundwater samples collected at the site. Soil samples from 2 of 84 locations and depths exhibited concentrations of copper exceeding the residential SCO.
Cyanide (Total)	X	--	--	X	--	No	Cyanide was detected at three monitoring locations near the former BPA at concentrations that met applicable water quality standards. All analyzed soil samples were below the unrestricted use SCO.
Iron	X	--	--	X	--	Yes	Groundwater samples collected from eight locations at the site exceeded water quality standard for iron. This is likely due to the chemically-reducing conditions that exists in the former BPA resulting in dissolution of naturally occuring iron.

Notes:

1. The table consists of validated and unvalidated laboratory analysis of samples collected in the period April 2006 to December 2008 on IBM Gun Club and Binghamton Country Club property. The water, soil, rock, and soil vapor samples were analyzed by Microseeps Laboratory of Pittsburgh, PA, Lancaster Laboratory of Lancaster, PA, University of Waterloo, Ontario, Canada, Guelph University, Ontario, Canada, or Stone Environmental, Inc. Montpelier, VT. The samples were analyzed using appropriate analytical techniques as discussed in the March 2006 Remedial Investigation Work Plan for the IBM Gun Club.

2. "Groundwater" indicates samples collected in monitoring wells, water supply well, or multi-level system. "Surface Water" indicate grab water sample collected from spring, seep, drainage or pond. "Rock Matrix" indicate analytical results of rock core samples. "Soil" indicate samples collected from test pits, drill cuttings, or surface sediment grab samples. "Soil Vapor" samples were collected from temporary monitoring points installed April 2006.

3. An "X" indicate that the compound or element has been detected in the indicated matrix. A blank indicate that the compound/element was not detected by the laboratory analysis. "--" indicate that the matrix was not analyzed for the compound/element.

4. Determination if compound/element is a site contamination is made based on review of pre 2006 data and data collected April 2006 to December 2008. A "(Yes)" indicates that the compound/element has not historically been considered a site contaminant, but that the RI investigation has found evidence of elevated concentrations.

5. VOCs are volatile organic compounds, SVOCs are semi-volatile organic compounds, THMs are trihalomethanes, MCLs are maximum contamination levels, SCOs are soil cleanup objectives and ug/L is micrograms per liter.

6. Please refer to Remedial Investigation Report text for further discussion.

Table 2
Summary of Organic Compounds and Metals Found in Samples
Remedial Investigation, IBM Gun Club
Former Burn Pit Area, Union, New York

COMPOUND/ ELEMENT	GROUNDWATER	SURFACE WATER	ROCK MATRIX	SOIL	SOIL VAPOR	SITE CONTAMINTNT?	COMMENTS
Lead		--	--	X	--	No	Lead was not detected in groundwater. All analyzed soil samples met the residential, commercial and industrial site use SCOs. Deposition of lead related to the former shooting range has been reported, however, the former BPA does not appear to be affected by the shooting activities. The one soil sample exceeding the unrestricted use SCO were located within the east to west oriented belt in the vicinity of the former burn pit area.
Manganese	X	--	--	X	--	Yes	Groundwater samples collected from 15 locations exceeded the EPA secondary MCL standards for manganese. This is likely due to the manganese reducing conditions that exists in the former BPA resulting in dissolution of naturally occuring manganese.
Mercury		--	--	X	--	No	Mercury was not detected in groundwater samples collected at the site. All analyzed soil samples met the unrestricted use SCO.
Nickel	X	--	--	X	--	No	Nickel was detected at two monitoring locations near the former BPA at concentrations that met applicable water quality standards. All analyzed soil samples met the residential SCO.
Selenium	X	--	--	X	--	No	Selenium was detected at four monitoring locations near the former BPA at concentrations that met applicable water quality standards. All analyzed soil samples met the unrestricted use SCO.
Silver		--	--	X	--	No	Silver was not detected in groundwater samples collected at the site. All analyzed soil samples met the unrestricted use SCO.
Sodium	X	--	--	--	--	(Yes)	This is likely due to naturally occuring sodium in the bedrock originally deposited in a marine environement combined with chemically-reducing conditions that exists in the former BPA.
Thallium		--	--	X	--	No	Thallium was not detected in groundwater samples collected at the site. All analyzed soil samples met the unrestricted use SCO.
Zinc		--	--	X	--	(Yes)	Zinc was not detected in groundwater samples collected at the site. All analyzed soil samples met the residential SCO for zinc.

Notes:

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2. "Groundwater" indicates samples collected in monitoring wells, water supply well, or multi-level system. "Surface Water" indicate grab water sample collected from spring, seep, drainage or pond. "Rock Matrix" indicate analytical results of rock core samples. "Soil" indicate samples collected from test pits, drill cuttings, or surface sediment grab samples. "Soil Vapor" samples were collected from temporary monitoring points installed April 2006.

3. An "X" indicate that the compound or element has been detected in the indicated matrix. A blank indicate that the compound/element was not detected by the laboratory analysis. "--" indicate that the matrix was not analyzed for the compound/element.

4. Determination if compound/element is a site contamination is made based on review of pre 2006 data and data collected April 2006 to December 2008. A "(Yes)" indicates that the compound/element has not historically been considered a site contaminant, but that the RI investigation has found evidence of elevated concentrations.

5. VOCs are volatile organic compounds, SVOCs are semi-volatile organic compounds, THMs are trihalomethanes, MCLs are maximum contamination levels, SCOs are soil cleanup objectives and ug/L is micrograms per liter.

6. Please refer to Remedial Investigation Report text for further discussion.

Table 3
Statistical Overview of Water Quality - Key Volatile Organic Compounds
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

		Chlorinated Ethenes																														Chlorinated Ethanes														
		Tetrachloroethene					Trichloroethene					Dichloroethene (cis-1,2-)					Dichloroethene (trans-1,2-)					Dichloroethene (1,1-)					Vinyl chloride					Trichloroethane (1,1,1-)					Trichloroethane (1,1,2-)					Dichloroethane (1,2-)				
NY State Groundwater Standards (μg/L)		5					5					5					5					5					2					5					1					0.6				
Well Name	No. Collected Samples	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean
BP-1	13	0	<0.5	--	<0.5	--	13	3.8	11	69	14	13	1.7	7.4	23	7.1	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	10	<0.3	<0.6	2.9	<0.9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	9	<0.1	<0.2	1.3	<0.4
BP-1A	9	0	<0.5	--	<1	--	9	7.9	83	210	98	9	6.4	30	91	42	8	<0.5	<0.7	3.7	<1.5	8	<0.2	<0.2	0.7	<0.4	9	0.3	6.2	41	14	0	<0.5	--	<1	--	5	<0.1	<0.4	0.5	<0.3	9	0.1	2.2	2.9	1.9
BP-2	15	0	<0.5	--	<0.5	--	14	<0.5	<0.9	3.1	<1.2	14	<0.2	<0.5	5	<1	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	5	<0.2	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-2A	12	1	<5	<38	50	<34	12	330	1,000	2,400	1,100	12	1,800	5,500	13,000	6,000	10	<2.6	<17	66	<27	11	<2.7	<14	32	<16	11	<25	<910	1,700	<920	0	<5	--	<50	--	1	<2.9	<38	50	<34	2	<1.1	<38	50	<34
BP-3	13	0	<0.5	--	<50	--	13	18	240	2300	660	13	62	1,100	5,000	1,500	12	<0.1	<1.3	50	<6.2	13	0.1	2.4	17	4.9	13	0.5	120	1,300	310	0	<0.5	--	<50	--	3	<0.1	<5	50	<11*	13	0.6	3.8	16	6.2
BP-4	11	0	<0.5	--	<0.5	--	10	<1.5	<1.8	20	<3.6	4	<0.1	<0.5	4.1	<0.8	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	3	<0.5	<0.5	7.1	<1.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.1	<0.5	0.5	<0.5
BP-4A	9	2	<0.1	<2.5	2.5	<1.6	9	100	210	330	230	9	4.9	6.1	42	11	2	<0.1	<2.5	2.5	<1.6	7	<0.4	<0.7	2.5	<1.2	8	<0.8	<2.5	17	<5.3	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	9	0.6	0.9	1.2	0.9
BP-5	12	0	<0.5	--	<0.5	--	4	<0.2	<0.5	0.8	<0.5	4	<0.2	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-5A	7	0	<0.5	--	<0.5	--	7	2	5.3	23	7.2	7	1.5	2.2	8.4	2.9	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	3	<0.3	<0.5	2.3	<0.7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	7	0.5	0.9	2.6	1.1
BP-6	12	0	<0.5	--	<5	--	12	18	23	86	37	12	2.1	4.1	10	4.6	0	<0.5	--	<5	--	8	<0.1	<0.25	5	<1	6	<0.1	<0.45	5	<1.1	0	<0.5	--	<5	--	0	<0.5	--	<5	--	10	<0.3	<0.55	5	<1.0
BP-7A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-8A	7	0	<0.5	--	<0.5	--	7	1.1	10	18	9.7	5	<0.1	<0.3	0.6	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-9A	9	0	<5	--	<50	--	9	890	2,800	7,000	2,800	9	64	170	390	190	1	<3.1	<25	50	<21*	4	<2.4	<10	50	<17	5	<5	<10	30	<14	0	<5	--	<50	--	0	<5	--	<50	--	9	5.9	20	32	18
BP-10A	10	0	<0.5	--	<0.5	--	10	0.1	1.8	4	1.9	4	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-11A	15	0	<0.5	--	<0.5	--	11	<0.5	<1.4	3.6	<1.6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12A	10	0	<0.5	--	<0.5	--	10	1.9	3.7	8.6	4.6	9	<0.1	<0.25	0.5	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	10	0.2	0.3	0.4	0.3
BP-12D-P1	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12D-P2	13	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12D-P3	12	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--
BP-12D-P4	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-12D-P5	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-12D-P6	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-12D-P7	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-13A	8	0	<0.5	--	<2.5	--	8	46	120	140	110	8	2	5.5	14	6.2	5	<0.1	<0.2	2.5	<0.5	7	<0.1	<0.3	2.5	<0.5	1	<0.2	<0.5	2.5	<0.7	0	<0.5	--	<2.5	--	6	<0.2	<0.2	2.5	<0.5	6	<0.2	<0.25	2.5	<0.56
BP-13D-P1	5	0	<0.5	--	<0.5	--	5	17	89	130	89	5	5.2	23	26	23	4	<0.1	0.2	0.5	0.2	5	0.2	0.5	0.6	0.5	4	<0.5	<2	3	<2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	5	0.2	0.45	0.5	0.5
BP-13D-P2	12	0	<0.5	--	<1	--	12	75	100	130	99	12	11	16	23	16	10	<0.1	<0.1	0.8	<0.2	11	<0.2	0.3	1	0.3	11	<0.4	<0.7	1.6	<0.8	0	<0.5	--	<1	--	0	<0.5	--	<1	--	12	0.3	0.4	0.6	0.4
BP-13D-P3	12	0	<0.5	--	<0.5	--	11	<2	<3.1	31	<3.1	11	<0.6	<0.85	8.8	<0.9	1	<0.3	<0.5	0.5	<0.5	1	<0.1	<0.5	0.5	<0.5	9	<0.1	<0.5	0.6	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5
BP-13D-P4	11	0	<0.5	--	<1	--	10	1.4	<2.8	35	<2.7	10	0.9	<2.1	5.9	<2	0	<0.5	--	<1	--	1	0.1	<0.5	1	<0.5	9	<0.1	<0.2	1	<0.3	0	<0.5	--	<1	--	0	<0.5	--	<1	--	1	0.1	<0.5	1	<0.5
BP-13D-P5	10	0	<0.5	--	<1	--	9	0.5	<1.8	7.6	<1.9	9	0.6	<1.1	2.8	<1.1	0	<0.5	--	<1	--	0	<0.5	--	<1	--	6	<0.1	<0.2	1	<0.3	0	<0.5	--	<1	--	0	<0.5	--	<1	--	1	0.5	<0.5	1	<0.5
BP-13D-P6	12	0	<0.5	--	<5	--	9	<0.9	<1.3	5	<1.2	6	<0.7	<0.75	5	<1.5	0	<0.5	--	<5	--	0	<0.5	--	<5	--	3	<0.1	<1.5	5	<1.8	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--
BP-13D-P7	10	0	<0.5	--	<5	--	9	<0.1	<0.2	2.3	<0.7	2	<0.1	<0.5	5	<1.4	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--
BP-14A	4	0	<0.5	--	<0.5	--	4	0.3	0.3	0.3	0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P1	9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P2	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P3	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P4	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P5	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-14D-P6	9	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-15A	3	0	<0.5	--	<0.5	--	3	6.6	11	14	11	3	0.1	0.2	0.2	0.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P1	4	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.6	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P2	10	0	<0.5	--	<0.5	--	1	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P3	11	0	<0.5	--	<0.5	--	1	<0.3	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P4	9	0	<0.5	--	<0.5	--	1	<0.1	<0.5	0.5	<0.5	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P5	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P6	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P7	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-16A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-17A	12	0	<0.5	--	<0.5	--	12	0.4	1	6.9	1.6	7	<0.1	<0.4	0.5	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-18A	8	0	<0.5	--	<0.5	--	8	9.3	13	19	13	7	<0.1	<0.2	0.5	<0.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-19A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-20	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-20A	6	2	<0.1	<0.5	0.5	<0.4	6	2.3	9.2	14	8.8	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-21	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-21A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-22A	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-23A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-24A	6	0	<0.5	--	<0.5	--	6	0.2	1.6	1.9	1.2	6	0.1	0.4	0.4	0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-25A	6	0	<0.5	--	<0.5	--	6	1.1	2.7	3.9	2.6	4	<0.1	<0.3	0.5	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-26A	6	0	<0.5	--	<0.5	--	6	0.2	0.6	0.8	0.6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-27	8	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-27A	5	0	<0.5	--	<0.5	--	5	12	14	20	15	5	2.4	3.3	3.9	3.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-28A	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-29	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-30A	6	6	0.5	5.1	6.4	4	6	8.6	48	64	41	6	0.2	1.7	2.5	1.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	4	<0.1	<0.25	0.5	<0.3
BP-31A	8	3	<0.1	<0.5	2.2	<0.9	8	0.3	2.4	38	11	2	<0.5	<0.5	1.4	<0.7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	4	<0.1	<0.45	0.5	<0.4
GC-1-P1	11	0	<0.5	--	<0.5	--	11	22	33	72	44	11	3.2	12	16	12	7	<0.1	<0.3	0.6	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.1	<0.5	0.5	<0.4	11	1	1.7	2.6	1.9
GC-1-P2	12	0	<0.5	--	<0.5	--	12	20	45	65	43	12	4.6	19	26	19	8	<0.1	<0.2	0.5	<0.3	1	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	12	1.1	1.7	2.5	1.8
GC-1-P3	11	0	<0.5	--	<0.5	--	11	13	43	59	38	11	4.5	18	33	20	5	<0.1	<0.5	0.5	<0.4	1	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	1.2	1.7	2.4	1.7
GC-1-P4	11	0	<0.5	--	<0.5	--	11	3.3	9.2	22	8.9	11	1.4	2.1	4.5	2.1	1	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.3	0.3	0.6	0.3
GC-1-P5	11	0	<0.5	--	<0.5	--	11	3.1	7.4	21	8.2	11	1.7	4.3	6.3	4.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.3	0.4	0.7	0.4
GC-1-P6	11	0	<0.5	--	<0.5	--	11	2	2.4	19	3	11	1.1	8.2	14	7.9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.3	0.5	0.7	0.4
GC-1-P7	10	0	<0.5	--	<1	--	10	0.2	0.4	11	0.4	10	0.5	15	31	16	4	<0.1	<0.35	1	<0.4	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	10	0.3	0.5	1	0.5
GC-1-P8	11	0	<0.5	--	<1	--	11	0.2	0.4	6.7	0.4	11	1.5	16	23	17	9	<0.1	0.2	0.5	0.3	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.4	0	<0.5	--	<1	--	0	<0.5	--	<1	--	10	<0.4	0.6	0.8	0.6
GC-A	3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
GC-2A	7	0	<0.5	--	<0.5	--	7	2.2	3.1	3.4	2.9	7	0.1	0.1	0.2	0.1	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
GC-B	2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
RP-9-380	4	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--
RP-13-885	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--

Please refer to notes on page 3 of Table 3

Table 3
Statistical Overview of Water Quality - Key Volatile Organic Compounds
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

		Aromatics																														Ketones														
		Ethylbenzene					Isopropylbenzene					Xylene (m,p-)					Xylene (o-)					Toluene					Benzene					Acetone					Butanone (2-)					Methyl-2-pentanone (4-)				
NY State Groundwater Standards (µg/L)		5					5					5					5					5					1					50					50					50				
Well Name	No. Collected Samples	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean
BP-1	13	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	5	<0.2	<0.5	0.5	<0.4	3	<0.1	<0.5	0.5	<0.4	2	<0.2	<0.5	0.7	<0.5	2	<0.1	<0.5	0.5	<0.5	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-1A	9	3	<0.1	<0.5	1.4	<0.6	2	<0.5	<0.5	1	<0.6	4	<0.1	<0.5	2	<0.7	2	<0.1	<0.5	1	<0.5	3	<0.1	<0.5	1	<0.4	7	<0.2	<0.4	0.6	<0.4	2	<5	<5	11	<5.8	0	<5	--	<10	--	0	<5	--	<10	--
BP-2	15	2	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	4	<0.2	<0.5	0.7	<0.5	3	<0.1	<0.5	0.5	<0.4	1	<0.1	<0.5	1	<0.5	1	<0.5	<0.5	0.5	<0.5	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-2A	12	11	<2.3	<28	130	<34	1	<5	<38	50	<35	9	<2.2	<37	370	<65	8	<1.2	<25	170	<40	11	<6.7	<41	500	<88	7	<1.2	<12	50	<23	0	<50	--	<500	--	0	<50	--	<500	--	0	<50	--	<500	--
BP-3	13	5	<0.1	<1.7	50	<11*	1	<0.3	<5	50	<11*	11	<0.3	<2.6	50	<7.4	9	<0.2	<1.4	50	<9.1	13	1.5	36	170	65	12	<1	<2.9	50	<7.9	13	6.8	1,100	7,800	2,500	7	<5	<62	500	<130	11	<2.9	<79	390	<110
BP-4	11	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	2	<0.3	<0.5	0.5	<0.5	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.8	--	2	<0.2	<0.5	0.5	<0.5	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-4A	9	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	8	<0.4	<1.6	2.5	<1.5	0	<5	--	<25	--	0	<5	--	<25	--	0	<5	--	<25	--
BP-5	12	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	4	<0.1	<0.5	0.5	<0.4	2	<0.1	<0.5	0.5	<0.4	1	<0.2	<0.5	0.6	<0.5	2	<0.2	<0.5	0.5	<0.5	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-5A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	2	<0.1	<0.5	0.9	<0.5	3	<3	<5	5.5	<4.6	0	<5	--	<5	--	0	<5	--	<5	--
BP-6	12	1	<0.2	<0.5	5	<1.2	0	<0.5	--	<5	--	2	<0.3	<0.5	5	<1.2	2	<0.1	<0.5	5	<1.2	10	<0.1	<1.1	5	<1.5	11	<0.6	<1.8	7.2	<2.4	12	19	560	1,200	600	11	<3	<22	50	<21	11	<1.1	<7	50	<13
BP-7A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.3	<0.5	0.5	<0.5	1	<0.1	<0.5	0.5	<0.5	1	<0.3	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-8A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-9A	9	0	<5	--	<50	--	0	<5	--	<50	--	0	<5	--	<50	--	0	<5	--	<50	--	0	<5	--	<50	--	1	<3	<25	50	<21	0	<50	--	<5,000	--	0	<50	--	<500	--	0	<50	--	<500	--
BP-10A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-11A	15	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	2	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-12A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	2	<5	<5	7.4	<5.3	1	<1.1	<5	5	<4.6	0	<5	--	<5	--
BP-12D-P1	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	9	0.5	2.4	37	5.4	0	<0.5	--	<0.5	--	2	<3.1	<5	14	<5.6	1	<1.4	<5	5	<4.7	0	<5	--	<5	--
BP-12D-P2	13	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	13	0.2	1.8	19	5	0	<0.5	--	<0.5	--	1	<5	<5	8.2	<5.2	2	<1.2	<5	6.3	<4.8	0	<5	--	<5	--
BP-12D-P3	12	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	1	<0.1	<0.5	2.5	<0.6	0	<0.5	--	<2.5	--	12	3.8	29	350	88	0	<0.5	--	<2.5	--	7	<3.3	<5	38	<11	9	<1.5	<4.8	52	<10	5	<2.9	<5	13	<5.5
BP-12D-P4	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	6	<0.1	<0.1	1	<0.3	1	<0.1	<0.5	1	<0.5	11	22	160	280	150	8	<0.1	<0.1	1	<0.3	8	<3.8	<5.8	36	<9.2	10	<1	<5	47	<8.7	5	<1.1	<5	13	<5.4
BP-12D-P5	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	10	14	32	78	38	0	<0.5	--	<1	--	5	<4.1	<5.7	10	<6.4	6	<1.7	<5	12	<5.2	6	<1	<2.3	5	<2.9
BP-12D-P6	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	11	10	22	48	25	0	<0.5	--	<1	--	2	<5	<5	11	<6.4	4	<2.1	<5	10	<4.9	3	<1.6	<5	5	<4.2
BP-12D-P7	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	10	10	30	88	41	0	<0.5	--	<1	--	1	<5	<5	10	<5.5	4	<1	<5	10	<4	1	<2.4	<5	10	<5.2
BP-13A	8	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	1	<0.1	<0.5	2.5	<0.7	1	<0.1	<0.5	2.5	<0.7	0	<5	--	<25	--	0	<5	--	<25	--	0	<5	--	<25	--
BP-13D-P1	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.1	<0.5	0.5	<0.5	5	24	41	78	41	5	0.1	0.25	0.3	0.3	2	<3.5	<5	5	<5	1	1.7	<5	5	<5	1	<1	<5	5	<5
BP-13D-P2	12	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	12	0.4	1.1	15	2.2	5	<0.1	<0.1	1	<0.3	0	<5	--	<10	--	1	<1	<5	10	<5	0	<5	--	<10	--
BP-13D-P3	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	12	0.6	3.2	48	10	0	<0.5	--	<0.5	--	1	<5	<5	6	<5	7	<1.3	<2.5	6.8	<3	1	<3.2	<5	5	<4.7
BP-13D-P4	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	8	0.3	<0.5	81	<0.4	4	0.1	<0.1	1	<0.3	5	<4.5	<5	10	<5.1	8	<1.2	<5	17	<6.3	4	<1.1	<5	5	<4.7
BP-13D-P5	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	10	55	80	180	76	7	<0.1	<0.1	1	<0.2	7	<3.2	<6.7	28	<12	10	1.2	9.9	51	17	7	<1.5	<4.3	10	<4
BP-13D-P6	12	3	<0.1	<1.3	5	<1.7	0	<0.5	--	<5	--	3	<0.2	<1.4	5	<1.8	0	<0.5	--	<5	--	12	250	450	670	440	4	<0.3	<1.4	<5	<1.8	7	<9.8	<16	50	<24	10	<11	<18	50	<24	5	<2.4	<15	50	<18
BP-13D-P7	10	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--	0	<0.5	--	<5	--	10	1.9	2.3	78	8	0	<0.5	--	<5	--	5	<4.3	<5	67	<19	7	<1.4	<5	31	<10	1	<3.2	<5	50	<14
BP-14A	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-14D-P1	9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	5	0.3	0.5	5.2	1.7	0	<0.5	--	<0.5	--	2	3.8	5	7.4	5.1	0	<5	--	<5	--	0	<5	--	<5	--
BP-14D-P2	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	9	0.5	5	32	11	1	<0.1	<0.5	0.5	<0.5	7	4.2	5.7	87	16	1	<1.1	<5	5	<4.6	0	<5	--	<5	--
BP-14D-P3	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	12	0.6	8.6	16	6.8	1	<0.4	<0.5	0.5	<0.5	12	29	62	240	77	12	1.2	2	3.7	2.2	1	<3.3	<5	5	<4.9
BP-14D-P4	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	10	2	14	16	10	1	<0.1	<0.5	0.5	<0.5	10	6.2	18	220	42	3	<1.4	<5	6.2	<4.6	3	<1.2	<5	5	<4.2
BP-14D-P5	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	0	<0.5	--	<1	--	11	1.1	11	160	22	1	<0.3	<0.5	0.5	<0.5	11	14	53	330	73	6	1	5	5.5	3.3	1	<4.4	<5	5	<4.9
BP-14D-P6	9	0	<0.5	--	<1	--	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.5	0	<0.5	--	<1	--	9	5.9	99	250	86	8	<0.1	<0.2	0.5	<0.3	9	56	84	410	120	8	<2.2	<2.6	7.2	<3.4	5	<2.1	<3.7	5	<3.9
BP-15A	3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-15D-P1	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	4	0.3	0.4	1.2	0.6	0	<0.5	--	<0.5	--	1	<5	<5	23	<9.5	1	<2.7	<5	5	<4.4	0	<5	--	<5	--
BP-15D-P2	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	10	15	22	110	37	1	<0.1	<0.5	0.5	<0.5	2	<4.6	<5	13	<5.8	3	<1.2	<5	5	<3.9	0	<5	--	<5	--
BP-15D-P3	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.2	2.9	14	3.6	0	<0.5	--	<0.5	--	1	<5	<5	7.4	<5.2	0	<5	--	<5	--	0	<5	--	<5	--
BP-15D-P4	9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	8	0.5	20	78	23	0	<0.5	--	<0.5	--	3	<4.1	<5	120	<18	3	<1	<5	5	<3.8	0	<5	--	<5	--
BP-15D-P5	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	10	13	38	50	35	6	<0.1	<0.3	0.8	<0.3	8	<3.9	<9.7	350	<47	9	<1.1	<2.6	10	<3.5	1	<1.2	<5	5	<4.6
BP-15D-P6	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	1.1	12	25	12	0	<0.5	--	<0.5	--	3	<5	<5	18	<7.3	2	<1.1	<5	5	<4.4	0	<5	--	<5	--
BP-15D-P7	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	10	37	53	78	56	2	<0.1	<0.5	0.5	<0.4	6	<5	<7.9	20	<9.2	6	<1.2	<4	5.3	<3.5	3	<1	<5	5	<4.1
BP-16A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-17A	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-18A	8	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-19A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-20	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-20A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-21	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-21A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<3.5	<5	5	<4.8	1	<1.2	<5	5	<4.4	0	<5	--	<5	--
BP-22A	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<5	<5	7.5	<5.6	0	<5	--	<5	--	0	<5	--	<5	--
BP-23A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-24A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<3.6	<5	5	<4.8	0	<5	--	<5	--	0	<5	--	<5	--
BP-25A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-26A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-27	8	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<3.1	<5	5	<4.8	0	<5	--	<5	--	0	<5	--	<5	--
BP-27A	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-28A	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.3	<0.5	0.5	<0.5	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-29	5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-30A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
BP-31A	8	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
GC-1-P1	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	10	<0.2	<0.5	5.7	<0.8	2	<0.1	<0.5	0.5	<0.5	4	<3.6	<5	16	<4.7	1	<1.5	<5	5	<5	1	<2.6	<5	5	<5
GC-1-P2	12	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	6	<0.1	<0.5	5.1	<0.4	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
GC-1-P3	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	6	<0.1	<0.5	6.3	<0.4	0	<0.5	--	<0.5	--	1	<5	<5	5.8	<5	0	<5	--	<5	--	0	<5	--	<5	--
GC-1-P4	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.1	0.2	2.4	0.2	0	<0.5	--	<0.5	--	2	<4.9	<5	11	<5	0	<5	--	<5	--	0	<5	--	<5	--
GC-1-P5	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.2	0.3	5	0.3	0	<0.5	--	<0.5	--	4	<4.5	<5	14	<5	0	<5	--	<5	--	0	<5	--	<5	--
GC-1-P6	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	11	0.8	1	18	1	0	<0.5	--	<0.5	--	5	<3.2	<5.2	9	<5.2	0	<5	--	<5	--	1	<2.3	<5	5	<5
GC-1-P7	10	0	<0.5	--	<1	--	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.4	0	<0.5	--	<1	--	10	31	62	240	63	9	<0.1	<0.2	1	<0.2	10	3.7	11	64	13	8	<2	<5.4	6.5	<4.6	9	<1.1	<2.7	10	<2.8
GC-1-P8	11	0	<0.5	--	<1	--	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.4	0	<0.5	--	<1	--	11	25	94	200	110	11	0.1	<0.2	3.7	<0.2	11	12	21	210	42	10	<3.8	<4.4	12	<5.4	11	1.7	3.3	4.7	3.5
GC-A	3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--
GC-2A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	5	<4.5	<5	29	<8.5	1	<1.7	<5	5	<4.5	0	<5	--	<5	--
GC-B	2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<4	<4.5	5	<4.5	0	<5	--	<5	--	0	<5	--	<5	--
RP-9-380	4	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	3	<3.3	<4.9	25	<9.5	0	<5	--	<25	--	0	<5	--	<25	--
RP-13-885	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<5	--	<5	--	0	<5	--	<5	--	0	<5	--	<5	--

Please refer to notes on page 3 of Table 3

Table 3
Statistical Overview of Water Quality - Key Volatile Organic Compounds
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

		Chlorinated Methanes																			
		Carbon tetrachloride					Chloroform					Chloromethane					Methylene chloride				
NY State Groundwater Standards (μg/L)		5					7					5					5				
Well Name	No. Collected Samples	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean	Detects	Min.	Median	Max.	Mean
BP-1	13	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-1A	9	0	<0.5	--	<1	--	7	<0.2	<0.3	0.5	<0.3	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-2	15	0	<0.5	--	<0.5	--	4	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-2A	12	0	<5	--	<50	--	2	<1.2	<38	50	<34*	1	<5	<25	50	<31	0	<5	--	<50	--
BP-3	13	0	<0.5	--	<50	--	12	<1.1	<11	68	<26	1	<0.2	<5	50	<11*	3	<0.5	<2.7	50	<12
BP-4	11	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	1	<0.5	<0.5	3.6	<0.8
BP-4A	9	5	<0.5	<0.9	2.5	<1.3	4	<0.4	<0.8	2.5	<1.4	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--
BP-5	12	0	<0.5	--	<0.5	--	2	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-5A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-6	12	0	<0.5	--	<5	--	2	<0.2	<0.5	5	<1.3	2	<0.1	<0.5	5	<1.2	1	<0.3	<0.5	5	<1.2
BP-7A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-8A	7	4	<0.1	<0.2	0.5	<0.3	5	<0.1	<0.2	0.5	<0.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-9A	9	0	<5	--	<50	--	9	4	9.9	68	19	0	<5	--	<50	--	1	<5	<25	50	<21
BP-10A	10	5	<0.1	<0.4	0.5	<0.3	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-11A	15	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12A	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.5	<0.5	0.9	<0.5
BP-12D-P1	12	0	<0.5	--	<0.5	--	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12D-P2	13	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-12D-P3	12	0	<0.5	--	<2.5	--	1	<0.1	<0.5	2.5	<0.6	0	<0.5	--	<2.5	--	1	<0.2	<0.5	2.5	<0.6
BP-12D-P4	11	0	<0.5	--	<1	--	2	<0.3	<0.5	1	<0.5	0	<0.5	--	<1	--	3	<0.2	<0.5	1	<0.5
BP-12D-P5	10	0	<0.5	--	<1	--	4	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<1	--	1	<0.2	<0.5	1	<0.5
BP-12D-P6	11	0	<0.5	--	<1	--	2	<0.1	<0.5	1	<0.5	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-12D-P7	10	0	<0.5	--	<1	--	1	<0.2	<0.5	1	<0.5	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-13A	8	8	0.9	1.2	2.3	1.4	8	0.6	0.9	1.3	0.9	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--
BP-13D-P1	5	4	<0.1	<0.3	0.5	<0.3	5	0.2	0.85	1.2	0.9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-13D-P2	12	11	<0.2	<0.4	0.5	<0.3	12	0.3	0.6	0.7	0.6	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-13D-P3	12	1	<0.2	<0.5	0.5	<0.5	2	<0.1	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-13D-P4	11	1	<0.2	<0.5	1	<0.5	3	0.2	<0.5	0.5	<0.5	0	<0.5	--	<1	--	1	<0.3	<0.5	1	<0.5
BP-13D-P5	10	0	<0.5	--	<1	--	3	0.2	<0.5	0.5	<0.5	0	<0.5	--	<1	--	1	<0.2	<0.5	1	<0.5
BP-13D-P6	12	0	<0.5	--	<5	--	2	<0.2	<0.8	5	<1.7	0	<0.5	--	<5	--	1	<0.3	<1.5	5	<1.9
BP-13D-P7	10	0	<0.5	--	<5	--	1	<0.2	<0.5	5	<1.4	0	<0.5	--	<5	--	1	<0.2	<0.5	5	<1.4
BP-14A	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--
BP-14D-P1	9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P2	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P3	12	0	<0.5	--	<0.5	--	5	<0.1	<0.5	0.5	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P4	10	0	<0.5	--	<0.5	--	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-14D-P5	11	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.5	1	<0.5	<0.5	0.6	<0.5	0	<0.5	--	<1	--
BP-14D-P6	9	0	<0.5	--	<1	--	1	<0.1	<0.5	1	<0.5	0	<0.5	--	<1	--	0	<0.5	--	<1	--
BP-15A	3	2	<0.1	<0.2	0.5	<0.3	2	<0.1	<0.1	0.5	<0.2	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P1	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P2	10	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P3	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.4	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--
BP-15D-P4	9	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P5	10	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.2	<0.5	0.5	<0.5
BP-15D-P6	11	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-15D-P7	10	0	<0.5	--	<0.5	--	4	<0.1	<0.5	0.5	<0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-16A	7	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-17A	12	2	<0.1	<0.5	0.5	<0.4	3	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-18A	8	8	0.3	0.45	0.6	0.5	8	0.3	0.3	0.6	0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-19A	6	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-20	6	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-20A	6	3	<0.2	<0.35	0.5	<1.7	6	0.2	0.25	0.4	0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-21	5	0	<0.5	--	<0.5	--	1	<0.4	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-21A	6	0	<0.5	--	<0.5	--	1	<0.4	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-22A	4	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-23A	6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-24A	6	0	<0.5	--	<0.5	--	2	<0.2	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-25A	6	1	<0.1	<0.5	0.5	<0.4	1	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-26A	6	6	0.1	0.5	0.6	0.5	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-27	8	0	<0.5	--	<0.5	--	2	<0.5	<0.5	0.7	<0.6	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-27A	5	5	0.4	0.4	0.5	0.4	5	0.3	0.3	0.5	0.3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-28A	5	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-29	5	0	<0.5	--	<0.5	--	2	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-30A	6	5	<0.3	<0.5	0.7	<0.5	6	0.1	0.55	0.8	0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
BP-31A	8	2	<0.2	<0.5	0.5	<0.4	4	<0.3	<0.5	0.5	<0.5	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
GC-1-P1	11	11	0.9	2.7	3.7	2.7	10	<1.4	2.2	3.1	2.4	1	<0.3	<0.5	0.5	<0.5	1	<0.2	<0.5	0.5	<0.5
GC-1-P2	12	12	1.1	2.4	3.3	2.3	11	<1.8	2.1	3	2.2	0	<0.5	--	<0.5	--	1	<0.5	<0.5	0.7	<0.5
GC-1-P3	11	11	0.4	1.9	3.2	2	10	<1.7	2.1	3.1	2.2	0	<0.5	--	<0.5	--	1	<0.5	<0.5	0.5	<0.5
GC-1-P4	11	10	<0.2	<0.2	0.7	<0.2	10	<0.3	0.4	0.8	0.4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--
GC-1-P5	11	7	<0.2	<0.3	0.5	<0.3	10	<0.2	0.4	0.8	0.4	0	<0.5	--	<0.5	--	1	<0.3	<0.5	0.5	<0.5
GC-1-P6	11	3	<0.1	<0.5	0.5	<0.5	9	<0.2	<0.3	1.1	<0.3	0	<0.5	--	<0.5	--	1	<0.4	<0.5	0.5	<0.5
GC-1-P7	10	0	<0.5	--	<1	--	3	<0.4	<0.5	1	<0.5	0	<0.5	--	<1	--	1	<0.5	<0.5	1	<0.5
GC-1-P8	11	0	<0.5	--	<1	--	3	<0.2	<0.5	1	<0.5	6	<0.1	<0.5	1.2	<0.4	2	<0.2	<0.5	1	<0.4
GC-A	3	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	1	<0.5	<0.5	3.9	<1.6
GC-2A	7	7	7.2	18	25	17	7	0.6	1.8	2.1	1.6	1	<0.1	<0.5	0.5	<0.4	0	<0.5	--	<0.5	--
GC-B	2	2	0.2	0.3	0.4	0.3	1	<52	<68	83	<68	1	<0.8	<0.85	0.9	<0.9	0	<0.5	--	<0.5	--
RP-9-380	4	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--	0	<0.5	--	<2.5	--
RP-13-885	4	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.5	--	0	<0.5	--	<0.6	--

Notes:

1.The table summarizes principal site contaminant VOC concentrations in Groundwater observed during the remedial investigations

2. For monitoring locations where an analyte was detected during one sample event or more, the number of detects, minimum, median, maximum, and arithmetic mean concentrations were calculated including the detection limit as a value during sample events where the compound was not detected. If no detections are listed, the minimum and maximum concentrations represents the minimum and maximum detection limits observed for the compound at that particular monitoring location.

3. Gray shaded cells indicate mean values above NY State Groundwater Standard Maximum Contaminant Levels (MCLs), as established in Part 703, Surface Water and Groundwater Quality Standards.

* Indicates that individual concentrations did not exceed the applicable groundwater standard. Calculated mean value includes non-detected values that have been diluted, causing a high bias. These locations were not included in the count of total number of exceededences for the compound.

'--' Indicates the median and mean values were not calculated because all samples were reported as below analytical detection limits.

"<" indicates that calculated value includes one or more samples where analyte was below analytical detection limits.

4. The median and mean values for wells BP-13D (all multi-level intervals) and GC-1 (all multi-level intervals) were calculated only using data that was collected between November 2007 and December 2008, whereas the number of detects, minimum, and maximum at reflect all available data.

5. Refer to Table 2 and report text for further discussion.

Table 4
Qualitative Exposure Assessment - Summary of Exposure Pathways
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

Transport Medium	Release/Source Mechanism	Primary Routes of Exposure	Primary Constituents of Concern	Primary receptors/ Exposure Points	Discussion	Pathway Completion Possible?	Additional Information/ Action Required?
Surficial Soil	Direct contact with surficial soils containing residuals of former Burn Pit activities.	Dermal, inhalation, or incidental ingestion.	VOCs including TCE, cDCE, chloroform, o-xylene, and acetone Trace metals including As, Cd, Cu, Pb, Ni, Zn and Cr PCB-1254	Present and Future Receptors include workers and visitors of B665, trespassers of site. Future receptors could include workers involved in implementing site remediation.	The area where surficial soils have been observed to contain the metals and PCBs is largely within a 6-acre area with access restricted by chain link fencing. The area is well vegetated with only limited exposed soil with no material potential for erosion and soil transport. VOCs have not been detected in surficial soils or have been found at concentrations below unrestricted use standards. The fencing limits access to workers and visitors of the B665. The normal commercial use of the site does not involve activities that would lead to disturbance of the soil or dust generation. The occupational activities are largely within the building, concrete loading dock, and paved areas leading to and adjacent to the building. Therefore, the normal site activities under present use would not result in human contact with the soils. There is negligible potential for incidental exposure of trespassers to the small area of metals and PCB containing soils outside of the fenced area. Proper work procedures and/or controls would be necessary should future remediation activities involve disturbance of soil.	Yes	None
Groundwater	Migration of dissolved VOCs principally chlorinated ethenes sourced from VOC mass residing in the primary pore water and sorbed to the rock solids. Back diffusion from the primary pore space into water flowing in fractures and advective-dispersive transport downgradient in the fractures constitutes the primary mechanisms for transport. Site characterization data support groundwater flow radially away from the BPA located on topographically high ground and vertically downward.	Direct contact, inhalation, or ingestion via water supplies.	Dissolved phase VOCs.	1. Workers and visitors of B665.	Water for washing hands and flushing toilets is provided by water supply well GC-A which is located less than 200 feet from the primary source area. Monitoring of the water supply since 1979 has not detected site related VOCs in water from well GC-A and the site characterization data indicates that this well is not at material risk under current use. Nonetheless, bottled water is used for drinking water at B665. We believe that GC-A has not been impacted because, 1) the well yields water from intervals over 100 feet below ground; 2) the majority of VOC mass is found in the upper tens of feet of bedrock; and 3) the relatively small volume withdrawals from the well.	No	Continued monitoring of groundwater quality including GC-A is prudent.
				2. Workers and users of the Binghamton Country Club.	Water for irrigation, facilities and potable use is provided by the public water supply.	No	None
				3. Residents of Glen Crest Estates Subdivision.	The water supplies serving five residences located 800 to 1,500 ft southeast of primary source area across Robinson Hill Road (RHR). Monitoring wells located between the source zone in rock and the water supplies yield samples with key VOCs at or below a few tens of μg/L were sampled in 2003 and again in the spring of 2008. The drilled bedrock wells receive their water below the inferred aquitard down to a depth of approximately 120 ft below ground surface. Site related VOCs have not been detected in the private water supply wells, nor have they been detected in samples from the on-site water supply well located much closer to the source area.	No	Continued monitoring of groundwater quality with existing monitoring wells.
				4. Residences served by private water supply wells north and northeast along RHR.	Groundwater monitoring does not indicate a northerly component of migration. The water table monitoring wells just north of the primary source area do not indicate water quality impacts. The nearest private residence is located over 1,700 feet to the north.	No	Continued monitoring of groundwater quality with existing monitoring wells.
				5. Skylane Terrace subdivision.	Served by public water supply.	No	None

Notes:

1. This table is intended to document a systematic screening of potential pathways of human and biotic exposure completed in consideration of the available site characterization data and our knowledge about existing patterns of human use of the site and vicinity. This screening was conducted in accordance with the requirements for a Qualitative Exposure Assessment as outlined under CMR375 Part 3.6 and ECL 27-1415. Please refer to the RI report text section 7.0 for additional details.

2. The Primary Contaminants of Concern are constituents highlighted due to observed concentrations relative to applicable standards, clean up objectives and guidance and/or those believed by SHA to contribute most to potential risks to human health. Other contaminants not listed have been detected and may contribute to somewhat to risk.

3.. The following abbreviations are used:
VOCs: Volatile Organic Compounds, PCBs : Polychlorinated Biphenyls, SVOCs: Semi volatile Organic Compounds.
MCLs: Maximum Contaminant Levels
SCOs: Soil Cleanup Objectives
RHR: Robinson Hill Road

Table 4
Qualitative Exposure Assessment - Summary of Exposure Pathways
Remedial Investigation
IBM Gun Club - Former Burn Pit Area, Union, New York

Transport Medium	Release/Source Mechanism	Primary Routes of Exposure	Primary Constituents of Concern	Primary receptors/ Exposure Points	Discussion	Pathway Completion Possible?	Additional Information/ Action Required?
Surface Water (springs, seeps and wet Areas)	Dissolved phase VOCs found in wet areas and streams due to discharge of VOC-containing groundwater transported in bedrock and overburden.	Direct contact, and incidental ingestion.	Seeps on the IBM Gun Club property between the fenced area and the southerly property line.	1. Workers and visitors to B665 and users/ trespassers.	Key VOCs have been detected at up to tens of µg/L and as much as 10 times above groundwater/drinking water standards in samples from seeps located within the primary source area between the fencing and the southerly Gun Club property boundary at monitoring well BP-9A. The presence of the seepage has been observed to be seasonal during fall, winter, and spring wet weather. Normal activities of workers and visitors to B665 do not involve this area. However, the perimeter road is used under an easement with IBM by the local water utility to access a water tower. Access to this area is not controlled by fencing. Human and biotic exposure is a possibility for users of the perimeter road and trespassers. Such exposure potential would be considered non-systematic, incidental, and seasonal. Extending fencing to the southerly property boundary would further limit human access.	Yes	Continued monitoring of the seeps is warranted.
			Man-made pond and associated seeps and downstream surface drainage.	2. Workers and users of the Binghamton Country Club.	VOCs have been detected at up to a few µg/L and below drinking water quality standards. Normal occupational and recreational use of the Country Club does not involve the man-made pond and associated seeps. We know of no systematic use of this area. Human and biotic exposure would be incidental if at all.	Yes	Continued monitoring of groundwater and surface water is recommended.
			Seeps and surface drainage along RHR on Country Club Property.	3. Workers and Users of Country Club, downstream.	Site related VOCs, principally TCE, have been detected in water collected form seep location 116 which we believe is the discharge of a man-made golf course subsurface drainage system. The concentrations have ranged up to approximately two times the applicable MCLs. The seepage of water to the ground surface is seasonal occurring in a small area during snow melt and after larger precipitation events. Human or biotic contact if at all would be seasonal and incidental.	Yes	Continued monitoring of groundwater and surface water is recommended.
Subsurface Vapors (soil gas)	Partitioning from VOC mass present in fractured bedrock and in dissolved phase above the zone of saturation and in groundwater. Vapor migration by diffusion in air filled soil/bedrock void space into occupied building space.	Inhalation	VOCs principally chlorinated ethenes, chloroform.	1. Workers and visitors of B665.	The B665 laboratory facility is located west of the former Burn Pit area and away from the path of VOC migration. More than two years of groundwater monitoring have not indicated detectable concentrations of VOCs in shallow groundwater near B665. The silt-clay rich low porosity and permeability soils and bedrock at the site are not conducive to vapor migration.	No	Continued monitoring of groundwater quality at the water table in the vicinity of B665.
				2. Residences North, South, East and West of Gun Club BPA.	The presence of VOCs in groundwater does not extend beneath residential areas to the north, or south-southwest. Sampling of sub slab soil vapor and indoor air in the Glen Crest Estates subdivision showed no material concern for vapor intrusion.	No	Continued monitoring of water quality between the primary source area and residential properties.
				3. Workers and users of the Binghamton Country Club facilities	No buildings are located within the area of the Country Club where VOCs have been found in groundwater. The soil and bedrock in this area are not particularly conducive to vapor migration. Should future use of the area of VOC presence involve construction of human occupied buildings, vapor intrusion potential can be controlled via engineered means.	No	Continued monitoring of groundwater quality.

Notes:

1. This table is intended to document a systematic screening of potential pathways of human and biotic exposure completed in consideration of the available site characterization data and our knowledge about existing patterns of human use of the site and vicinity. This screening was conducted in accordance with the requirements for a Qualitative Exposure Assessment as outlined under CMR375 Part 3.6 and ECL 27-1415. Please refer to the RI report text section 7.0 for additional details.

2. The Primary Contaminants of Concern are constituents highlighted due to observed concentrations relative to applicable standards, clean up objectives and guidance and/or those believed by SHA to contribute most to potential risks to human health. Other contaminants not listed have been detected and may contribute to somewhat to risk.

3.. The following abbreviations are used:
VOCs: Volatile Organic Compounds, PCBs : Polychlorinated Biphenyls, SVOCs: Semi volatile Organic Compounds.
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TABLE 5
Identification and Preliminary Screening of Remedial Technologies
Remedial Investigation
IBM Gun Club – Former Burn Pit Area, Union, NY

Technology-Method	Process Description	Screening Factors		Screening Outcome
		Site Characteristics	**Technology Limitations**	
CONTAINMENT TECHNOLOGIES – for capture/control of groundwater flow to limit contaminant migration; typically coupled with an *ex situ* groundwater treatment technology				
Hydraulic Containment/ Vertical Extraction Wells in Bedrock	Groundwater extraction from vertical wells drilled into bedrock within or near the apparent contaminant source zone to provide near-source hydraulic containment of dissolved-phase contamination and limit the potential for contaminant transport away from the source zone. Applied to the site, this technology would likely include an array of vertical extraction wells equipped with pumps to convey recovered groundwater to a central *ex situ* treatment system consisting of one or more of the treatment technologies outlined below.	Favorable • The site contaminants are readily amenable *ex situ* treatment. • The site is relatively unencumbered by structures or subsurface utilities, which would allow for unencumbered siting, drilling, and construction of vertical extraction wells and conveyance piping. Unfavorable • Extraction from vertically-installed wells is an inefficient means to achieve hydraulic containment of contaminants migrating in a thin zone of modest permeability; as such a relatively dense grid of wells with low-yield pumps would be required. • Hydraulic containment does not materially address mass adsorbed in the rock or present in matrix pore water; the ability to remove contaminant source mass would be limited by the rate of diffusion from the rock matrix into the groundwater.	Advantages • Hydraulic containment using vertical extraction wells is a relatively simple, conventional technology that is applicable to a variety of settings and depths. • Would provide a means of limiting contaminant mass transport away from the source zone; • Would not limit and could complement application of reduction measures. Limitations • This method is extremely inefficient at contaminant mass removal. Proper well siting would be necessary to achieve contaminant migration control. • Would require on-going operations and maintenance of system components; without mitigation of VOC source zone mass, it would need to operate indefinitely. • Treatment residuals/emissions must be managed.	**Retain for further consideration** – this technology offers a relatively proven means for contaminant migration control. Interminable operation and maintenance. unless coupled with effective source reduction
Hydraulic Containment/ Collection Trench in Bedrock	Groundwater extraction from a collection trench in bedrock equipped with one or more extraction sumps. Trench installation would require excavation of overlying soil fill/residual soil, followed by hammering or blasting of bedrock, or creation of zones of enhanced permeability by hydraulic or pneumatic fracturing. Applied to the BPA, this method could potentially be constructed as a man-made zone of more fractured bedrock created by drilling and pneumatic fracturing or an excavated trench cut about 10 to 15 ft bgs into bedrock oriented perpendicular to groundwater flow from the source zone. An excavated trench could be filled with crushed rock, or backfilled media, and equipped with vertical wells with pumps to convey recovered groundwater to a central *ex situ* treatment system consisting of one or more of the treatment technologies outlined below.	Favorable • The site contaminants are readily amenable to *ex situ* treatment. • A collection trench installed downgradient of the source zone would provide a greater likelihood of intercepting groundwater as compared with vertical extraction wells. • The observed rock fracturing and rock core VOC data indicate a collection trench constructed to a depth of 15 ft bgs or less along a relatively short length would largely intercept the mass flux from the source zone. • The site is relatively unencumbered by structures or subsurface utilities, which would allow for easier siting and construction of a collection trench. Unfavorable • Excavation of a trench in bedrock difficult and costly and may not be possible without drilling and blasting. • Hydraulic containment does not materially address contaminants adsorbed in the rock mass or present in matrix pore water; in a fractured bedrock system, the ability to remove contaminant source mass would be limited by the rate of diffusion from the rock matrix into the groundwater.	Advantages • Hydraulic containment using a collection trench offers a greater potential for substantially intercepting contaminant mass flux in low- to modest-permeability settings from relatively shallow depths, as compared to vertical extraction wells. • Would provide a means of limiting transport away from the source zone, and would not limit future application of other source reduction. • Compatible with enhanced in situ biodegradation. Limitations • This method is extremely inefficient at contaminant mass removal. • Would require on-going operations and maintenance of system components; without mitigation of VOC source zone mass, the containment and treatment systems would need to operate indefinitely. • Treatment residuals/emissions must be managed.	**Retain for further consideration** – this technology offers a relatively effective means for contaminant migration control in low- to modest-permeability settings. Interminable operation and maintenance. unless coupled with effective source reduction
Capping	A low permeability soil barrier or impermeable barrier such as a geomembrane or synthetic clay liner could be constructed above the primary source rock reducing groundwater recharge. Applied to the BPA in whole or in part, a cap may limit groundwater flow and lower groundwater levels in the source rock. Could be applied in combination with in situ thermally enhanced extraction.	Favorable • The site is relatively unencumbered by structures or subsurface utilities, which would allow for construction of a surface cap • The source zone is near the top of a hill, which would facilitate effective diversion of precipitation and would limit the introduction of surface runoff from proximate areas onto the capped area. • Capping would limit potential for direct contact with metals- and other non-VOC-containing soils in the source area. Unfavorable • Would not result in removal of contaminant mass from the bedrock source zone. • A decrease in the flow of groundwater downgradient of the primary source zone may actually increase concentrations fed by diffusion from downgradient rock matrix.	Advantages • A synthetic barrier layer is a simple technology that is applicable to a variety of settings. • Would require relatively less maintenance as compared to active groundwater capture to reduce contaminant mass flux from the source zone. Limitations • Would not remove contaminant mass from the source zone. • Would need to be maintained indefinitely. • Without active groundwater interception, may require increased monitoring to confirm performance.	**Retain for further consideration** – this technology offers a relatively simple means for reducing flow of water through the source zone. Could be applied in combination with thermally enhanced extraction. Absent effective source reduction would therefore require long-term monitoring and maintenance.
***IN SITU* CONTROL TECHNOLOGIES –** technologies that control/limit contaminant migration using *in situ* treatment methods				
Phytoremediation	This "passive" technology involves the use of plants to extract, accumulate, and/or transform VOCs present in the groundwater and soils. Plants such as poplar trees are capable of sequestering and transforming certain VOCs with water released to the atmosphere via transpiration. Phytoremediation is likely occurring under present conditions limiting migration of VOC-containing groundwater above the bedrock surface. Enhanced through additional planting it could be applied toward: (i) targeting low-level concentrations of VOCs in unsaturated and saturated surficial soils, (ii) increase transpiration as a removal mechanism and (iii) decreasing precipitation recharge feeding seeps, springs, and to fractured rock. For example, deciduous trees, and/or conifers could be planted over additional areas of the BPA Binghamton Country Club properties to increase the vegetative density,	Favorable • The primary site contaminants are readily amenable to phytoremediation using species known to extract and/or transform chlorinated VOCs. • This technology could be applied over a wide area on- and off-site, and would be consistent with the current wooded landscape. • Would limit VOC-containing groundwater discharge to surface seeps and springs. Unfavorable • Phytoremediation relies on healthy vegetative growth and respiration. Several years would be required for plants to mature to a stage where results are observable. • Plant roots will not materially penetrate deeper than about 4 feet and the bedrock fracture zone where much of the contaminant transport is occurring. • The effectiveness of phytoremediation would be seasonal, and would be limited during cold seasons.	Advantages • *In situ* treatment for contaminant migration control could supplement active groundwater extraction and treatment or enhanced in situ biological treatment. • By limiting active groundwater extraction and treatment, associated treatment residuals and operations and maintenance costs would be marginally reduced. • Would offer the potential for both containment and treatment of groundwater contaminants. Limitations • Would not be capable of groundwater uptake from below root zone depth or in bedrock, and therefore would not address contaminant mass in rock. • Years to decades may be required for this technology to achieve its potential treatment capability.	**Retain for further consideration –** this technology offers a passive, *in situ* means for control and treatment of contaminants, principally applicable to reducing flow to surface seeps and springs. Would likely be combined with other containment or source removal technologies.

TABLE 5
Identification and Preliminary Screening of Remedial Technologies
Remedial Investigation
IBM Gun Club – Former Burn Pit Area, Union, NY

Technology-Method	Process Description	Screening Factors		Screening Outcome
		Site Characteristics	**Technology Limitations**	
Permeable Reactive Barrier (PRBs)	An *in situ* groundwater treatment zone is created by constructing a trench containing a permeable reactive media. The trench is installed perpendicular to the path of horizontal groundwater flow. As VOC-containing groundwater flows through the PRB, the VOCs are broken down by biotic and/or abiotic processes. PRBs could be considered for installation either proximate to the source zone, or at the downgradient property boundary, to reduce contaminant mass transport. Reactive media include reactive metal, such as zero-valent iron particles, iron filings, or other electron donor or donor/catalyst combinations. Recently, biodegradable organic matter products such as mulch combined with vegetable oil have been used for treatment of VOCs in PRB applications. Excess available organic matter produces a strongly reducing environment as a result of high carbon loading, which stimulates dechlorination of chlorinated solvents. At the Gun Club site, a PRB could potentially be constructed as a linear or semi-circular trench cut to about 10 to 15 ft bgs into rock oriented perpendicular to groundwater flow from the source zone. The excavated trench would be filled with reactive media as described above.	Favorable • The primary site contaminants (chlorinated VOCs) are readily amenable to reductive dechlorination using PRBs containing media such as zero-valent iron or organic matter. • The bedrock aquitard inferred to be present at a depth of about 20 ft bgs would allow the PRB to be keyed into the rock and limit potential for underflow. • The site is relatively unencumbered by structures or subsurface utilities, which would allow for unencumbered siting of a PRB. Unfavorable • Construction of a PRB in bedrock by excavation may be impractical depending on length, depth, and thickness required to achieve containment and treatment objectives. PRBs are typically installed and most effective in shallow, granular soil settings. • PRB performance is somewhat a function of contact time within the PRB. Unequal flow into and out of the PRB due to fracturing may be a performance limitation. • Incomplete dechlorination of site contaminants in a PRB may create vinyl chloride, which could migrate with groundwater flow downgradient of the PRB.	Advantages • *In situ* treatment for contaminant migration control would potentially eliminate the need for active groundwater extraction and treatment, and the associated treatment residuals and operations and maintenance costs. • Would provide a potential means of gaining control over contaminant mass transport away from the source zone. • Would not limit and could complement application of other contaminant source removal measures. • A PRB with iron or mulch may combine both chemical and biological treatment, possibly increasing removal rates and remediation efficiency. Limitations • As a containment technology, PRBs do not remove residual contaminant mass at the source, but instead limits downgradient contaminant migration. • The barrier must remain effective for as long as a contaminant source is present. Long-term effectiveness of barriers may be compromised by loss of porosity due to inorganic precipitation, fouling, loss of reactivity, or other factors. Performance would need to be monitored indefinitely.	**Retain for further consideration** – this technology offers an *in situ* means for contaminant migration control. However, construction feasibility via an excavated trench in bedrock may be limited. Absent effective source removal the PRB treatment would need to be maintained for an interminable period. Eliminate from consideration in application to bedrock containment, retain for consideration in limited application to treat water in situ in overburden proximate to points of discharge at seeps and springs.
Electrochemical Treatment/ *In situ* Electrode Barriers	The installation of electrodes into groundwater and soil environments is a novel technology that has shown promise in stimulating both chemical and biological degradation of solvents. In electrode technologies, a circuit is created in the subsurface where electrons are either deposited or taken up from an environment, thereby providing an energy cycle for abiotic and biological transformations of chlorinated constituents. Electrodes can be operated in either a cathode (electron donor) or anode (electron acceptor) mode, depending upon the process of interest. If operating in cathode mode (termed an E-barrier), electrons from the surface of the electrode, supplied via an external power source, are donated to the subsurface environment to stimulate reduction of chlorinated solvents. When operating in anode mode (termed a fuel cell), energy is created when electrons are transferred to the surface of the electrode via biological or chemical mechanisms. In application to the BPA site, an *in situ* E-barrier could be implemented as a lateral or semi-circular trench cut to about 10 to 15 ft bgs and oriented perpendicular to groundwater flow from the source zone. The trench would be excavated, set with electrodes, and backfilled with permeable media. It may also be possible to install electrodes directly into rock, in an array or barrier pattern.	Favorable • Detectable concentrations of daughter products (*cis*-DCE, vinyl chloride, ethene) relative to TCE source concentrations indicate that reductive dechlorination is already occurring to varying degrees *in situ*. • The depth of the majority of source mass is relatively shallow and potentially accessible for electrodes. • The site is relatively unencumbered by structures or subsurface utilities, which would allow for relatively easier siting of electrodes. Unfavorable • Other VOCs detected at the site (e.g. ketones and hydrocarbons) may not be conducive to treatment using electrode treatment methods.	Advantages • TCE removal has been documented at the field scale using electrode methods. • Electrode treatment designs are flexible, and could consist of either electrodes installed in a trench oriented perpendicular to flow (termed E-barrier), or regularly spaced electrodes within a source area. • E-barriers combine both chemical and biological treatment, possibly increasing removal rates and efficiency. Limitations • E-barriers are a novel technology and long-term performance has not yet been shown. • If functioning as a biological stimulant, an E-barrier may need to be combined with amendment injection to ensure that other nutrient resources (e.g. carbon, nitrogen, phosphorus) are not limiting in the subsurface. • Incapable of addressing residuals present in the source rock. The barrier must remain effective for as long as a contaminant source is present. Performance would need to be monitored indefinitely. • Loss of reactivity or biofouling on electrodes has been documented under certain subsurface conditions. • There remains limited documentation of other biogeochemical changes associated with electrode use in the subsurface (changes in pH, sorption/desorption processes, other types of biostimulation) making troubleshooting and field optimization difficult.	**Eliminate from further consideration** – because of absence of a positive track record at the field scale, particularly in fractured rock settings and provides no more advantage over other more proven technologies.
Monitored Natural Attenuation (MNA)	Monitoring of the natural or "intrinsic" processes occurring in the subsurface environment to gradually reduce VOC contaminant mass and concentrations in groundwater. These processes include biodegradation, dispersion, dilution, adsorption, volatilization, and abiotic degradation. A long-term program of routine monitoring and data evaluation would be required to verify and confirm that the intrinsic attenuation processes continue to be active. Could be applied to certain downgradient portions of the BPA site in conjunction with other containment or in situ control technologies or source reduction measures.	Favorable • Site data support that reductive dechlorination is already occurring to varying degrees *in situ*. • The extent of contamination downgradient is not expected to increase as it is believed to reflect a steady state condition. • A relatively extensive network of monitoring wells currently exists at the site for characterizing source-dependent biogeochemical conditions, quantifying degradation rates, and developing a long-term program of monitored natural attenuation processes. Unfavorable • Geochemical assessment and daughter product concentrations of *cis*-DCE and vinyl chloride suggest dechlorination is stalling prior to generation of non-toxic end products outside of the immediate vicinity of the source zone where biological degradation may be limited by available carbon and redox conditions. • The amount of mass present and transport mechanisms likely may limit the effectiveness of passive intrinsic processes to achieve remedial objectives within a reasonable time frame (e.g., 30 years or one generation) as referenced in certain regulatory guidance.	Advantages • Treatment occurs *in situ*, thereby eliminating above ground treatment system components and generation of treatment wastes. • This approach requires less site disturbance as compared to active remedial approaches. Limitations • This approach is not considered reliable/effective for remediating source zone contaminant mass, but it is more likely to be appropriate for application to the VOC presence in groundwater downgradient that are is longer increasing in concentration or extent. • The long-term reliability and effectiveness of this approach is uncertain in consideration of potential changes in hydraulic or geochemical conditions.	**Retain for further consideration** – although this approach is not suited for significant reduction of contaminant source mass, it could be considered for areas that do not pose an unacceptable risk of human exposure. Additional biogeochemical sampling is recommended to further assess in situ processes under existing conditions and extrapolate long-term conditions.

TABLE 5
Identification and Preliminary Screening of Remedial Technologies
Remedial Investigation
IBM Gun Club – Former Burn Pit Area, Union, NY

***EX SITU* TREATMENT TECHNOLOGIES –** for treatment of VOC-containing aqueous streams generated by groundwater extraction				
Air Stripping	VOCs are removed from the aqueous stream by contact with air, which facilitates partitioning into the gas phase. The three most common designs are packed tower, tray aeration, and diffused aeration.	Favorable • The primary site contaminants, including TCE and *cis*-DCE, are readily amenable to air stripping. • Effective for removal of certain VOCs that may be present in the groundwater, including vinyl chloride, but which are not readily treated by other *ex situ* treatment technologies, such as activated carbon. • Inorganic water quality in uppermost fractured zone indicates relatively "soft" water with suggests lower potential for air stripper fouling by precipitation of hardness. Dissolve reduced iron and manganese offer some potential for fouling.. Unfavorable • Water quality at intermediate depth may indicate air stripper scaling problems. • Ketones and petroleum hydrocarbons are not as amenable to air stripping as chlorinated VOCs.	Advantages • Assuming no air emissions controls are necessary, this method offers a low-cost means of removing VOCs from aqueous streams. Limitations • Employs mechanical equipment (e.g., pumps, blower) that use energy and must be regularly maintained. • Contaminants are transferred to the vapor-phase, which are then either discharged or must undergo further treatment.	**Retain for further consideration** – this technology would be considered if hydraulic containment is selected as a remedial technology.
Aqueous-Phase Activated Carbon Adsorption	VOCs are removed from the aqueous stream by physical or chemical adsorption processes to granulated activated carbon. Typically, the VOCs are desorbed from carbon through steam or other thermal processes and incinerated.	Favorable • The primary site contaminants, including TCE and *cis*-DCE, are readily amenable to carbon adsorption treatment Unfavorable • Vinyl chloride, ketones, and certain other site contaminants are not amenable to carbon adsorption, therefore this method would need to be combined with air stripping or another technology to treat all site VOCs. • Activated carbon has the potential for metal (Fe and Mn) and microbial fouling, which would cause a loss of treatment efficiency and/or flow rate. • If groundwater is extracted from deeper bedrock zones, carbon adsorption efficiency may be influenced by inorganic water quality with elevated Fe, Mn, and hardness.	Advantages • This method offers a relatively low-cost means of removing VOCs from aqueous streams. • Carbon treatment units require less mechanical equipment prone to malfunction as compared to air stripping or advanced oxidation. Limitations • Transfers mass from an aqueous phase to carbon that must be further treated and disposed. • Spent activated carbon must be treated or disposed off-site.	**Retain for further consideration** – this technology would be considered if hydraulic containment is selected as a remedial technology.
Advanced UV/Chemical Oxidation	Advanced oxidation uses ultraviolet light in conjunction with standard oxidants, such as hydrogen peroxide or ozone, to achieve greatly increased treatment performance over that obtained with standard chemical oxidants alone. In this process, irradiation with ultraviolet light converts injected hydrogen peroxide or ozone into reactive hydroxyl radicals through a photolytic reaction. The radicals rapidly oxidize most organic and inorganic constituents in the water and, in the case of chlorinated VOCs, break down the organic constituents to carbon dioxide, water, and chloride.	Favorable • This technology would be quite effective for destroying known site contaminants, with the added benefit of producing non-toxic end products. • The technology is amenable to batch treatment of low flow rates. Unfavorable • This method has the potential for precipitation and scaling from reduced minerals (iron, manganese), which would cause a loss of treatment efficiency and/or flow rate.	Advantages • Advanced oxidation has a successful track record in industrial wastewater and remediation applications and offers the advantage of permanent destruction of chlorinated contaminants. Limitations • Treatment equipment is relatively complex and of higher cost as compared to air stripping or carbon adsorption equipment. • Complexity of operation can lead to more frequent downtime and maintenance as compared to air stripping or carbon adsorption treatment. • Treatment efficiency is largely a function of effective irradiation and contact time, and is affected by the presence of an oxidant.	**Retain for further consideration** – this technology would be considered if hydraulic containment was selected as a remedial technology
SOURCE MASS REMOVAL/*EX SITU* TREATMENT TECHNOLOGIES –technologies intended to actively remove contaminant mass from source zones in combination with *ex situ* treatment or containment methods				
Source Zone Excavation	This approach would involve excavation of rock containing residual VOC mass that constitutes the primary source for groundwater contamination. The excavated materials would be segregated and non-contaminated soils and rock would be backfilled, while contaminated materials would be either treated *ex situ* and productively used, or transferred to and treated and/or disposed at an off-site disposal facility.	Favorable • If excavated to a depth of 15 ft bgs, a large proportion of source mass could be removed. • The site is relatively unencumbered by structures or subsurface utilities, which would allow for relatively easier implementation of bedrock excavation. • The practicability of excavation is limited when the source is difficult to delineate or access (*e.g.*, in deep bedrock locations). However, site investigation activities to date indicate that the source zone in uppermost fracture rock has been well characterized. Unfavorable • This approach could be relatively cost prohibitive due to the volume of rock to be removed and challenges associated with rock excavation. • Excavation offers some potential to increase mobility through mobilization of NAPL and mechanical fracturing of the rock increasing surface area and permeability.	Advantages • This method provides direct removal of contaminant source material from the subsurface environment. It is most effective for relatively small, well-defined, shallow source zones. Limitations • Excavation of hard well cemented rock by mechanical means alone may be extremely time consuming and costly and serve as a source of nuisance noise and dust. Blasting is ruled out due to noise, and the introduction of new contaminants. • Contamination left behind would continue to be a source of VOCs in groundwater, so the benefits downgradient outside of the excavation may be limited. • Excavation would serve to alter site hydrology probably increasing infiltration and the volume of groundwater flow downgradient. • Excavated materials must be treated using another *ex situ* technology or disposed at an off-site secure landfill. • Management of groundwater inflow and surface runoff would be required.	**Retain for further consideration –** offers the potential for removing a large proportion of contaminant source mass from the uppermost bedrock.
Subsurface Vapor Extraction (SVE)	This technology targets removal of VOC contaminant mass from the unsaturated zone by facilitating volatilization via application of vacuum to extraction wells (or trenches) and forcing air flow through pore or fracture spaces. Extracted vapor is typically treated *ex situ* by activated carbon treatment. SVE may be applied simultaneously with groundwater extraction at the same well (see dual-phase extraction) or at different wells to increase mass removal below the ambient water table.	Favorable • The site contaminants are readily amenable to vapor extraction coupled to *ex situ* treatment provided that adequate air flow can be achieved at depths/locations where the VOC mass resides. Unfavorable • SVE could not achieve sufficient vacuum to desaturate the rock matrix to access VOCs present in the saturated rock matrix. • The ability to remove mass would be limited by the rate of diffusion from the rock matrix to the vapor phase in fractures under vacuum. • SVE would likely increase oxygen levels in the shallow subsurface potentially altering the existing biochemical degradation processes.	Advantages • Subsurface vapor extraction is a relatively simple, widely used technology that is typically more efficient for mass removal than aqueous phase extraction. • There is little risk that SVE implementation would exacerbate VOC mobility. Limitations • Successful application requires achieving a vacuum and air flow within the subsurface zones/units that contain residual contaminant mass. This may be practicable in bedrock fractures (secondary porosity) but highly impracticable for the unfractured rock (primary porosity) where the nearly all the mass resides. • Vapors extracted using SVE may require *ex situ* treatment.	**Eliminate from further consideration** – because contaminant source mass is located largely below the water table in bedrock and inaccessible to vapor extraction.

TABLE 5
Identification and Preliminary Screening of Remedial Technologies
Remedial Investigation
IBM Gun Club – Former Burn Pit Area, Union, NY

Dual-Phase (Soil Vapor/ Groundwater) Extraction	This technology involves the simultaneous extraction of subsurface vapor (SVE discussed above) and groundwater from wells installed within/proximate to VOC source zones in order to: (i) reduce contaminant mass in the source zone through extraction of vapor-phase and dissolved-phase contaminants; and (ii) provide near-source hydraulic containment of dissolved phase contamination and limit the potential for contaminant transport away from the source zone. Extracted water and vapor would be conveyed to an *ex situ* treatment system.	Favorable - Favorable factors include those listed under SVE and hydraulic containment. - Groundwater extraction would enable water table depression into bedrock, marginally increasing enabling SVE from the uppermost fractured bedrock and surficial soils. - The site contaminants are readily amenable to groundwater and vapor extraction coupled with *ex situ* treatment. Unfavorable - Unfavorable factors include those listed under SVE and hydraulic containment. - In a fractured bedrock system, the ability to remove mass would be limited by the rate of contaminant diffusion from the rock matrix to the groundwater or vapor phase.	Advantages - Advantages are similar to those of SVE with the added advantages of potentially increased mass removal from below the ambient water table and source zone containment associated with groundwater extraction. Limitations - The *ex situ* treatment system would need to address both the vapor and aqueous phases, and can be relatively complex and costly to implement, operate, and maintain.	**Eliminate from further consideration** – considered a proven technology for removal of mass from highly permeable soils where a large proportion of mass and/or DNAPL is present. This technology is not suited for application along to the low permeability rock setting but could be applied in thermal treatment/extraction.
Thermally Enhanced Extraction	Thermally enhanced extraction technologies involve the process of heating soil and groundwater that would increase solubility, diffusivity, and volatility of contaminants. Compounds are extracted using other methods (*e.g.* soil vapor extraction, groundwater pumping) and subsequently treated or *ex situ*. Heating can be implemented in one of several different methods, including electrical resistive heating, steam injection, or thermal conductive heating. Thermal treatment has typically been applied in NAPL source areas, with NAPL residuals and/or solute removal typically accomplished using other chemical or biological methods. Applied to the BPA this conductive heating would be the likely choice implemented as an array of electrodes placed in boreholes drilled into bedrock and connected to an external source of electric power. Vapor and groundwater extraction would occur from the vertical wells and conveyed to an *ex situ* treatment system.	Favorable - The majority of the source mass is relatively shallow (depth of 10 to 15 ft bgs) and accessible for heat addition. - The site is relatively unencumbered by structures or subsurface utilities, which would allow for easier implementation of thermal treatment. - The principal site contaminants (chlorinated solvents) along with other VOCs present at the site are readily amenable to thermal treatment, provided that efficient vacuum and groundwater extraction could be achieved in the subsurface. As discussed for SVE/Dual Phase Extraction, vapor and groundwater would be treated *ex situ*. Unfavorable - Based on case studies of thermal treatment in bedrock, it may be difficult to raise temperatures sufficiently given the thermal conductivity of rock materials. This may reduce efficiency and increase long-term costs for a thermal treatment strategy. - Mass removal would be limited by the rate of diffusion from the rock matrix to the aqueous or vapor phase, although heat addition would enhance the diffusion rate. - Mass removal would also be constrained by limitations on vapor and groundwater transport in bedrock.	Advantages - This technology offers the potential for rapid removal of contaminant mass from source rock, which would potentially reduce longer-term monitoring and migration controls. - Elevated temperatures outside the treatment zones would likely stimulate faster rates of *in situ* microbial degradation, provided that other resources are not limiting. Limitations - Requires a relatively large mobilization of sophisticated equipment and technical expertise. However, the duration for which thermal technologies are employed can be significantly shorter than other approaches, reducing long-term operational costs. - Requires huge inputs of energy resources. - High temperatures (greater than 60°C) for long periods would likely deter the *in situ* microbial community within the treatment area. Therefore, biostimulation/ bioaugmentation may be necessary to address contaminant mass remaining after thermal treatment.	**Retain for further screening –** Based on discussions with IBM and the Agencies. This technology is largely dependent on the ability to effectively heat the subsurface and extract vapor and groundwater from the treatment zone, which would be difficult in the fractured bedrock setting. Although we know of no successful implementation in fractured sedimentary bedrock it is retained for further screening via discussions with USEPA researchers and vendors. Extensive lab and pilot testing would be required to further, assess thermal technologies.
SOURCE MASS REMOVAL/*IN SITU* TREATMENT TECHNOLOGIES – technologies intended to reduce source zone contaminant mass using *in situ* treatment methods				
***In Situ* Chemical Oxidation (ISCO)**	This technology involves the subsurface injection of oxidizing reagents into residual VOC source zones to chemically mineralize organic compounds, thereby destroying them *in situ*. Strong chemical oxidants, such as hydrogen peroxide, potassium or sodium permanganate, perchlorate, or ozone are injected into the subsurface and react with the chlorinated solvent to release chlorine atoms and result in a more oxidized form of carbon (e.g. CO_2). Applied to the site, this technology would likely include installation of an array of vertical/horizontal injection and extraction wells to establish a subsurface circulation zone to facilitate oxidant delivery and distribution. Piping would be necessary for conveying oxidants to injection points from a central location, and for recirculating groundwater from extraction to injection locations.	Favorable - Chlorinated and hydrocarbon VOCs are readily amenable to chemical oxidation. - There is limited risk for the production of more mobile or toxic daughter products (e.g. vinyl chloride) with oxidation processes. - ISCO could be implemented in a gradual, phased approach that builds on the initial findings and performance of the technology at the site. Unfavorable - The site bedrock is a "reducing environment" that would consume chemical oxidants without addressing VOC mass. ISCO is generally incompatible with a naturally reduced subsurface environment. - ISCO would not directly address contaminants adsorbed in the rock mass or present in matrix pore water; in a fractured bedrock system, the ability to destroy contaminant source mass would be limited by the rate of diffusion from the rock matrix into the groundwater. - Fracturing may contribute to short-circuiting and limit effective delivery and distribution of oxidants in the subsurface unless a dense array of vertical injection wells is used. - High concentrations of reduced inorganic species or organic carbon, such as ketones and hydrocarbons, would consume agents and limit the destruction of chlorinated VOCs. - Elevated concentrations of daughter products relative to TCE indicate that reductive dechlorination is already occurring through natural biological processes *in situ*. ISCO will react with all organic materials in the subsurface, including microbes, hindering biodegradation processes.	Advantages - Chemical reagents can be directly injected into wells with limited disruption to site activities. - As an aggressive source zone remediation technology, *in situ* chemical oxidation offers the potential for direct and permanent destruction of contaminant mass, which could reduce the potential for contaminant migration with groundwater flow. - The kinetics of chemical treatment are extremely rapid. Limitations - VOC mass destruction is largely a function of subsurface hydraulics and the ability to deliver/distribute oxidants into the subsurface. Case studies on remediation of chlorinated solvents in bedrock show limited success with ISCO as evidenced by contaminant rebound after injection ceases. - Oxidants have a rapid reaction time and will likely react with compounds present in secondary porosity groundwater (fractured bedrock), rather than targeting mass diffused in rock. Given inorganic and organic concentrations in the uppermost fractured bedrock, mineral precipitation and clogging is not likely in shallow rock zones. - If injected into deeper bedrock zones, efficiency may be influenced by mineral precipitation and clogging as a result of elevated inorganics in groundwater at depth. - There is some documentation of increased mobilization of target contaminant due to changes in solubility and pressure as a result of chemical oxidation processes. Because limited DNAPL has been found at the site, this would not likely be an issue.	**Eliminate from further consideration –** because of the challenges associated with oxidant delivery, the lack of a positive track record in fractured bedrock systems, and because oxidation processes would be incompatible with the reducing environment and associated active *in situ* biological processes.
***In Situ* Chemical Reduction (ISCR)/ Zero-valent Iron (ZVI)**	The injection of highly reactive reducing agents into residual VOC source zones to promote dehalogenation processes, thereby destroying contaminants *in situ*. Reagents typically include colloidal or nanoscale iron particles (*e.g.* zero-valent iron) that react directly with VOC compounds in stepwise reduction processes. ZVI technology is becoming more commonly used for chlorinated VOC removal, and has been successfully employed at the field scale, in sediments typically resulting in fairly rapid removal of contaminant mass with limited byproduct production. There is ongoing research in improving iron particle delivery, focused on particle size and makeup (e.g. combining with polymers). Applied to the site, installation of an array of vertical/horizontal injection and extraction points to establish a subsurface circulation zone to facilitate reagent delivery and distribution. Piping would be necessary for conveying reagents to injection points from a central location, and for recirculating groundwater from extraction to injection locations.	Favorable - TCE and its associated daughter products are readily amenable to chemical reduction. - ISCR could be implemented in a gradual, phased approach that builds on the initial performance of the technology at the site. Unfavorable - Will not penetrate the unfractured rock and as such contaminant mass destruction would be limited by the rate of VOC diffusion from the rock matrix to water/reagent-containing fractures. - Fractures may contribute to short-circuiting and limit effective delivery and distribution of reagents in the subsurface unless a dense array of vertical injection wells is used. - There is some risk of the production of more mobile or toxic daughter products using ZVI if reactions occur slowly or if sufficient reagent is not delivered to complete dechlorinatation. - Other VOCs detected at the site (e.g. ketone and petroleum) are not be conducive to ZVI treatment.	Advantages - Reductants such as nanoscale ZVI particles could be directly injected into fractures. - By causing highly reducing conditions in groundwater, ZVI injection may facilitate enhanced biological reductive dechlorination of chlorinated solvents. Limitations - VOC mass destruction is largely a function of subsurface hydraulics and the ability to deliver/distribute reductants into the subsurface. Case studies on remediation of chlorinated solvents in bedrock show limited success with ISCR as evidenced by contaminant rebound after injection ceases. - Reductants have a rapid reaction time and will likely react with naturally occurring compounds present in fractured bedrock. - If injected into deeper bedrock zones, efficiency may be influenced by reactions with elevated inorganics in groundwater at depth. - Even more so than ISCO, distribution of materials into source areas is the largest challenge in ZVI technologies due to the potential of subsurface clogging by iron particles.	**Eliminate from further consideration –** because of the challenges associated with reagent delivery, lack of positive track record, and potential for rapid reaction with naturally occurring compounds in a fractured rock setting and subsurface clogging.

TABLE 5
Identification and Preliminary Screening of Remedial Technologies
Remedial Investigation
IBM Gun Club – Former Burn Pit Area, Union, NY

Enhanced Biochemical Degradation (Biostimulation/ Bioaugmentation)	Biostimulation is the process of adding amendment(s) to the subsurface for the purpose of stimulating the growth of specific groups of bacteria that are capable of breaking down chlorinated solvents in groundwater and soil environments. Amendments are typically injected under pressure to the subsurface. Common amendments for enhancing biochemical degradation of VOCs include sources of carbon or electron donors (acetate, lactate, whey) and sources of nutrients (ammonium, phosphate). Bioaugmentation is the direct injection of a collection of bacteria, typically species of *Dehalococcoides* and *Dehalobacters* along with growth amendments that stimulate the reductive biodegradation of contaminants in the subsurface. The justification for bioaugmenting the subsurface would be that bacteria involved in key VOC degradation steps are not present at the site; therefore, by introducing them via injection, rates governing VOC mass removal are improved. At the Gun Club, this technology could range from injection of liquids into an array of wells or trenches to facilitate bioamendment delivery and distribution or direct emplacement of solid electron donor material. Piping would be necessary for conveying amendments to injection points from a central location, and for recirculating groundwater from extraction to injection locations if necessary.	<u>Favorable</u> • Detectable concentrations of TCE daughter products (e.g., *cis*-DCE, vinyl chloride, ethene) relative to TCE source concentrations and the findings of geochemical testing of water support that reductive dechlorination is already occurring to varying degrees *in situ*. • Geochemical assessment indicates that other areas are currently limited by available carbon materials. • Enhanced biodegradation can be implemented in a gradual, phased approach that builds on the initial performance of the technology at the site. • TCE has been successfully remediated at the field scale using biostimulation/ bioaugmentation methods. <u>Unfavorable</u> • The capability to destroy contaminant mass would be limited by the rate of VOC diffusion from the rock matrix to water/amendment-containing fractures. • Fractures would limit effective delivery and distribution of amendments in the subsurface unless a dense array of vertical injection wells is used. • Inherent uncertainties in flow pathways and the interconnectivity of bedrock may require multiple injection events at several different injection points to improve amendment distribution. • There is some risk of the production of more mobile or toxic daughter products using enhanced biochemical degradation if reactions occur slowly or complete dechlorination does not occur.	<u>Advantages</u> • Enhanced biochemical degradation could be implemented with limited disruption to site activities; food and nutrients would be directly injected into the subsurface and biological treatment would occur *in situ*. • Offers the potential for direct permanent destruction of contaminant source mass, which could reduce the potential for contaminant migration with groundwater flow. <u>Limitations</u> • VOC mass destruction is largely a function of subsurface hydraulics and the ability to deliver or distribute amendments, nutrients, and/or cultures into the subsurface. Distribution and residence time of materials into source areas is the largest challenge in enhanced biochemical degradation technologies. • The efficiency of enhanced biochemical degradation technologies may be effected by a number of biogeochemical factors that are not well known or documented (e.g., changes in pH, sorption/desorption, loss of agents to the matrix and or other processes). • Bioaugmentation products are typically proprietary; users have limited control over the initial design, health, and cost of these cultures.	**Retain for further consideration** – this approach has the potential to enhance biological processes that are already evident at site. However, matrix diffusion effects would likely limit the rate of mass removal and increase the duration of implementation. Unless coupled with other effective mass removal, this would be a migration control technology that would require long-term maintenance for an interminable period. We recommend additional bench-scale testing, field sampling, and/or pilot testing to further assess technology applicability.
ENHANCED EXTRACTION TECHNOLOGIES – technologies intended to increase fracture density and aperture diameter to enhance permeability and/or increase surface area for diffusive mass transfer, thereby improving contaminant mass removal/recovery				
Hydraulic or Pneumatic Fracturing	Hydraulic and pneumatic fracturing are techniques developed in the oil, gas, and water industry to increase well productivity. In hydraulic fracturing, fluids (typically sand and water slurries) are injected into a packer-isolated borehole at pressures greater than the weight of the overlying rock/overburden. Sand or other inert media is used to prop open newly created fractures. Similarly, pneumatic fracturing involves injecting highly pressurized air to extend existing fractures, and to create a secondary network of fissures and channels.	<u>Favorable</u> • There would be little risk of damage to site structures, utilities, or water wells. <u>Unfavorable</u> • Some risk of opening up new horizontal and vertical pathways for contaminant migration away from the contaminant source zone.	<u>Advantages</u> • This technology could potentially greatly increase the efficiency of extraction technologies by creating zones of greater permeability for advective flow and diffusion-controlled mass transfer. • Hydraulic fracturing could be combined with hydraulic containment/migration control technologies and/or *in situ* treatment technologies, to improve their effectiveness. <u>Limitations</u> • Fracturing would need to be combined with another *in situ* or *ex situ* technology. • Potential for short-term excursion of VOC-containing fluids and vapors beyond the target zone.	**Retain for further consideration –** hydraulic fracturing combined with an *in situ* or *ex situ* treatment may be an efficient means for targeting source zone VOCs or improving the effectiveness of hydraulic containment/migration control technologies.
Explosive Fracturing	Blast-enhanced fracturing through the controlled use of explosives is a technique used to improve the rate of groundwater flow in fractured bedrock by enhancing fracture interconnectedness and increasing hydraulic conductivity. Detonation of explosives in boreholes can create an intensely fractured area of bedrock. Groundwater recovery wells installed in this area, often referred to as a "fracture trench", can potentially capture greater quantities of groundwater, intercepting flow from fractures that they were not previously hydraulically interconnected.	<u>Favorable</u> • There would be little risk of damage to site structures, utilities, or water wells near the Former Burn Pit Area using fracturing technologies. <u>Unfavorable</u> • Blasting agents, typically ammonium nitrates and/or hydrocarbons, would serve as a new source of groundwater contaminants. • Some risk of opening up new horizontal and vertical pathways for contaminant migration away from the contaminant source zone.	<u>Advantages</u> • This technology could greatly increase the efficiency of extraction by creating higher zones for advective flow and diffusion-controlled mass transfer. <u>Limitations</u> • Fracturing would need to be combined with another *in situ* or *ex situ* technology. • This technology is still in research and development for environmental remediation applications and has largely been used only for increasing oil and gas well yields.	**Eliminate from further consideration –** due to the probability of introducing new contaminants.

Note: This table presents a systematic screening of remedial technologies for consideration in application to the IBM Gun Club Burn Pit Area. Please refer to the RI report text Section 8.0 for additional details.

FIGURES

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Notes:

1. The basemap consists of a 24 tile mosaic of orthorectified (adjusted to scale) true color digital aerial photographs accessed by SHA in September, 2007 via the New York State geographical information systems (NYGIS) website. The aerial photographs are dated April, 2006.

2. The IBM Gun Club site limit are based on information contained in two AUTOCAD drawings entitled "UNION2000.DWG" and "UNIONEAST.DWG" that were provided to SHA on October 10, 2002 by the Broome County Tax Mapping Services division. Areas north of the Gun Club site and south of Struble Road have been modified since acquisitions due to updates in the tax map.

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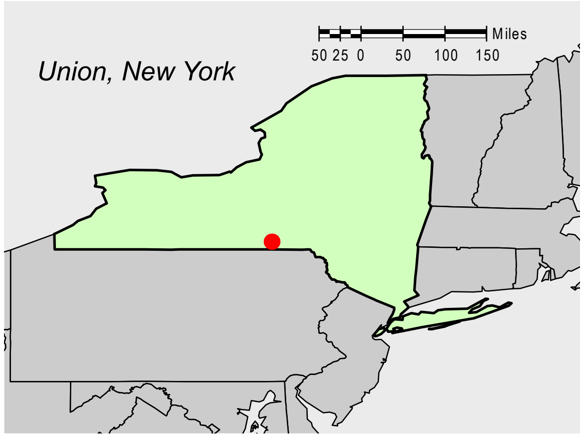

Figure 1

Locus Plan

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By: S. Warner
Designed By: A. Horneman
Reviewed By: A. Horneman
Date: August 2009

Feet
500 250 0 500 1,000 1,500

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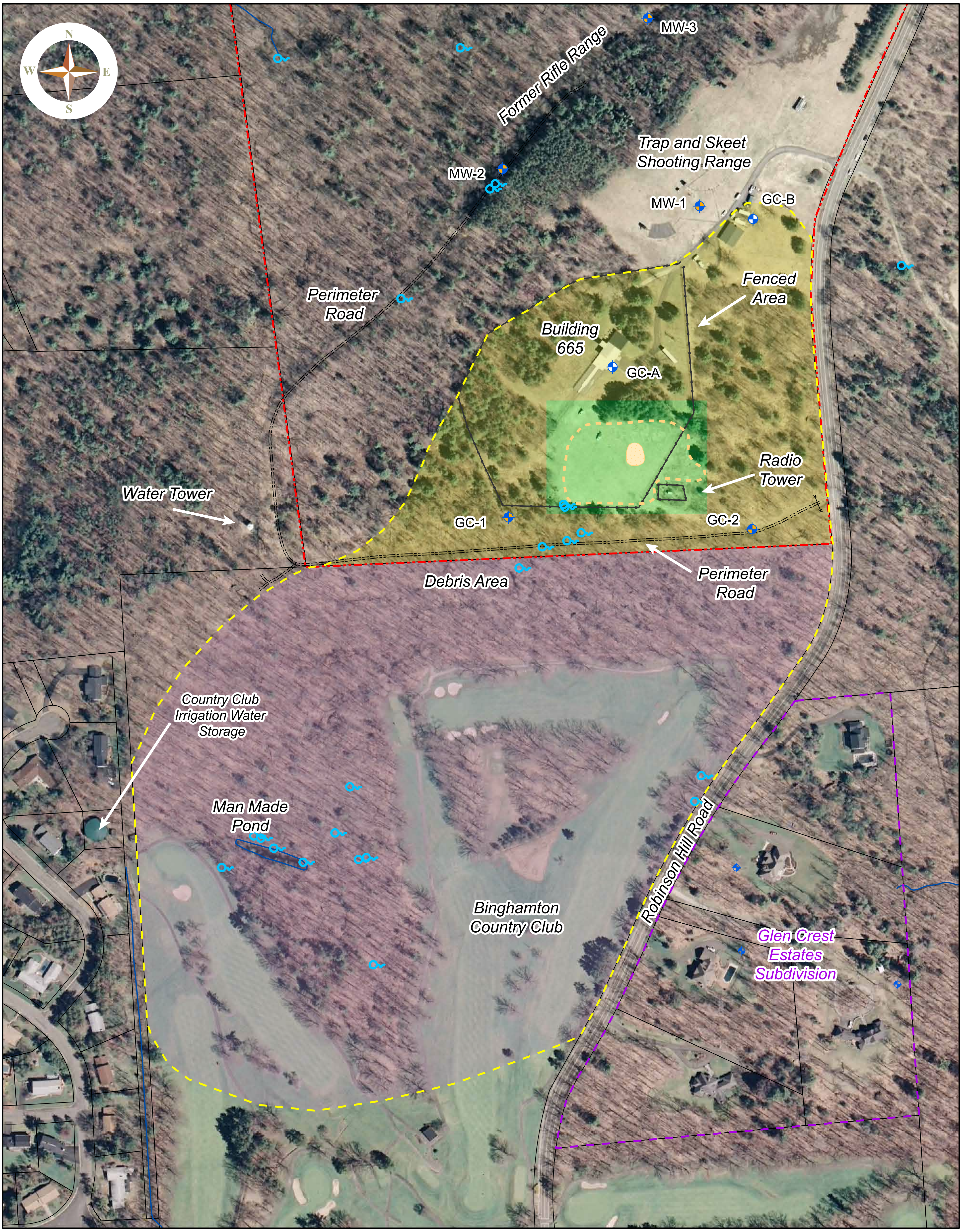

Legend

Investigative Areas

Inital Investigative Area	🟩
Investigative Area by 2007	🟨
Off Site Investigative Area	🟪

Former Burn Pit	●
Site Water Supply Well	⊕ GC-A
Former Open Borehole Monitoring Well (Installed by Others)	⊕ GC-1
Approximate Locations of Private Water Supply Wells	◆
Observed Seep or Spring Locations	○
USGS Perennial Streams	——
Perimeter Road	══════
Parcels	——
Limit of Gun Club Property	-·-·-·-
Burn Pit Area 1980	- - -
Approximate Extent of SHA Investigation	- - -

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Figure Narrative:

This figure is intended to show approximate locations of site features associated with the IBM Gun Club Burn Pit Area and the investigative area. This figure is also meant to supplement discussions in Sections 1.0 and 2.0 of the text. The inferred boundaries of the investigative work are approximated.

Figure 2

Site Plan

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By: S. Warner/J. Williams
Designed By: S. Warner
Reviewed By: A. Horneman
Date: August 2009

100 50 0 100 200 300 Feet

Figure 3

Summary of Hydrologic Conditions

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By:	J. Williams
Designed By:	S. Warner
Reviewed By:	A. Horneman
Date:	August 2009

Notes:

1. The 10 foot photogrammetric topography is based on United States Geological Survey (USGS) digital elevation model (DEM). SHA acquired the USGS DEMs from Geo Community website in June 2008.

2. The Perennial Stream features were from mapping acquired from the New York State GIS website. These features originated from the USGS National Hydrography Dataset. Observed drainage features were observed by SHA during field reconnaissance or from aerial photos.

3. Please refer to Figures 1 and 2 for additional notes and legend.

Legend

- Property Served by Private Water Supply Well
- — 1320 — 10ft Topographic Contour (AMSL)
- A ······ A' Hydrogeologic Profile Section Line

Hydrologic Features

- USGS Perennial Streams
- Observed Drainage Feature (Arrows indicate flow direction)
- Observed Seep or Spring Locations
- Culvert

300 150 0 300 600 900 Feet

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Figure 4

Location Plan

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By:	S. Warner/J. Williams
Designed By:	S. Warner
Reviewed By:	A. Horneman
Date:	August 2009

Notes:

1. The figure is intended to summarize the location of monitoring wells, multi-level systems, and surface water sampling points within the investigative area. The location of certain water supply wells are also included on the figure.

2. The 2 foot photogrammetric topography is based on an Auto CAD deliverable from Butler Land Surveying, LLC. of Little Meadows, Pennsylvania (Butler) dated 8/11/08.

3. Site features including monitoring wells, seeps, and culverts were surveyed by Butler.

4. Please refer to Figures 1 through 3 for additional notes and legend.

Legend

A ▪▪▪▪ A'	Hydrogeologic Profile Section Line
—— 1320 ——	2ft Topographic Contour (AMSL)

Groundwater and Surface Water Sample Locations

118 ⌶	Culvert
Seep1 ○~	Seep or Spring Sampling Location if labeled
BP-2A ◆	Monitoring Well
BP-14D ◆	Multi Level Monitoring Installation

100 50 0 100 200 300 Feet

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Figure 5

Bedrock and Groundwater Elevation Contours

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By:	S. Warner/J. Williams
Designed By:	S. Warner
Reviewed By:	A. Horneman
Date:	August 2009

Notes:

1. Site features including monitoring wells were surveyed by Butler Land Surveying, LLC. of Little Meadows, Pennsylvania (Butler).

2. The inferred groundwater elevation contours are based on measurements of depth to groundwater collected in June 2008 from water table monitoring wells. Other interpretations are possible.

3. The inferred top of bedrock contours are based on observations from rock core drilling, direct push probing, and test pits. Other interpretations are possible.

Legend

Site Features

●	Rock Core
●	Rock Probe
●	Test Pit
BP-2A ✦	Monitoring Well
BP-2A ✦	Multi Level Monitoring Well
— 1355 —	5ft Top of Bedrock Contour (AMSL)
— 1290 —	Groundwater Contours June 2008
→	Inferred Flow Directions

100 50 0 100 200 300 Feet

SHA
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LEGEND:

- BP-5A o/s 28' NE 1387.0 — Well Designation / Offset from Section Line / Ground Surface Elevation
- Location of Flute or Monitoring Well Screened Interval
- (1349.2) Water Level Elevation
- Approximate Location of Spring or Seep Observed in Site Reconnaissance
- Equipotential Line (shaded where less constrained) Groundwater Flow Direction Indicated by Arrow
- Inferred Water Table Surface
- Inferred Depth of First Aquitard Interval
- Inferred Groundwater Divide

Lithology

- 🟫 Glacial Till
- 🟩 Shale
- 🟪 Siltstone
- 🟥 Sandstone
- ▨ Unclassified Rock

Observed Fracture Morphology

- Near Horizontal Fracture
- Diagonal Fracture
- Near Vertical Fracture
- Intersecting Fractures

Notes:

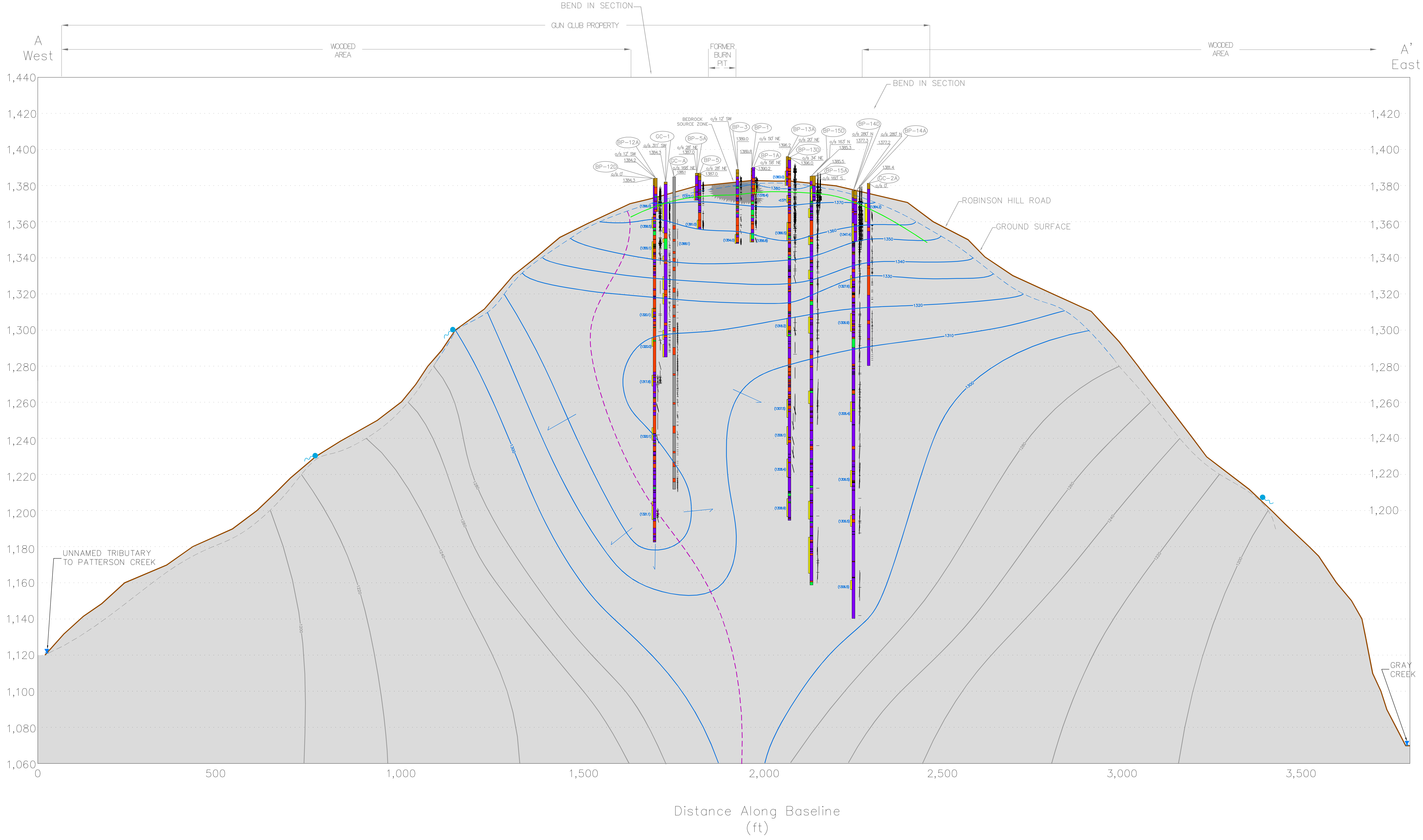
1. This figure depicts a profile view based on available inference of bedrock lithology, locations of groundwater monitoring wells, and approximate locations of surface features in feet above mean sea level, National Geodetic Vertical Datum of 1929. The cross section alignment is indicated on Figures 3 and 4.

2. The ground surface profile was derived from United States Geological Survey (USGS) digital elevation model accessed by SHA in February 2006 via the New York State Geographical Information System (NYGIS) website. Well elevations are projected orthogonally onto topography and sometimes project above or below the section surface.

3. Lithology and inferred aquitard surface are based on logging of rock core borings. Borehole geophysics and downhole video data for BP-13D, BP-14D, BP-15D, and GC-1 were also considered in interpretation of lithology.

4. The groundwater equipotentials and flow directions were inferred by SHA based on water level measurements recorded in June and July 2008 and are intended to portray apparent hydraulic gradients and flow patterns consistent with the available data. The actual groundwater flow conditions vary and likely are more complex than those shown. Other interpretations are possible.

5. Refer to Remedial Investigation Report text for further discussion.



SCALE: 1 INCH = 100 FEET (HORIZONTAL), 1 INCH = 20 FEET (VERTICAL)

SHA
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DRAWN BY: EMB
DESIGNED BY: PJM/AHH
CHECKED BY: AHH
REVIEWED BY: DBC
PROJECT MGR: AHH
PIC: DBC
DATE: AUG 09

NO. DATE DESCRIPTION BY

REMEDIAL INVESTIGATION
IBM GUN CLUB – FORMER BURN PIT AREA
UNION, NEW YORK

HYDROGEOLOGIC PROFILE A–A'

PROJECT NUMBER: 2400

FIGURE: 6

LEGEND:

BP-5A o/s 28' NE 1387.0	Well Designation Offset from Section Line Ground Surface Elevation
∿	Approximate Location of Spring or Seep Observed in Site Reconnaissance
▮	Location of Screened Interval
⟋	Equipotential Line (shaded where less constrained) Groundwater Flow Direction Indicated by Arrow
- - -	Inferred Water Table Surface
──	Inferred Depth of First Aquitard Interval
- - -	Inferred Groundwater Divide

Lithology

🟫	Glacial Till
🟩	Shale
🟪	Siltstone
🟥	Sandstone

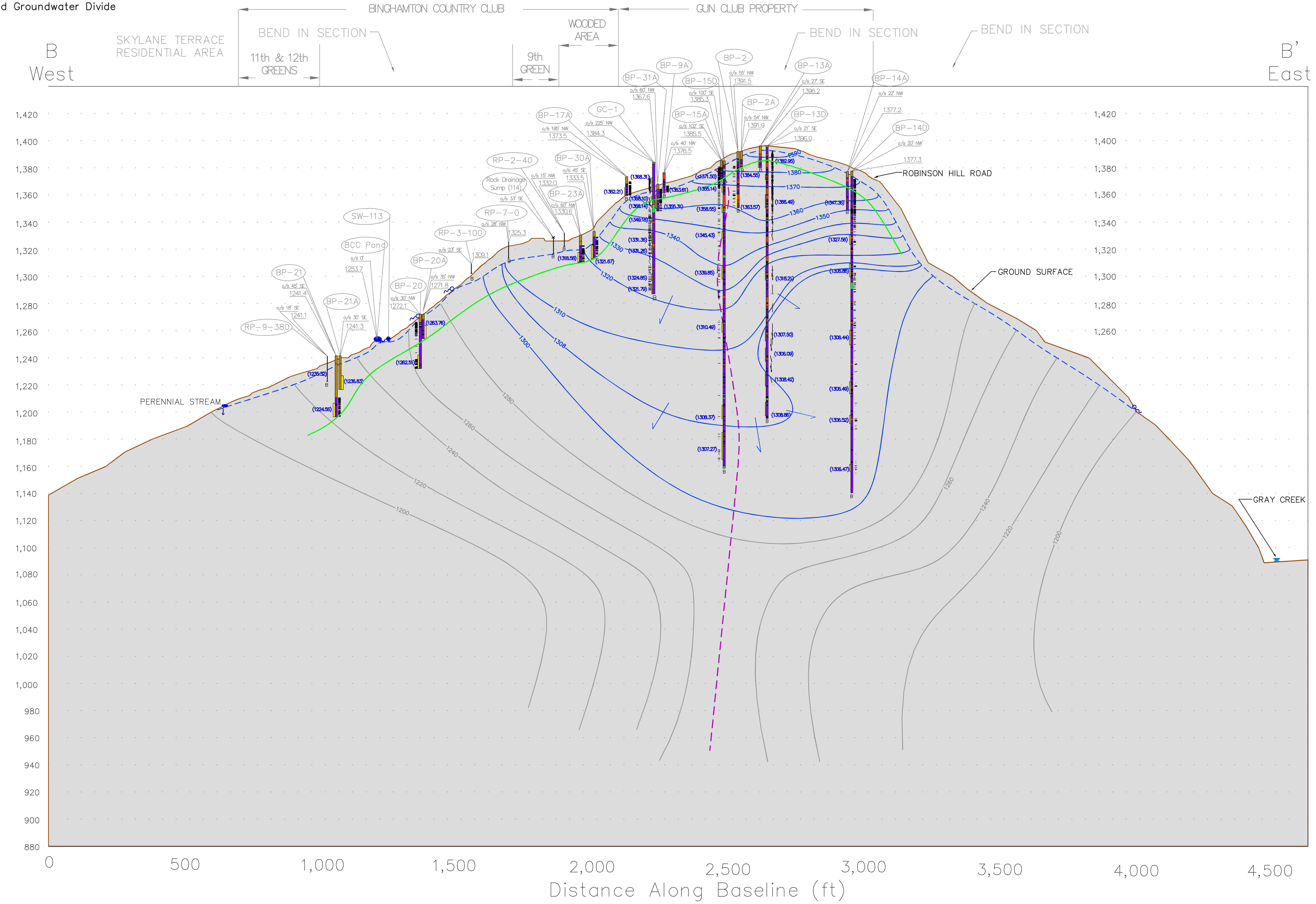
Observed Fracture Morphology

──	Near Horizontal Fracture
╲	Diagonal Fracture
│	Near Vertical Fracture
✳	Intersecting Fractures

Notes:

1. This figure depicts a profile view based on available inference of bedrock lithology, locations of groundwater monitoring wells, and approximate locations of surface features in feet above mean sea level, National Geodetic Vertical Datum of 1929. The cross section alignment is indicated on Figures 3 and 4.

2. See Figure 6 for additional notes and legend.



SCALE: 1 INCH = 200 FEET (HORIZONTAL), 1 INCH = 40 FEET (VERTICAL)

NO.	DATE	DESCRIPTION	BY

DRAWN BY: EMB
DESIGNED BY: PJM/AHH
CHECKED BY: AHH
REVIEWED BY: DBC
PROJECT MGR: AHH
PIC: DBC
DATE: AUG 09

REMEDIAL INVESTIGATION
IBM GUN CLUB - FORMER BURN PIT AREA
UNION, NEW YORK

HYDROGEOLOGIC PROFILE B-B'

PROJECT NUMBER: 2400

FIGURE: 7

FILE: E:\PORTLAND\2400\dwg\20090401_Figure 7.dwg
LAYOUT: B-B'
CTB FILE: SHA STANDARD.CTB
PLOT DATE: 7-31-09

Figure 8

Summary of Groundwater Quality Conditions - Plan View

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By:	J. Williams/S. Warner
Designed By:	A. Horneman
Reviewed By:	A. Horneman
Date:	August 2009

Notes:

1. The groundwater data for site key VOCs including TCE, cDCE, vinyl chloride, and carbon tetrachloride from water table monitoring wells are presented as pie diagrams. The wedges of each pie diagram represent concentrations of the four compounds expressed in micrograms per liter (µg/L) and are based on arithmetic mean values of data collected by SHA from July 2006 to December 2008. During this time period locations were sampled between 4 and 13 times. The relative diameter of each pie diagram varies based on the sum of the four VOCs at each location.

2. The water table wells 5 µg/L TCE contour is based on arithmetic mean TCE values from water table monitoring wells and observations from temporary rock probes. The intermediate depth wells and multi level system 5 µg/L contour is based on arithmetic mean values of TCE from all wells and multi level systems screened below the first inferred aquitard.

3. Only VOC concentrations from water table monitoring wells are depicted as pies.

4. The rock probe data displayed is based on sampling events completed by SHA between the spring of 2007 and the spring of 2008 as discussed in Appendices F.3.1 and F.4.1.

5. Refer to Report text for further discussion.

Legend

Groundwater Quality Pies

Analytes

- 🟥 Trichloroethene
- 🟪 cis-1,2-Dichloroethene
- 🟪 Vinyl Chloride
- 🟧 Carbon Tetrachloride

- ✛ No Analytes Detected
- ● < 1 µg/l
- ● 1 to 10 µg/l
- ● 10 to 100 µg/l
- ● 100 to 1000 µg/l
- ● > 1000 µg/l

TCE Detected in Rock Probes (µg/l)

- ● TCE Not Detected
- ● < 1
- ● 1 to 5
- ● 5 to 10
- ● > 10

Values posted on the figure are the arithmetic means of TCE concentrations in µg/l

Inferred Extent of Primary Sourcing in Rock

Limits of Groundwater Concentrations Exceeding New York Groundwater Standards for TCE

- > 5 µg/L Water Table Monitoring Wells
- > 5 µg/L Intermediate Depth Wells and Multilevel Systems

100 50 0 100 200 300 Feet

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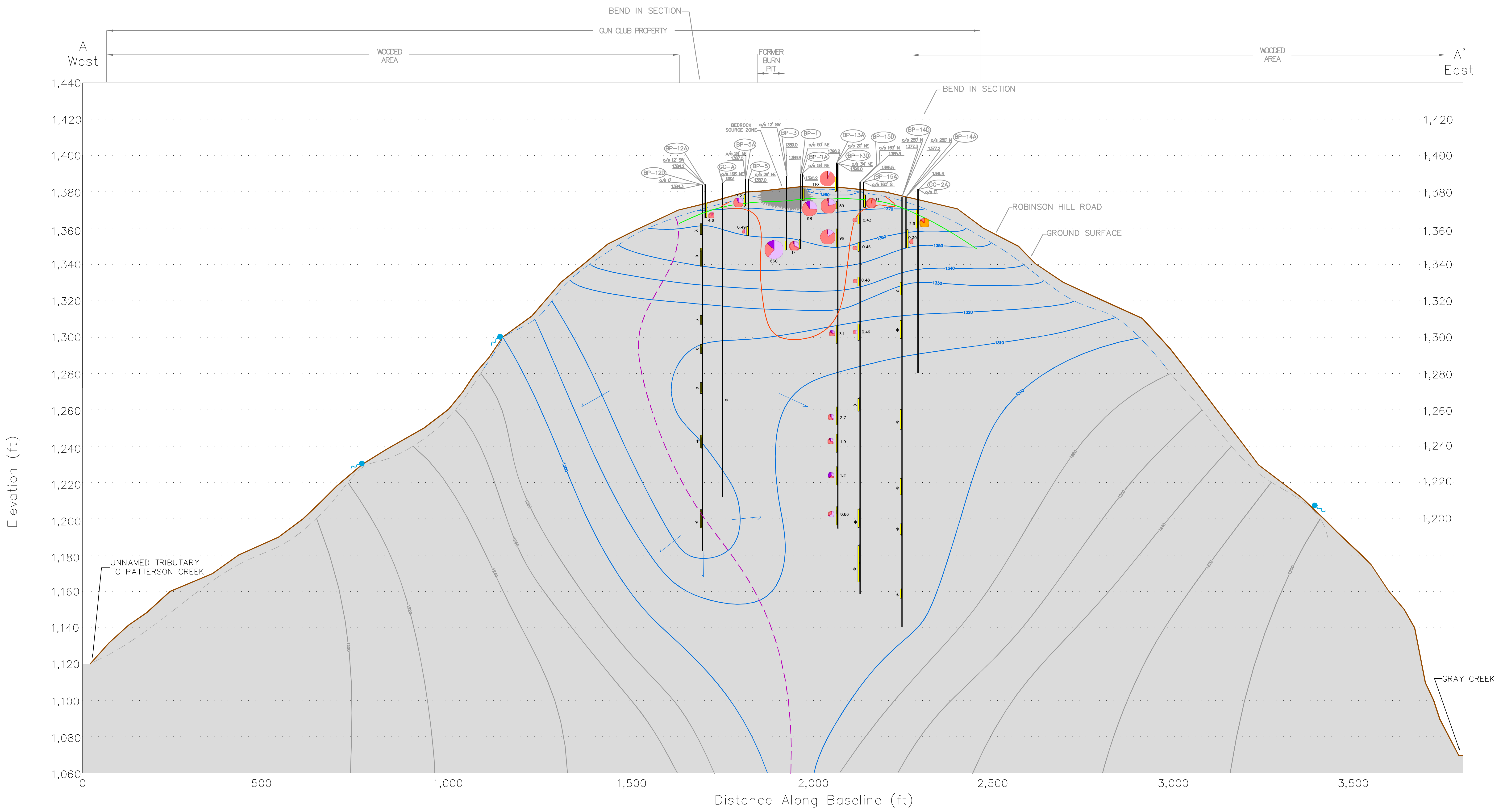
LEGEND:

BP-5A o/s 28' NE 1387.0	Well Designation Offset from Section Line Ground Surface Elevation
●	Approximate Location of Spring or Seep Observed in Site Reconnaissance
▮	Location of Screened Interval
	Equipotential Line (shaded where less constrained) Groundwater Flow Direction Indicated by Arrow
	Inferred Water Table Surface
	Inferred Depth of First Aquitard Interval
	Inferred Groundwater Divide
	Inferred 5 ug/L TCE Concentration Contour

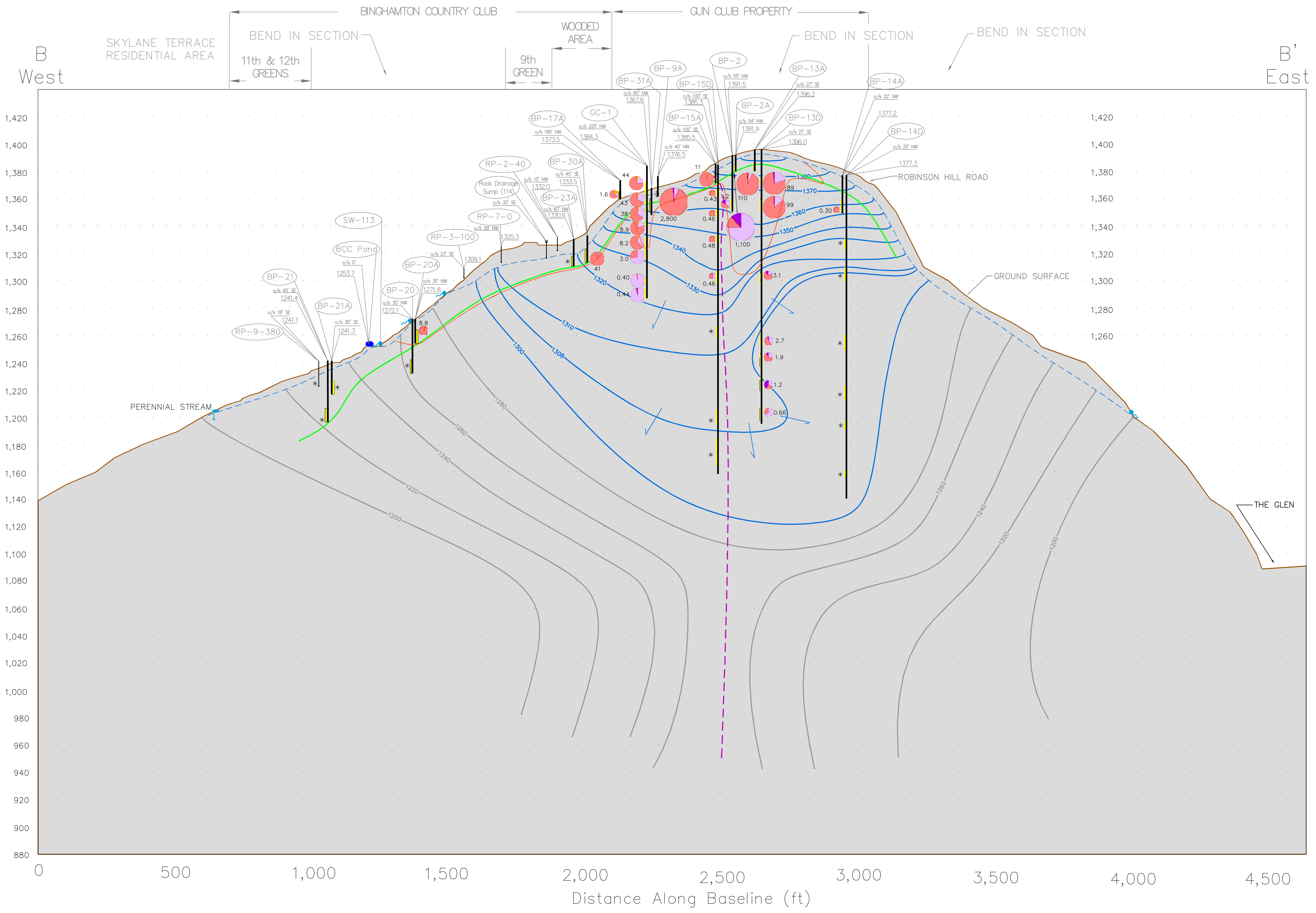
Sum of Mean Key VOCs in Groundwater

8.1	Mean TCE Concentration
*	No Analytes Detected
●	< 1 ug/L
●	1 to 10 ug/L
●	10 to 100 ug/L
●	100 to 1,000 ug/L
●	> 1,000 ug/L

🟥	Trichloroethene
🟪	cis-1,2-Dichloroethene
🟪	Vinyl Chloride
🟧	Carbon Tetrachloride



SCALE: 1 INCH = 150 FEET (HORIZONTAL), 1 INCH = 30 FEET (VERTICAL)



SCALE: 1 INCH = 200 FEET (HORIZONTAL), 1 INCH = 40 FEET (VERTICAL)

Notes:

1. The figure depicts profile views intended to show groundwater quality conditions at certain depth intervals, locations of groundwater monitoring wells, and inferred groundwater equipotentials. The two cross section locations are indicated on Figures 3 and 4.

2. VOC data for water samples are presented as pie charts and represent mean values for groundwater samples collected by SHA between July 2006 and December 2008. The wedges of each pie chart diagrammatically represent concentrations of the four compounds listed in the legend, expressed in micrograms per liter. The relative diameter of each pie chart varies based on the sum of the key VOCs in the monitoring interval.

3. Refer to Figures 6 and 7 for additional notes and legend.

NO.	DATE	DESCRIPTION	BY

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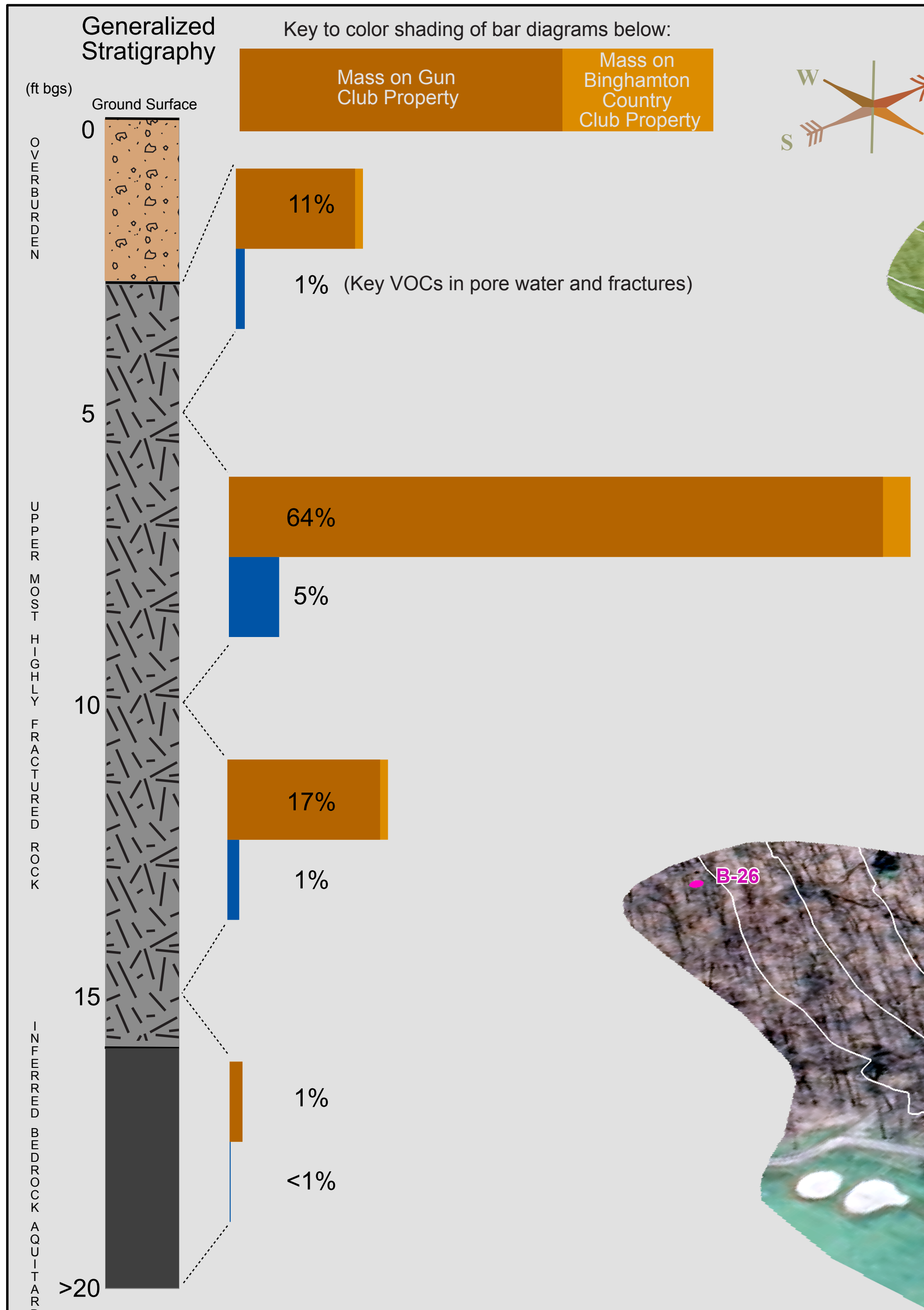
DRAWN BY: EMB
DESIGNED BY: PJM/AHH
CHECKED BY: AHH
REVIEWED BY: DBC
PROJECT MGR: AHH
PIC: DBC
DATE: AUG 09

REMEDIAL INVESTIGATION
IBM GUN CLUB – FORMER BURN PIT AREA
UNION, NEW YORK

SUMMARY OF GROUNDWATER QUALITY
CONDITIONS – PROFILE VIEWS

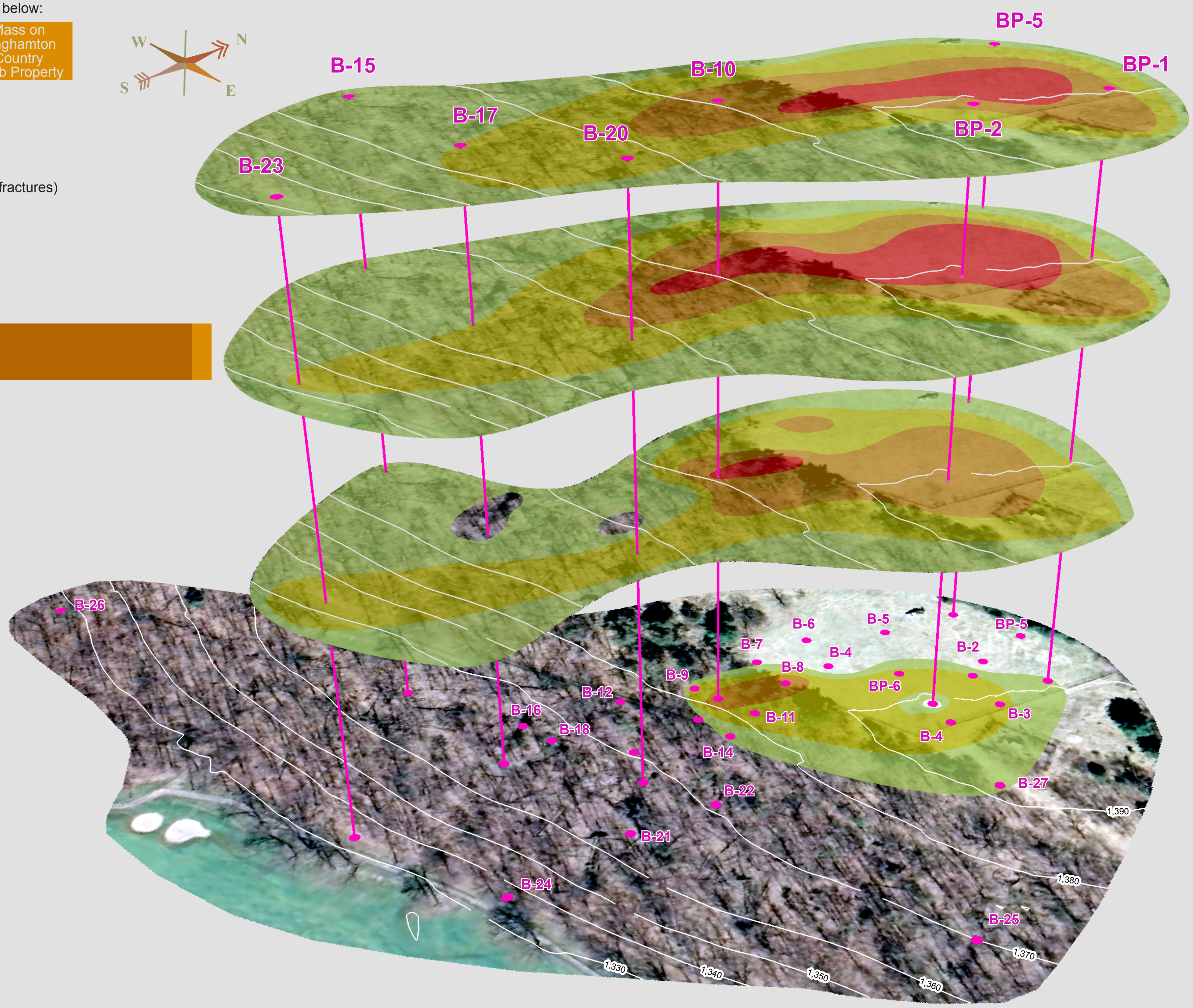
PROJECT NUMBER:
2400

FIGURE:
9



Generalized Stratigraphy

Key to color shading of bar diagrams below:



Plan View Location Map
Total Key VOC Isopleths (Sum of all Depths)

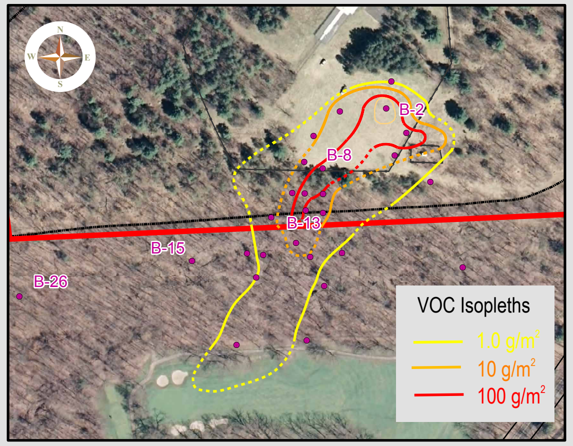


Figure 10

Distribution of Key VOC Mass in Rock Matrix

Remedial Investigation
IBM Gun Club - Former Burn Pit Area

Union, New York

Drawn By: S. Warner/J. Williams
Designed By: S. Warner/P. Mouser
Reviewed By: A. Horneman
Date: August 2009

Figure Narrative:

This figure illustrates the relative distribution of the mass of nine key VOCs including TCE, cis-DCE, trans-DCE, vinyl chloride, 1,2-DCA, chloroform, carbon tetrachloride, 2-butanone, and acetone in the subsurface on the Gun Club and Binghamton Country Club properties. Mass estimates are based on bedrock cores collected during three field events in July 2006, May 2007 and June 2008. Mass estimates at the four depth intervals are in units of grams per cubic foot (g/ft^3), whereas the key VOC isopleths on the plan view figure insert are in units of grams per square meter (g/m^2). Bedrock core samples were analyzed as described in Appendix F.

The layered isopleth image represents the inferred distribution of total key VOC mass at four depth intervals below ground surface (0-5 ft, 5-10 ft, 10-15 ft, and depths greater than 15 ft). Isopleths were created from the total key VOC mass from individual core samples over each depth interval and interpolated using a common ArcGIS algorithm (Natural Neighbor). The isopleths have been overlaid on a digital elevation model created from surveyed ground surface elevations; this is intended to show the general topography of the site.

The generalized stratigraphy is meant to show a generalized representation of subsurface conditions observed by SHA personnel during site investigation. Actual subsurface conditions vary across the site. Mass distributions are represented in a bar graph format as the percentage of total key VOC mass estimated to be in pore water and the rock matrix. Please see Appendix F.1 and report text for further discussion.

Legend

Sum of Chlorinated Key VOC Isopleths

🟩	🟨	🟧	🟥
0.001 g/ft^3	0.01 g/ft^3	0.1 g/ft^3	1.0 g/ft^3

B-26 | Rock Core (Line does not represent actual length)

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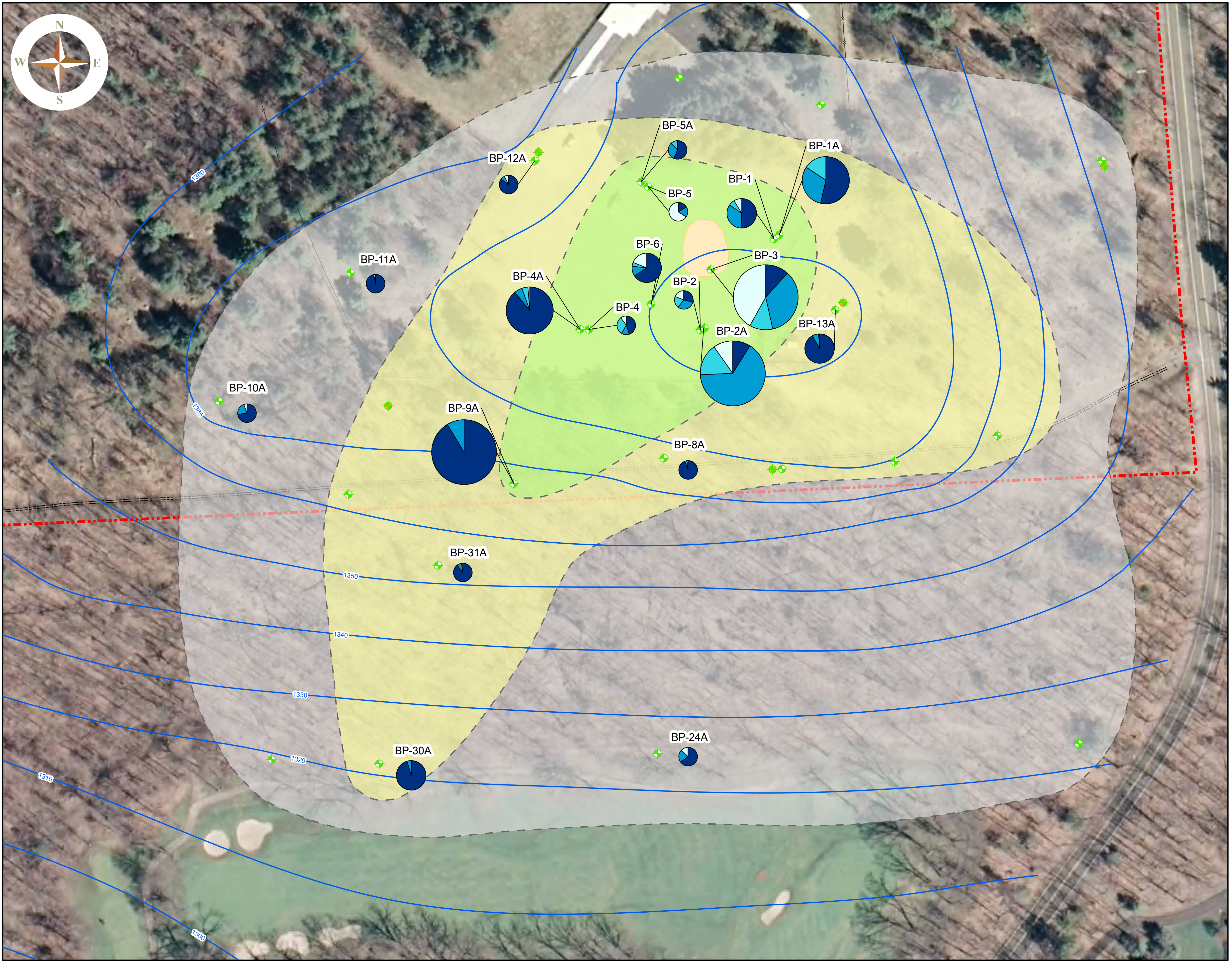

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Figure 11

Evidence of Biochemical Degradation and Groundwater Biogeochemistry

Union, New York

Drawn By: J. Williams
Designed By: P. Mouser/A.Horneman
Reviewed By: D. Carr
Date: August 2009

Figure Narrative:
This figure shows the relative proportion of parent and daughter product VOCs on a micromolar basis (pie charts) with the primary terminal electron accepting processes (TEAPs) (isopleths) inferred based on water quality data for selected monitoring wells screening the uppermost highly fractured rock and intermediate depths.

The TEAPs were inferred from geochemical information for the following oxidized and reduced chemical species: oxygen, nitrate, nitrite, Fe(III), Fe(II), sulfate, sulfide, and methane, where available, or from oxidation-reduction potentials recorded during low-flow sampling. Please see the Remedial Investigation report text for further information.

Legend

- 🟧 Burn Pit
- ● Monitoring Well
- ● Multi Level Monitoring Well
- —1330— Groundwater Contours (June 2008)

Primary TEAP

- ⬜ Suboxic
- 🟨 Nitrate/Manganese/Iron Reducing
- 🟩 Sulfate Reducing/Methanogenesis

- 🟦 Parent VOC (Trichloroethene)
- 🟦 Primary Daughter Product (*cis*-1,2DCE)
- 🟦 Secondary Daughter Product (Vinyl Chloride)
- ⬜ Terminal Breakdown Products (Ethane, Ethene)

Total Chlorinated Ethanes & Ethenes in Groundwater (umol/L)

- 0.01 to 0.1
- >0.1 to 1
- >1 to 10
- >10 to 100

Feet
50 25 0 50 100 150

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Figure 12

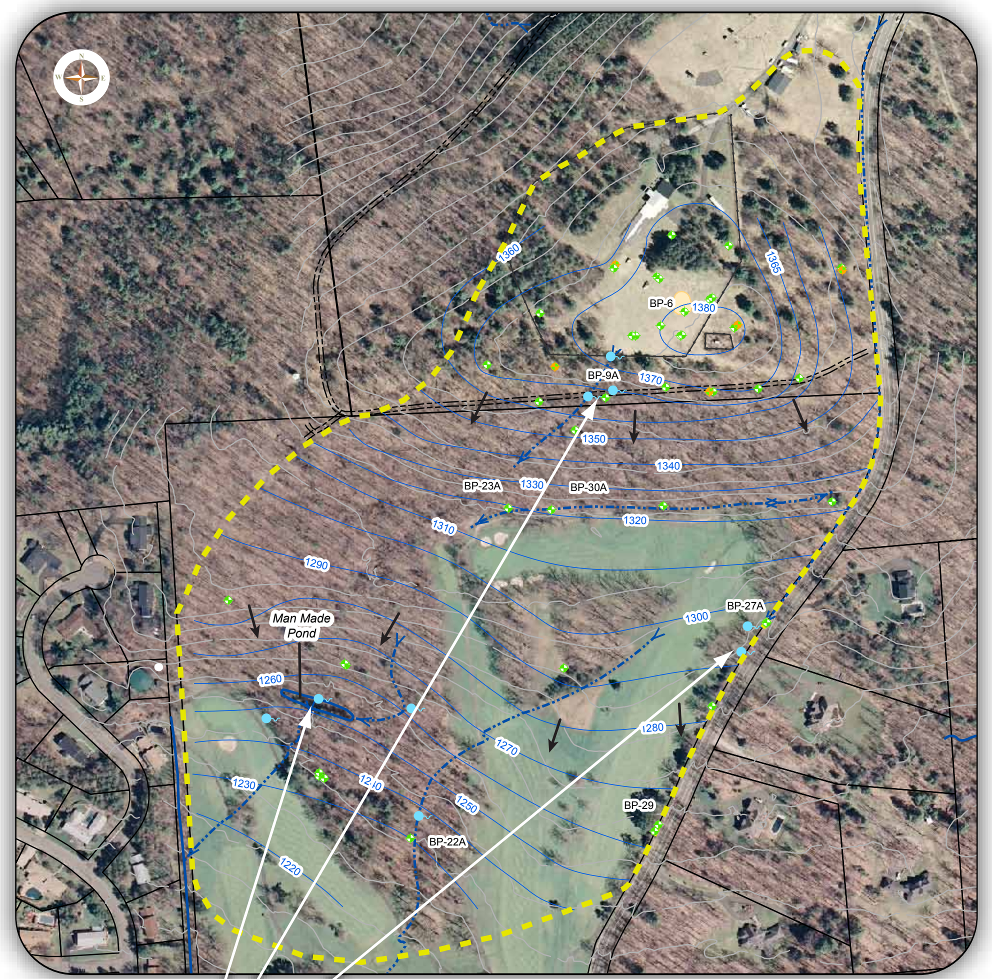
Summary of Site Conditions

Remedial Investigation
IBM Gun Club - Former
Burn Pit Area

Union, New York

Drawn By: S. Warner/J. Williams
Designed By: A. Horneman
Reviewed By: A. Horneman
Date: August 2009

12C GROUNDWATER FLOW INFLUENCED BY HORIZONTAL FRACTURING IN UPPERMOST HIGHLY FRACTURED ROCK



RAPID GROUNDWATER TRANSPORT IN FRACTURES

Majority of VOC mass transport is through horizontal bedding-parallel fractures in the upper 40 feet of rock driven by recharge of incident precipitation through the hilltop.

The flow of groundwater through the BPA and vicinity is expected to be on the order of a few gallons per minute.

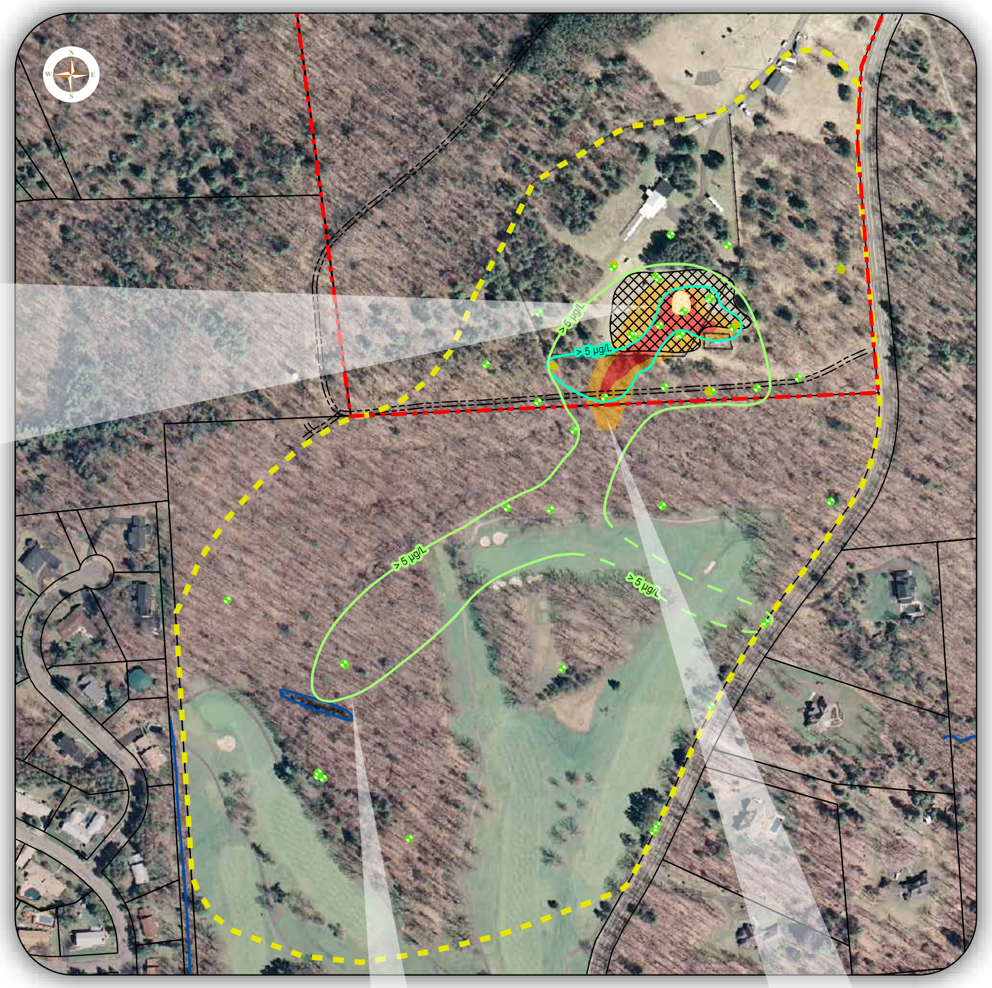
Estimated groundwater travel times to points of groundwater discharge range from a few weeks to half a year.

Therefore, remediation that contains the primary source zone may lead to improved water quality conditions down gradient within a relatively short time.

GROUNDWATER DISCHARGE AS SEEPS AND SPRINGS

The majority of water recharged at or within the BPA flows radially away in horizontal fracturing. In a few places, this flow breaks out as seeps and springs along the hill slope.

12A NATURE AND EXTENT OF CONTAMINATION UNDERSTOOD



SUCCESSFUL REMOVAL OF RESIDUAL VOCs IN SOIL

1980's soil excavation was successful in removing soil containing residuals of oils and solvents from the BPA.

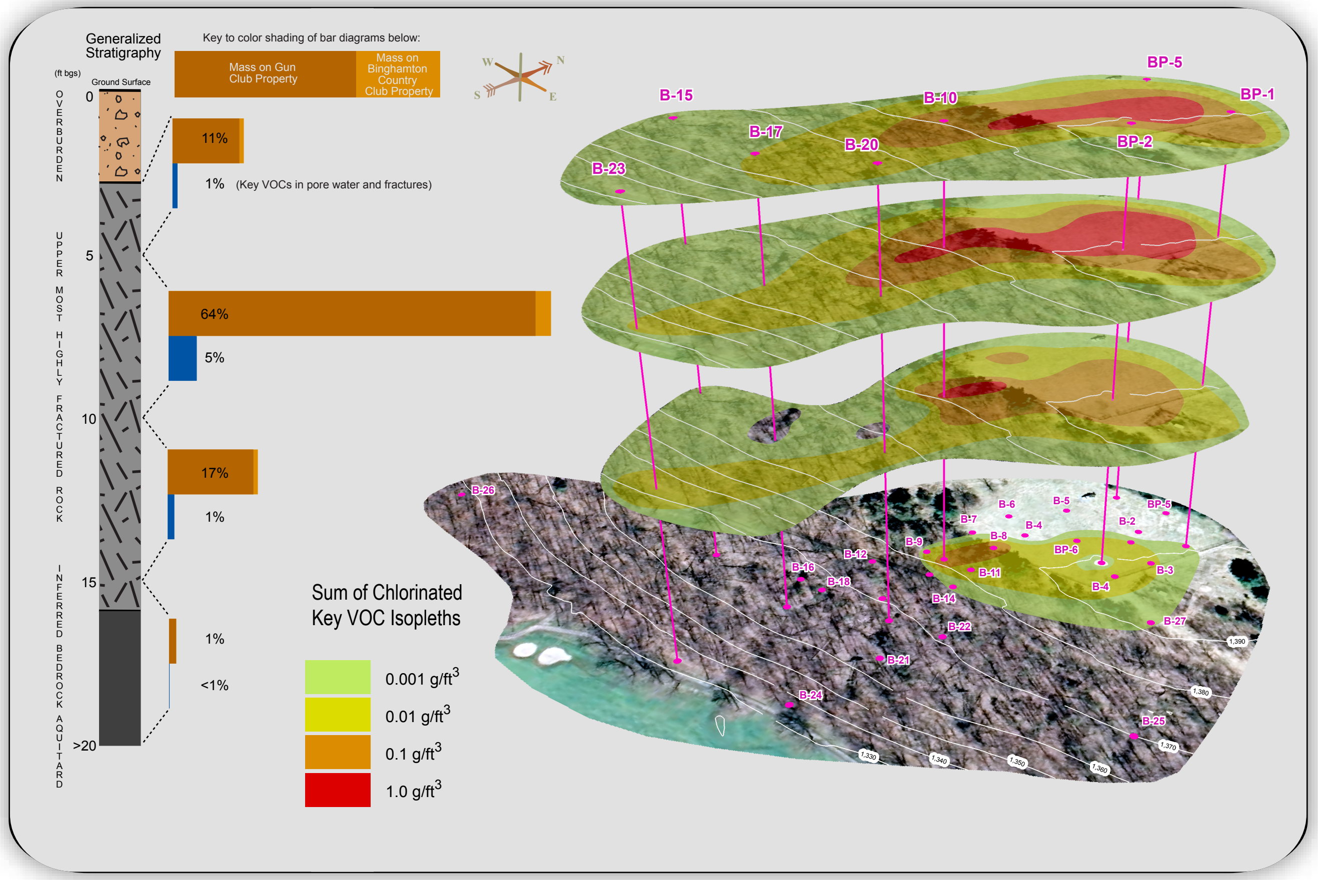
Trace metals and PCBs found in soil in the area of soil removal reflect residuals of former Burn Pit disposal, which are largely contained in the secure fenced area.

VOC SOURCING FROM SOLVENT MASS IN LOW PERMEABILITY SEDIMENTARY BEDROCK

Primary source of on-going presence of VOCs in groundwater is VOC mass residing in the matrix of rock beneath a one and one-half acre area extending southerly from the BPA along a trough-like depression in the bedrock surface as shown by orange shading.

This is believed to reflect the probable limit of the historical penetration of a mixture of separate phase oil and solvent into fractures. See Figure 12B for additional details.

12B VOC SOURCING FROM ROCK MATRIX DEFINED BY ANALYSIS OF ROCK CORE SAMPLES



Sum of Chlorinated Key VOC Isopleths

🟩	0.001 g/ft^3
🟨	0.01 g/ft^3
🟧	0.1 g/ft^3
🟥	1.0 g/ft^3

ROCK CORE ANALYSIS DATA INDICATES A MIXTURE OF PETROLEUM AND SOLVENTS

The data definitively show that the majority of VOC mass is beneath IBM property diffused into rock at about water table depth between 5 and 10 feet below ground. The most commonly detected VOCs include chlorinated ethenes, ketones, and constituents of petroleum.

The orange and red shaded areas represent key VOCs in the primary source rock that contain over 90% of the VOC mass, principally sorbed to the rock solids. Pore water concentrations in this rock are estimated to be on the order of 10,000s to 100,000s of µg/L.

The yellow and green shading reflects rock concentrations one to two orders of magnitude lower from diffusion of VOCs dissolved in migrating groundwater.

OBSERVED EXTENT OF VOCs IN GROUNDWATER

Largely bounded in all directions and reflects limited transport at the water table in the uppermost highly fractured rock. Transport estimated at a few tenths of a pound per year is controlled by matrix diffusion, sorption, and biological degradation.

At depth, the extent of VOCs in groundwater exceeding water quality standards is only found beneath IBM property proximate to the BPA.

Given the limited mass transport and the attenuation mechanisms the extent is not expected to increase with time. No private or public water supplies are at risk.

Legend

⬭	Burn Pit
- - -	Approximate Extent of SHA Investigation
⌖	Monitoring Well
●	Multi Level System

Hydrogeologic Conditions

→	Inferred Groundwater Flow Direction
●	Seeps or Springs
— 1250 —	Groundwater Contours
— 1380 —	10 ft Topographic Contours

Contaminant Conditions

▩	Burn Pit and Approximate Extent of 1980 Soil Removal and Disturbance (BPA)
-·-·-	Limit of Gun Club Property
🟧 🟥	Primary Source Zone in Rock

Limits of Groundwater TCE Concentrations Exceeding New York Standards

— >5 µg/L —	Water Table Monitoring Wells
— >5 µg/L —	Deeper Wells

250 125 0 250 500 Feet

Notes

1. The figure is intended to summarize site conditions including hydrology and the presence and extent of VOCs in groundwater and rock matrix.

2. Refer to Remedial Investigation Report for additional discussion.

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APPENDIX A

LIMITATIONS

APPENDIX A
LIMITATIONS

1. The conclusions and recommendations described in this report are based in part on the data obtained from a limited number of soil and rock samples from widely spaced subsurface explorations. The nature and extent of variations between these explorations may not become evident until further investigation, pilot testing, or potential remedial effort is initiated. If variations or other latent conditions then appear evident, it will be necessary to re-evaluate the recommendations of this report.

2. The generalized lithologic profiles depicted on figures and described in the text are intended to convey trends in subsurface conditions. The lithologic boundaries between strata are interpretations that are approximate and idealized and have been developed based on data and observations from of widely spaced explorations and samples. The actual soil transitions are probably more gradual. For specific information, refer to the exploration logs.

3. Water level measurements have been recorded for the monitoring wells and multi-level system monitoring intervals and surface water sampling points at times and under conditions stated within the text of the report and indicated on the exploration logs. Note that fluctuations in the water levels may occur due to variations in rainfall and other factors not evident at the time measurements were made.

4. Quantitative laboratory analyses were performed as part of the investigation as noted within the report. The analyses were performed for specific parameters that were selected during the course of this study. It must be noted that additional compounds not searched for during the current study may be present in soil and groundwater at the site. Moreover, it should be noted that variations in the types and concentrations of contaminants and variations in their distribution within the groundwater and soil may occur due to the passage of time, seasonal water table fluctuations, recharge events, and other factors.

5. The conclusions and recommendations contained in this report are based in part upon various types of chemical data as well as historical and hydrogeologic information developed by previous investigators. While SHA has reviewed that data and information as stated in this report, any of SHA's interpretations, conclusions, and recommendations that have relied on that information will be contingent on its validity. Should additional chemical data, historical information, or hydrogeologic information become available in the future, such information should be reviewed by SHA and the interpretations, conclusions and recommendations presented herein should be modified accordingly.

6. This report has been prepared for the exclusive use of the International Business Machines Corporation for specific application for the Remedial Investigation of the IBM Gun Club – Former Burn Pit Area, in Union, NY, in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

7. The analyses and recommendations contained in this report are based on the data obtained from the referenced subsurface explorations. The explorations indicate subsurface conditions only at the specific locations and times, and only to the depths penetrated. They do not necessarily reflect strata variations that may exist between such locations. The validity of the recommendations is based in part on assumptions SHA has made about conditions at the site. Such assumptions may be confirmed only during remediation. If subsurface conditions different from those described become evident, the recommendations in this report must be re-evaluated.

8. In the event that any changes in the nature, design, or location of the facilities are planned, the conclusions and recommendations contained in this report should not be considered valid unless the changes are reviewed and conclusions of this report modified or verified in writing by SHA. SHA is not responsible for any claims, damages, or liability associated with interpretation of subsurface data or re-use of the subsurface data or engineering analyses without the express written authorization of SHA.

9. This report contains comparative cost estimates for the purpose of preliminary evaluation of remedial technologies. These estimates involve approximate quantity evaluations. These quantity evaluations are of insufficient accuracy to prepare a construction bid. Since SHA has no control over the cost of labor or materials, the competitive bidding climate at the time of the bid, SHA does not guarantee the accuracy of cost estimates as compared to potential contractors' bids for costs.

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APPENDIX B THROUGH K
(Supplied on Disk)

LIST OF APPENDICES PROVIDED ON DISK

Appendix B Field Explorations and Testing Logs and Data

- B.1 Mapping and Photographic Documentation of the Site and Vicinity
  - B.1.1 IBM Gun Club Boundary Survey
  - B.1.2 Summary of Surface Water Sampling Points
  - B.1.3 Summary of Wet Areas
  - B.1.4 Country Club Debris Area
- B.2 Physical Data - Wells and Surface Water Monitoring Points
  - B.2.1 Physical Data - Wells and Surface Water Monitoring Points
  - B.2.2 Location Plan
- B.3 Boring and Monitoring Point Installation Logs
  - B.3.1 Summer 2006 Boring and Monitoring Point Installation Logs
  - B.3.2 Fall 2006 Boring and Monitoring Point Installation Logs
  - B.3.3 Spring 2007 Boring and Monitoring Point Installation Logs
  - B.3.4 Spring and Summer 2008 Boring and Monitoring Point Installations Logs
- B.4 Water Level Data
- B.5 Soils Laboratory Data and Inference
- B.6 Summary of Hydrogeologic Property Estimates

Appendix C Soil Vapor Survey, Soil Sampling and Analysis

- C.1 Soil Vapor and Soil Sampling April 2006
- C.2 Supplemental Soil Sampling and Analysis
- C.3 Summary of April 2006 and September 2009 Soil Sampling

Appendix D Geophysical Logging and Testing of Existing Bedrock Boreholes

Appendix E Bedrock Core Drilling, Borehole Logging, Installation and Testing of New Multilevel Devices and Monitoring Wells

- E.1 Drilling, Testing, and Completion of Multilevel Boreholes BP-12D and BP-13D, and Shallow Boreholes, Fall 2006
- E.2 Summary of Findings, Drilling and Testing of Bedrock Boreholes BP-14 and BP-15, Spring 2007 Drilling and Testing Program

Appendix F Bedrock Core Sampling and Laboratory Analysis of Rock Samples

- F.1 Summary of Work
- F.2 July 2006 Sampling Event
- F.3.1 Spring 2007 Rock Probing and Wet Area Sampling
- F.3.2 Spring 2007 Sampling Event
- F.4.1 Spring 2008 Rock Probing and Wet Area Sampling
- F.4.2 Summer 2008 Sampling Event

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