REPORT

# SUPPLEMENTAL FEASIBILITY STUDY

# SOLID WASTE MANAGEMENT UNIT S: FORMER B001 WASTE TCA TANKS

## Former IBM Kingston Facility
## Site #356002
## Order on Consent Index No. D3-10023-6-11

**Submitted To:** New York State Department of Environmental Conservation
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## 1.0 INTRODUCTION

Golder Associates Inc. (Golder) prepared this Supplemental Feasibility Study (FS), on behalf of International Business Machines Corporation (IBM), for Solid Waste Management Unit (SWMU) S: Former Building B001 Waste 1,1,1-Trichloroethane (TCA) Tanks (SWMU S) at the former IBM Kingston Facility (site) located at 300 Enterprise Drive, Kingston, Ulster County, New York (see Figure 1).

This FS is based on the findings of the SWMU S investigation described in the *Supplemental Remedial Investigation Report: Solid Waste Management Unit S: Former B001 Waste TCA Tank* (SWMU S SRIR) submitted to the New York State Department of Environmental Conservation (NYSDEC) on October 29, 2012. Potential remedial alternatives to remove and/or treat dense (i.e., a liquid with a greater density than water) non-aqueous phase liquid (DNAPL) located in the SWMU S area that serves as a source of impact to downgradient groundwater are evaluated herein.

### 1.1 Site Description and Background

The site is located north of the City of Kingston in the Town of Ulster, Ulster County, New York and is bounded by John M. Clarke Drive and Route 9W to the east, Old Neighborhood Road and Route 209 to the north, Esopus Creek to the west, and Boices Lane to the south (see Figure 2). The portion of the site located east of Enterprise Drive is referred to as the East Campus and includes the majority of the buildings at the site, many of which are vacant. The approximately 258-acre property was first developed by IBM from farmland during the 1950s. IBM's primary activities included the manufacturing of electric typewriters and the development, manufacture and testing of computer systems and related components and technologies. IBM ceased operations during the early-1990s and the property was subsequently subdivided into multiple parcels. In 1998, IBM sold the site to AG Properties of Kingston, LLC and Ulster Business Complex, LLC. The site is currently managed by TechCity.

The entire site was listed as a Class 4 Site (Site # 356002) in the Registry of Inactive Hazardous Waste Disposal sites in New York State and was managed in compliance with an October 4, 1996 Hazardous Waste Management Permit #3-5154-00067/00090 (6 NYCRR Part 373) until the Administrative Order on Consent Index No. D3-10023-6-11 (Order) was signed with NYSDEC by IBM and TechCity on July 8, 2011. The Order, which supersedes and replaces the former Permit, divides the site into ten Operable Units (OUs), as depicted in Figure 2.

Prior to the execution of the Order, IBM completed extensive Resource Conservation and Recovery Act (RCRA) Facility Investigations (RFIs) beginning in the 1990s through 2002 to delineate the occurrence and extent of volatile organic compounds (VOCs) in groundwater beneath the site. The site-wide VOC groundwater plume comprises four distinct groundwater plumes that have been described as follows:

- **North Parking Lot Area Plume (NPLA):** located to the north of Buildings B001 and B003, primarily composed of trichloroethylene (TCE) and TCA, and to a lesser degree tetrachloroethene (PCE). Based on previous investigatory work, the primary source area appears to be the portion of Industrial Waste (IW) sewer lines located north of Building B001 and northeast of Building B003 (i.e., SWMU U).

- **Building B005 Plume:** located beneath Buildings B001, B002, B003, B004 and B005, primarily composed of TCE and TCA. The plume is believed to have originated from activities in Buildings B001, B003, B004 and B005S. The primary source area appears to be the IW sewer lines located in Building B003 (i.e., SWMUs M and V).
- **Industrial Waste Treatment Facility (IWTF) Plume:** located in the vicinity of the former IWTF near Building B036, primarily composed of low-level concentrations of TCE and TCA. The plume in this area is not likely to have originated from the IWTF, but is believed to have migrated from the NPLA plume on the eastern campus along the underground utility pipes prior to the installation of the utility trench barrier wall (see Figure 2).
- **Isolated PCE Plume:** located along the southern portion of Building B005S, primarily composed of PCE. The plume is believed to have originated from a release from a PCE tank located in the southeastern corner of Building B005S (i.e., SWMU G).

Corrective Measures implemented by IBM prior to the execution of the Order include the operation and maintenance of a perimeter control system that intercepts the groundwater plume. The perimeter control system consists of two stormwater sewer systems, an unsaturated portion of the Surficial Sand Unit that underlies the western portion of the site, a utility trench barrier wall, and a groundwater collection system (see Figure 2). IBM currently performs groundwater quality monitoring to evaluate the effectiveness of the Corrective Measures.

The majority of groundwater impacts at the site are interpreted to originate beneath Operable Unit 3 (OU-3) which comprises the former IBM manufacturing areas (see Figure 3) and is restricted to future commercial use as defined by the Order. Currently active SWMUs in OU-3 include the following:

- M: Portions of the IW Sewer Lines (B001 and B003)
- S: Former Waste TCA Tanks (B001)
- T: Former Waste Oil Tank (B003)
- U: North Parking Lot Area Plume
- V: Portions of B005 Plume

The Order requires supplemental investigations of these SWMUs to evaluate the potential for remaining sources of VOC impacts to groundwater. Pursuant to the Order, IBM undertook supplemental investigations to better define the nature and extent of soil and groundwater impacts in the vicinity of SWMU S in October 2011 and March 2012.

The results of the SWMU S investigation included identification and delineation of a DNAPL (predominately TCA) source area approximately 90-feet long and approximately 40-feet wide located largely beneath Building B001. The presence of DNAPL is attributed to the downward migration of solvent from the former waste tank to the southeast along the slope of the contact between the Surficial Sand Unit and the Transition Zone, where it then settled within a localized depression observed in the lower-permeability Transition Zone soils beneath Building B001.

## 1.2 Purpose and Objective

This FS presents an evaluation of potential remedial alternatives for SWMU S. This evaluation has been conducted in accordance with guidelines presented in NYSDEC Division of Environmental Remediation (DER)-10 *Technical Guidance for Site Investigation and Remediation* (DER-10) Section 4.4(c) and 6 New York Codes, Rules, and Regulations (NYCRR) Part 375 *Environmental Remediation Programs.* This FS includes:

- Development of Remedial Action Objectives (RAOs)
- Assessment of remedial alternative protectiveness of human health and the environment based on available data
- Identification and evaluation of potential remedial alternatives
- Recommendation of a remedial alternative for implementation

Section 2.0 of this Report presents a summary of the history and use of the SWMU S area. Section 3.0 presents the Conceptual Site Model and summarizes key findings of the SWMU S SRIR (Golder 2012a). Section 4.0 presents the RAO and a preliminary screening of potential remedial alternatives. Section 5.0 presents a comprehensive assessment of the selected remedial alternatives and Section 6.0 recommends a remedial alternative for implementation.

## 2.0 SWMU S DESCRIPTION AND HISTORY

SWMU S includes a former 4,000-gallon TCA waste underground storage tank (UST) and associated 1,000-gallon supply UST (TCA tanks), which were co-located on the west side of Building B001 north of Building B021, between Buildings B001 and B023 (see Figure 4). The steel tanks were installed circa 1955 and were used in the manufacture of printed circuit cards through 1967. TCA was pumped both northward and southward into Building B001 from these tanks for use in multiple manufacturing operations, including use by the operation known as the “carousel”, a series of solvent-filled dip tanks located in northern Building B001, and the TCA Recovery Unit (SWMU AB)[1], located on the concrete floor along the western wall of Building B001 (see Figure 4).

The former TCA tank area was initially investigated using a gridded soil gas survey performed by Groundwater Sciences Corporation (GSC, 1996) that included installation of temporary groundwater monitoring wells. TCA and associated degradation compounds (i.e., 1,1-dichloroethene [1,1-DCE] and 1,2-dichloroethane [1,2-DCA]) were detected during this investigation. Elevated concentrations of TCA in groundwater were subsequently detected in a temporary monitoring well (TMP-8) located approximately 400 feet downgradient of the TCA Tanks.

To further investigate the Building B001 area downgradient of SWMU S, GSC installed five monitoring wells (MW-275S through MW-279S) in 1996. Soil samples collected from the borings for these wells were analyzed for VOCs. Analytical results from vadose zone soil samples did not indicate constituent levels above applicable NYSDEC criteria. Analytical results for groundwater samples collected from these wells indicated constituent concentrations greater than applicable New York State Groundwater Quality Standards (NYSGWQS).

Based on the continued detection of elevated dissolved-phase TCA concentrations in groundwater samples collected downgradient of SWMU S and pursuant to requirements in the Order to perform a supplemental investigation to evaluate the potential for a source of VOC impacts to groundwater in the vicinity of SWMU S, IBM initiated an investigation that resulted in the identification of DNAPL beneath Building B001. The complete results of this investigation are presented in the SWMU S SRIR and are briefly summarized in Section 3.2.

[1] SWMU AB was investigated concurrently with the March 2012 SWMU S investigation in accordance with the NYSDEC approved 2009 *RCRA Facility Investigation Work Plan Solid Waste Management Unit AB: Former B001 TCA Waste Recovery Unit*. Investigation results and findings for SWMU AB were presented to NYSDEC in the *Supplemental Remedial Investigation Report: Solid Waste Management Unit (SWMU) AB: Former B001 TCA Recovery Unit* dated October 31, 2012 (Golder, 2012b).

# 3.0 SITE-WIDE AND SWMU S CONCEPTUAL SITE MODELS

## 3.1 Site-wide Conceptual Site Model

Literature on regional geologic conditions and the findings of previous investigations conducted at the site indicate that glacially-derived sand and gravel directly overlies bedrock on the East Campus. The glacial till unit is overlain by, in order of increasing stratigraphic position, a Varved Clay Unit, a discontinuous Transition Zone composed of clay, silt, and sandy silt, and a Surficial Sand Unit composed of well sorted, fine to coarse-grained sand with intermittent, thin, silty-clay zones. Groundwater within the Surficial Sand Unit is unconfined across the site and groundwater flow velocities range from approximately 0.8 feet per day (feet/day) to 2.0 feet/day (GSC, 1997).

The dissolved-phase VOC plumes present in groundwater beneath the site are attributed to historical releases of chlorinated solvents associated with past site operations. Dissolved-phase VOC concentrations in localized areas of the site, such as the SWMU S area, indicate the potential presence of remaining source areas. However, over the majority of the site, the spatial distribution and magnitude of dissolved-phase VOC concentrations indicates the likely origin of these detections is residual concentrations retained in finer-grained materials (i.e., silt and/or clay lenses in the saturated Surficial Sand Unit, the Transition Zone/top of Varved Clay Unit). These residual sources are not indicative of NAPL and are frequently attributed to slow contaminant back-diffusion rates from low permeability units which cause contaminant persistence long after the source is isolated or removed (Parker et al., 2008).

The following sections summarize the findings of the SWMU S SRIR and the current conceptual site model of the SWMU S area.

## 3.2 SWMU S Conceptual Site Model

Pursuant to requirements in the Order, IBM undertook a supplemental remedial investigation to better evaluate soil and groundwater impacts near SWMU S. A complete description of investigation activities, methodologies, and results is provided in the SWMU S SRIR (Golder, 2012a). The following describes the conceptual site model specific to the SWMU S area.

SWMU S is located within OU-3, in the central portion of the East Campus (see Figure 2). The Surficial Sand Unit ranges in thickness from 17 to 25 feet in the SWMU S area. The absence of the intermittent silty-clay zones, observed in the Surficial Sand Unit in other areas of the site, facilitated the unimpeded migration of DNAPL from the source (i.e., the former SWMU S tanks) through the Surficial Sand Unit to the contact with the Transition Zone and/or the Varved Clay Units.

The Transition Zone in the vicinity of SWMU S consists of generally finer-grained sediments (i.e. a greater percentage of clay than silt) and is generally denser than observed in other areas of the site, however localized variations (i.e., areas of greater sand content) were observed. Vertical diffusion of DNAPL into the Transition Zone appears limited and is prevented from further vertical migration by the low permeability of the base of the Transition Zone.

In SWMU S, the upper portion (i.e., within 10 feet of the contact with the Transition Zone) of the Varved Clay Unit consists of gray plastic clay with variable amounts of fine sand above the typically red-brown and gray clay generally observed in other areas of the site. The Varved Clay unit, which serves as an aquitard across the site, was typically encountered between 23 to 28 feet below ground surface (feet bgs) in the SWMU S area, with greater or lesser depths of first occurrence in localized areas.

The base of the Surficial Sand Unit (i.e. the top of the Transition Zone) and the top of the Varved Clay Unit dip to the south and east of the former SWMU S tanks and create a localized depression located north of Building B021 and extending to the northeast under Building B001 (see Figure 4). The geometry of these lithologic units (see Figure 5) strongly influences the migration and occurrence of DNAPL, which in turn influences the distribution of dissolved-phase VOC impacts in and downgradient of the SWMU S investigation area, as DNAPL has the tendency to migrate vertically under gravitational forces through unsaturated and saturated porous media and then accumulate and spread laterally when encountering lower permeability material.

An area of DNAPL (comprised predominately of TCA) approximately 90-feet long and 40-feet wide was identified during the supplemental SWMU S remedial investigations (Figure 6). The presence of DNAPL was indicated by positive hydrophobic dye testing results, observations of NAPL in purge water collected from monitoring wells and TCA in groundwater samples at concentrations greater than 25% of the solubility threshold. The DNAPL is attributed to a release from the former SWMU S tanks that migrated downward and to the southeast along the slope of the contact between the Surficial Sand Unit and the Transition Zone, where it then settled within a localized depression observed in the lower-permeability Transition Zone soils beneath Building B001.

The highest total VOC concentrations in groundwater (i.e., greater than 200,000 micrograms per liter [µg/l]) were detected in samples collected within the Transition Zone south and east of the former waste TCA tank, immediately adjacent to areas of observed or suspected DNAPL. Total VOC concentrations attenuate rapidly within the Transition Zone and Varved Clay Unit indicating that the vertical diffusion of VOCs into the Transition Zone and/or Varved Clay Unit is limited to approximately five vertical feet in areas where DNAPL is present.

The DNAPL provides a source of dissolved-phase impacts to groundwater in the vicinity and downgradient of SWMU S. Historic TCA concentrations above 300 µg/l that have been reported in select monitoring wells located more than 400 feet downgradient of the SWMU S area are attributed to the presence of the DNAPL. The reported detections of 1,1-dichloroethane (1,1-DCA), 1,1-DCE, and 1,2-DCA in the groundwater sample collected from a well located downgradient of the DNAPL is attributed to degradation of the primary DNAPL component (TCA).

The DNAPL is generally contained within a localized depression in the Transition Zone. As a result of the concave nature of the depression, the thickness of DNAPL is likely greater in the center of the depression and thinner on the periphery. A conservative estimate of the area where DNAPL is present in the SWMU S area may be developed assuming DNAPL is present in the areas of observed dissolved-phase TCA concentrations greater than 25% of the single component solubility of TCA (i.e., an area comprising approximately 2,500 square feet [$ft^2$]).

## 4.0 REMEDIAL ACTION OBJECTIVE

Potential exposure pathways to human receptors identified at the site include dermal absorption, ingestion, and/or inhalation of VOC-impacted soil or groundwater. Potential exposure pathways to environmental receptors include groundwater migration to surface water bodies. These exposure pathways have been addressed at the site by previously implemented Corrective Measures and the establishment of institutional and engineering controls required by the Order as described the interim Site Management Plan ([SMP] TechCity, 2011) and are summarized as follows:

- In compliance with the Order, IBM characterized the top foot of soil to supplement previous soil characterization data in OU-3. The results of the surficial soils characterization confirmed that commercial-use soil standards have been met in OU-3 (GSC, 2011). As described in the SMP, an Intrusive Activities Work Plan (IAWP) must be prepared prior to subsurface activities in OU-3 to further mitigate the potential for impacts related to the direct contact exposure pathway.
- IBM evaluated potential vapor intrusion (VI) impacts in buildings adjacent to and downgradient of the SWMU S area (i.e., Buildings B021, B022, B023, and B024) in accordance with the Order and a Vapor Intrusion Assessment Work Plan (VIAWP) (Golder, 2011). The results of the VI evaluations of these buildings indicate that there were no exceedances of New York State Department of Health (NYSDOH) indoor air guideline values (Golder, 2012c through 2012f). However, at the request of NYSDEC and NYSDOH, IBM will conduct annual indoor air monitoring at select locations within these buildings. In addition, the SMP requires that vapor mitigation measures be considered for any proposed new development in OU-3 to address the vapor emissions and/or inhalation pathways.
- The groundwater ingestion pathway is considered an incomplete pathway as groundwater is not currently used for potable purposes at or in the vicinity of the site and VOC-impacted groundwater is intercepted by the perimeter control system. In addition, institutional controls required by the Order will restrict the potential for future potable use of groundwater beneath OU-3.

In summary, the combination of corrective measures previously implemented by IBM, and the institutional and engineering controls required by the Order and the SMP eliminate the potential threats to human health and the environment posed by the direct contact, vapor intrusion, and groundwater ingestion pathways in OU-3 and the SWMU S area. However, the DNAPL identified in the subsurface in the SWMU S area serves as a continuing source of dissolved-phase VOC impact to groundwater with OU-3. Therefore, consistent with the Order that requires the Respondents (IBM and TechCity) to “delineate and evaluate source removal” in the SMWU S area, the RAO for SWMU S is as follows:

- Remove and/or treat DNAPL located in the SWMU S area, to the extent practicable, that serves as a source of impact to downgradient groundwater

# 5.0 ALTERNATIVES ANALYSIS

The following sections present an analysis of potential remedial alternatives to remove and/or treat DNAPL, to the extent practicable, located in the SWMU S area. The first step in the process is the identification and screening of potentially applicable alternatives that satisfy the first two “threshold” criteria, as defined by DER-10 Section 4.2(a)1.i. The second step is a more detailed evaluation of alternatives that satisfy the “threshold” criteria based on the “balancing” criteria, as defined in DER-10 Section 4.2(a)1.ii.

## 5.1 Identification of Potentially Applicable Alternatives

Potential remedial alternatives were identified using a variety of sources including engineering experience, vendor information, and a review of available literature that includes the following:

- DER-15 Presumptive/Proven Remedial Technologies, NYSDEC , 27 February, 2007 (NYSDEC, 2007).
- Gavaskar, Arun, L. Tatar, and W. Condit, “Cost and Performance Report: Nanoscale Zero-Valent Iron Technologies for Source Remediation”, September, 2005 (Gavaskar et al, 2005).
- Interstate Technology Regulatory Control, “Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater, 2nd ed,”, January, 2005 (ITRC, 2005).
- Stegemeir, George and H. Vinegar, “Thermal Conduction Heating for In-Situ Thermal Desorption of Soils”, Hazardous & Radioactive Waste Treatment Technologies Handbook, 2001 (Stegemeir and Vinegar, 2001).
- USEPA, “Alternative Disinfectants and Oxidants Guidance Manual”, Office of Water (4607) EPA 815-R-99-014, April 1999 (USEPA, 1999a).

Utilizing these sources, Golder compiled the following potential remedial alternatives for initial screening:

- No further action
- Monitored Natural Attenuation (MNA)
- Excavation and treatment/removal
- Air sparging
- In-well air stripping (i.e., groundwater recirculation)
- Enhanced bioremediation
- In-situ Chemical Oxidation
- In-situ Chemical Reduction
- In-situ Thermal Desorption

## 5.2 Screening of Potentially Applicable Alternatives

The following sections present a summary of the initial screening of alternatives to remove and/or treat DNAPL in the SWMU S area. The potential remedial alternatives were first screened on the basis of technical applicability, effectiveness, and implementability to identify remedial technologies that are capable of effectively meeting threshold criteria, defined by NYSDEC as follows:

- **Protectiveness of Human Health and the Environment:** an evaluation of the ability of each alternative to protect public health and the environment
- **Regulatory Compliance:** an evaluation of how the alternative conforms to officially promulgated standards and criteria that are directly applicable or that are relevant and appropriate

The existing and/or planned engineering and institutional controls (i.e., environmental easements, requirements in the SMP, and the perimeter control system) ensure protectiveness of human health and the environment with or without implementation of SWMU S source control. Therefore, each of the identified potential remedial alternatives already satisfy the requirements for protectiveness of human health and the environment.

For the SWMU S area, the regulatory compliance threshold criteria will be screened based on the ability of the alternative to remove and/or treat DNAPL in the SWMU S area pursuant to requirements in DER-10 Section 4.1(d)(2)(i), which states that "all free product, concentrated solid or semi-solid hazardous substances, dense non-aqueous phase liquid, light non-aqueous phase liquid and/or grossly contaminated media should be removed and/or treated…to the extent feasible" (i.e., the RAO established in Section 4.0). Threshold criteria screening results are summarized in Table 1 and presented in the following sections.

### *5.2.1 No Further Action*

This alternative would leave the SWMU S area in its present condition. Impacted saturated soils and DNAPL would remain in place with no treatment and would not affect protection to human health and the environment. The perimeter control system would be maintained to mitigate the potential for migration of impacted groundwater off-site.

This alternative is not considered applicable as it would not result in the removal and/or treatment of the DNAPL in SWMU S area as required by DER-10 and thus does not meet the RAO (e.g., the regulatory compliance threshold criteria). Therefore, No Further Action is not an applicable remedial alternative for SWMU S and is not considered further in this screening analysis.

### *5.2.2 Monitored Natural Attenuation (MNA)*

The United States Environmental Protection Agency's (USEPA) MNA directive defines MNA as the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup approach, to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more proactive methods (USEPA, 1999b). MNA relies on natural processes such as sorption, dilution, dissolution, dispersion, volatilization, and microbial degradation to treat impacts to soil and/or groundwater. Under favorable conditions, extant microbe populations in the subsurface metabolize organic contaminants, digesting the contamination under existing temperature, nutrient, and oxygen conditions and converting the contaminants into water and harmless gases, such as carbon dioxide. An MNA alternative would not involve active remedial measures to remove and/or treat DNAPL in the SWMU S area.

While there is evidence that some degree of natural attenuation of dissolved-phase constituents is occurring, the on-going presence of DNAPL in the SWMU S area indicates that natural attenuation of the DNAPL is occurring very slowly or not at all. Very high chemical concentrations associated with chlorinated solvent NAPLs can prove toxic to microbe populations that otherwise would metabolize similar VOCs. Therefore, MNA is not considered a viable approach for the removal and/or treatment of the DNAPL in a reasonable timeframe. As such, MNA does not meet the RAO for SWMU S (e.g., the regulatory compliance threshold criteria) and is not considered further in this screening analysis.

### 5.2.3 Excavation and Treatment/Disposal

Excavation is the physical removal of impacted soil and/or NAPL from the subsurface. Following removal, the excavated materials can either be treated on-site or removed from the site for off-site treatment and/or disposal at an appropriately permitted treatment or waste disposal facility. Excavation can be rapidly implemented and may not require institutional and engineering controls if all impacted material is excavated and disposed off-site (NYSDEC, 2007). However, excavation and treatment/disposal is most effective for the removal of shallow soils above or immediately below the water table that can be accessed using standard excavation equipment that does not require shoring, extensive dewatering, or engineering support of existing buildings.

The SWMU S DNAPL source material is located beneath a minimum of 20 feet of overburden and approximately 14 feet below the water table beneath the Building B001 footprint. To access the source material, sheet pile walls or other form of excavation stabilization would be required and foundation supports may be required to preserve the integrity of the building. In addition, it would likely be necessary to implement dewatering during the excavation. Additional cost would be incurred to treat water generated during the excavation and to dispose of the waste soil and DNAPL, which would likely be classified as characteristic hazardous waste.

Therefore, even though excavation and treatment/disposal would potentially meet the SWMU S RAO if it could be implemented, it is not considered an applicable alternative and is no longer considered in this analysis because of the technical difficulties (i.e., implementability) associated with the excavation of materials located in saturated soils some 20 feet bgs beneath a building and is not considered further in this screening analysis.

### 5.2.4 Air Sparging

Air sparging is an in-situ treatment technology for volatile compounds in which pressurized air is injected beneath the zone of impact. Air rising through the pore spaces of the impacted zone volatilizes and flushes VOCs into the unsaturated zone where vapor extraction is typically used to remove the vapor phase from the subsurface.

Air sparging is most effective for dissolved phase VOCs and adsorbed contamination present in coarse-grained materials (i.e., sands and gravels) where effective porosity and therefore air distribution is typically more evenly distributed. The formation of air channels in finer-grained materials through which the injected air preferentially flows results in uneven distribution of injected air and associated contaminant volatilization in the subsurface. Air sparging is not as effective in substrates comprising moderate amounts of silts and clay (NYSDEC, 2007).

Site investigation results indicate that the highest concentrations of dissolved phase VOCs are present in the Transition Zone and/or Varved Clay Units and that the DNAPL has pooled at the contact of the Surficial Sand Unit and the Transition Zone. Treatment of DNAPL in the SWMU S area would require air injection below the DNAPL in the very fine-grained Transition Zone and/or Varved Clay Unit. Injection of air into these zones would likely result in preferential air pathways and uneven distribution. As such, air sparging is not an applicable technology to meet the RAO for SWMU S and is not considered further in this screening analysis.

### 5.2.5 In-well Air Stripping (Groundwater Recirculation)

In-well air stripping (i.e., groundwater recirculation) involves the treatment (stripping) of VOCs from groundwater within a specially designed groundwater recirculation well. Groundwater recirculation wells are constructed with dual casings and two (i.e., upper and lower) well screens. Air is injected into the inner casing and through a diffuser at the bottom of the well. The injected air pushes groundwater that enters the lower well screen upward in the well while volatizing dissolved-phase VOCs in the water. The air/water mixture rises in the well until it encounters a dividing device that diverts the water to the outer casing. The water reenters the formation through the upper well screen while the vapor is collected and extracted for ex-situ treatment and/or venting. Groundwater is continually drawn into the lower well screen to replace the water that is discharged through the upper well screen.

Similar to air sparging, in-well air stripping/groundwater recirculation systems are most effective in coarse-grained materials (i.e., sands and gravels) where the permeability of the formation is high such that groundwater can be rapidly drawn out of and re-infiltrated into the formation efficiently. In-well air stripping/groundwater recirculation systems are most appropriate for mobile, dissolved-phase impacts, not NAPLs.

Because the formation materials in the SWMU S source area are relatively fine-grained and this technology is more applicable to treat dissolved-phased groundwater impacts, not NAPL, in-well air stripping/groundwater recirculation is not an applicable alternative to meet the RAO for SWMU S and is no longer considered in this screening analysis.

### 5.2.6 Enhanced Bioremediation

Enhanced bioremediation involves the introduction of nutrients and/or microbial populations into the subsurface to enhance existing biodegradation of organic compounds. The microbes digesting the organic compounds under favorable temperature, nutrient, and oxygen conditions and convert the contaminants into water and harmless gases, such as carbon dioxide. Generally, the appropriate nutrients and/or microbes are pumped into the aquifer through injection wells. However, as described previously, chlorinated solvent NAPLs can prove toxic to microbe populations that otherwise would metabolize similar VOCs at lower concentrations.

Natural groundwater biogeochemical conditions in the SWMU S area are not favorable for MNA and would require enhancement via injection of microbes and nutrients. The toxic nature of chlorinated NAPLs to the microbe population and the low-permeability nature of the Transition Zone sediments will limit the distribution of nutrients and microbes in the subsurface. Enhanced bioremediation is not considered a viable remedial technology to remove/and or treat DNAPL in the SWMU S area and is not considered further in this screening analysis.

### 5.2.7 In-Situ Chemical Oxidation (ISCO)

In-situ chemical oxidation (ISCO) is the process by which oxidizing agents are used to destroy compounds such as chlorinated ethenes and chlorinated ethanes by removing electrons and reducing the chlorinated substances to carbon dioxide, water, and chloride ions. Commonly used oxidizing agents for chlorinated ethenes and chlorinated ethanes include potassium or sodium permanganate, sodium persulfate, peroxides/Fenton's reagent, ozone, and ozone with hydrogen peroxide (ITRC, 2005). Oxidants are typically applied to affected media through injection wells or soil mixing.

The rates of oxidation reactions are dependent on many variables that must be considered simultaneously, including temperature, pH, concentration of the reactants, catalysts, reaction by-products, and system impurities (e.g., natural organic matter, oxidant scavengers, etc.). In addition, like most in-situ remedial technologies, delivery of the oxidant to the impacted media (i.e. providing contact with the contaminant) can be a challenge. However, through oxidant selection and remedy design, chemical oxidation can rapidly treat most organic contaminants in both the dissolved and NAPL phases.

ISCR is considered a potentially applicable remedial technology to meet the SWMU S RAO (e.g., the regulatory compliance threshold criteria) and is therefore retained for detailed evaluation (see Section 6.1).

### 5.2.8 In-Situ Chemical Reduction (ISCR)

In-situ chemical reduction (ISCR) utilizes chemical reducing agents to change the mobility or form of contaminants in the subsurface, immobilizing metals and destroying organic contaminants. The most commonly used reductant is zero-valent iron (ZVI), which is used to remediate chlorinated ethenes and ethanes (ITRC 2011). During the ISCR process, chemical degradation of chlorinated VOCs occurs as a result of both abiotic (surface-mediated beta elimination reaction pathway) and biotic (reductive dehalogenation) processes. Soluble, absorbed-phase, and free-phase (NAPL) halogenated compounds all can be reduced using ZVI to targeted levels (USEPA, 2003). Micro-scale ZVI particles, that can be injected into the subsurface, have surface areas that are several times greater than larger-sized powders or granular iron particles that are commonly used in permeable reactive walls or trench applications.

Various forms of ZVI have been injected into source areas to provide source treatment. Emulsified Zero-Valent Iron (EZVI) can be used to enhance the destruction of chlorinated solvent DNAPL in source zones by creating intimate contact between the DNAPL and the ZVI. The EZVI is composed of food-grade surfactant, biodegradable vegetable oil, water, and ZVI particles (i.e., micro-scale iron). EZVI forms emulsion particles that contain the ZVI in water surrounded by an oil/liquid membrane. The exterior oil membrane has hydrophobic properties similar to that of DNAPL; therefore, the emulsion is miscible with the DNAPL. In addition to the abiotic degradation associated with the ZVI, EZVI injection will result in enhanced biodegradation of dissolved chlorinated ethenes because the vegetable oil and surfactant act as electron donors to promote anaerobic biodegradation processes (ITRC, 2011).

ISCR is considered a potentially applicable remedial technology to meet the SWMU S RAO (e.g., the regulatory compliance threshold criteria and is therefore retained for detailed evaluation (see Section 6.2).

### 5.2.9 In-Situ Thermal Desorption (ISTD)

In-situ thermal desorption (ISTD) and related thermal technologies have been promoted by the USEPA as a rapid, cost-effective remedy for a variety of constituents. Thermal desorption is a soil remediation process that re-mobilizes and extracts constituents utilizing either steam/hot air or other heat sources including radio frequency, surface heater blankets, thermal conduction, and electrical resistance. Heating vaporizes or destroys contaminants in the subsurface via a number of mechanisms including evaporation into the vapor phase, steam distillation into the water vapor phase, boiling, oxidation, and pyrolysis (Stegemeir and Vinegar, 2001).

The ISTD remedial process utilizes either electrical resistive heating (ERH) or thermal conductance heating (TCH). Both are equally effective in saturated and unsaturated soils. The ERH process uses heat generated by the resistance of the soil matrix to the flow of electrical current to raise subsurface temperatures up to the boiling point of water (100 degrees Celsius [°C]*)*. TCH relies on using electricity applied to heater wells to generate high temperatures (i.e., >400°C) at the heater well and can heat the vadose zone or de-watered zones to temperatures far above the boiling temperature of water, making it possible for thermal conduction heating to treat compounds with volatilization points greater than 100°C. To achieve the RAO for SWMU S, temperatures greater than 100°C are desirable, thus the following discussions of ISTD as a remedial alternative will pertain to TCH.

ISTD involves simultaneously heating and applying a soil vapor extraction (SVE) system to capture vapors generated from the high-temperature heating of groundwater. This is typically achieved with an array of multipurpose heater/vacuum wells. The vapor treatment train consists of a thermal oxidizer, heat exchanger, carbon bed absorbers, and vacuum blowers. Water vapor and contaminants are drawn by the SVE system in a direction opposite of heat flow into the vacuum source at the wells. In most applications contaminants in the soil can be almost completely destroyed, with displacement efficiencies approaching 100% assuming the treatment area can be uniformly heated for an extended period of time.

ISTD has the potential to meet the SWMU S RAO (e.g., the regulatory compliance threshold criteria) and is therefore retained for detailed evaluation (see Section 6.3).

# 6.0 DETAILED ALTERNATIVES ANALYSIS

Based on the preliminary alternatives screening using threshold criteria presented in Section 5.2, the following alternatives were identified as potentially applicable for SWMU S and are carried through for detailed evaluation:

- In-situ Chemical Oxidation (ISCO)
- In-situ Chemical Reduction (ISCR)
- In-situ Thermal Desorption (ISTD)

The following sections present the analysis conducted using the evaluation criteria set forth in 6 NYCRR 375-1.8(f) and in conjunction with additional guidance provided for each criterion in subdivisions (d) through (i) of DER-10 Section 4.2 . The additional "balancing" criteria evaluated for each alternative include:

- **Short-term Effectiveness:** an evaluation of the potential short-term adverse environmental impacts and human exposures during the construction and/or implementation of an alternative or remedy
- **Long-term Effectiveness:** an evaluation of the long-term effectiveness and permanence of an alternative or remedy after implementation
- **Reduction of Toxicity, Mobility or Volume of Contamination:** an evaluation of the ability of an alternative or remedy to reduce the toxicity, mobility and volume of site contamination
- **Implementability:** an evaluation of the technical and administrative feasibility of implementing an alternative or remedy
- **Cost effectiveness:** an evaluation of the overall cost effectiveness of an alternative or remedy
- **Land Use:** an evaluation of the current, intended and reasonably anticipated future use of the site and its surroundings, as it relates to an alternative or remedy, when unrestricted levels would not be achieved

Per DER-10 Section 4.3(a)5.iii, the costs associated with site management, institutional controls, and any legal and administrative requirements must be considered in the evaluation of the cost effectiveness of a remedy. Considering the requirements in the Order pertaining to preservation of existing engineering controls (i.e., site perimeter groundwater collection and treatment), site management and OU-3 specific institutional controls are applicable and equal to all of the remedial technologies under consideration, these costs are not included in the evaluation of the cost effectiveness of individual remedial alternatives in the following sections.

## 6.1 In-Situ Chemical Oxidation (ISCO)

ISCO involves treating the DNAPL and associated impacted soil and groundwater via reduction of the contaminants to non-toxic substances. During the ISCO process, hydroxyl radicals, which serve as the oxidizing agents, react with VOCs in the subsurface to form carbon dioxide, water, and, in the case of chlorinated VOCs, inorganic chloride ions.

ISCO would be applied to the source area by mixing the selected oxidant at the surface and injecting the solution into the subsurface at various depth intervals via a network of injection wells within the limits of the area where dissolved-phase concentrations of TCA have been observed at concentrations greater than 10 percent (%) of the single-component solubility of TCA. ISCO would be performed to depths of approximately 25 feet bgs, depending on location, within an area comprising approximately 3,480 $ft^2$ as indicated on Figure 6.

ISCO treatment would limit potential future impacts from DNAPL to groundwater by reducing or eliminating the amount of DNAPL present. Regular performance monitoring would be conducted to evaluate remedy effectiveness and assess the need for additional injections.

Prior to full-scale implementation, bench-scale testing of various oxidants and a pilot-scale study would be required to evaluate the effectiveness of various solution concentrations and optimal injection location spacing to achieve efficient solution distribution in the source area. Specific design details will be addressed as part of the remedial design.

### 6.1.1 Short-term Effectiveness

During implementation of this alternative, onsite remedial construction workers may potentially be exposed to impacted soil and groundwater during initial injection well and monitoring well installation activities. Other potential short-term risks include exposure to the chemical oxidants during application and vapors and/or heat generated by the chemicals reactions. Potential exposure to chemical constituents and chemical oxidants by ingestion, dermal contact, and/or inhalation would be reduced by the use of personal protective equipment (PPE) and good housekeeping procedures specified in a remedy-specific health and safety plan (HASP) that would be developed during the remedial design. Air monitoring would be performed during implementation of this alternative to confirm that VOC vapors are within acceptable levels and to evaluate the need for additional engineering controls (e.g., use of shop fans to increase air circulation and move stagnant air away from work areas).

Public access, and therefore risk to the community, is minimized by restricted public access to the site and the 24-hour security provided. Building B001 is currently unoccupied and access to the treatment area would be obtained solely through authorized access provided by site security and management.

### 6.1.2 Long-term Effectiveness

Initial ISCO treatment activities may require several weeks to complete and may require multiple injections over a period of months or years. Limitations related to the uniform delivery of oxidants to the impacted area can reduce the long term effectiveness of this technology. ISCO reactions predominantly take place in the aqueous phase within the soil medium pore space, not in or on the soil particles themselves. Therefore, in lower permeability zones (i.e., silty and clayey units), ISCO is not as efficient at removing contaminant source mass, as the low permeability substantially reduces the potential for contact between the ISCO reagent and sorbed contamination. Slow contaminant back-diffusion rates from low permeability units also further restricts the effectiveness of ISCO in removing source contaminant mass (ITRC, 2005). ISCO treatment is therefore much more effective in sands and gravels with low carbon content (low sorption potential) as opposed to fine grained materials with a high carbon content (high sorption potential). The long-term permanence of an ISCO remedy would require many years of monitoring and evaluation following final injection activities to evaluate the ultimate effectiveness of the remedy.

### *6.1.3 Reduction of Toxicity, Mobility, or Volume of Contamination*

The reduction of DNAPL has generally been sufficient to achieve residual dissolved-phase VOC concentrations in groundwater typically in the low µg/l ranges. Previous applications of oxidants have shown greater than 80% reductions in average TCA groundwater concentrations after a single application (ITRC, 2005).

### *6.1.4 Implementability*

Though the SWMU S source area is largely located beneath existing Building B001, the space is currently unoccupied and access to the area for vertical drilling and treatment is not precluded. Injection and uniform distribution pose challenges to the effective delivery of oxidant to the source area and pressure injection may be necessary. ISCO also oxidizes natural organic materials in the geologic formation and this oxidant demand must be accounted for during costing and design.

Quantifying the natural oxidant demand (NOD) of the soil matrix (including non-target chemicals, reduced metals, and sulfides, where present) is important when evaluating the applicability of ISCO and estimating oxidant requirements. The oxidant must be uniformly distributed throughout the treatment area in a dose sufficient to exceed NOD and therefore promote treatment of the source area. Preliminary analytical results from site-specific NOD testing in the Transition Zone in the southwest portion of the site (i.e., not SWMU S) indicate moderate NOD concentrations. Area-specific NOD concentrations would be evaluated and considered in the remedy design phase. Multiple injections are generally necessary to overcome substantial NOD conditions.

Limitations on the availability of personnel and material to implement an ISCO remedy, if selected, are not anticipated. Access to the treatment area, for which administrative protocols have been established in the Order, does not represent an impediment. Although redevelopment plans for Building B001 are not yet final, redevelopment is anticipated. As such, the potential need for multiple injections and the uncertainty in the timeline for completion are issues which must be considered in evaluating implementability of an ISCO remedy. No specific operating approvals are required prior to ISCO remedy implementation nor are any additional institutional or engineering controls required to effectively implement an ISCO remedy.

### 6.1.5 Cost Effectiveness

Bench and pilot-scale testing would be required to design and implement a full-scale ISCO treatment system. The cost for the bench-scale and pilot test, including the collection of pre-design parameters, is estimated at $150,000. For the purpose of this cost estimate, it is assumed that full-scale treatment would require five separate mobilizations and injections. Injections would be conducted every six months and reaction progress monitored with regular (i.e., quarterly) groundwater sampling events. Based on this schedule it would require approximately three years to complete injections, with an additional two years of subsequent groundwater monitoring. The total cost for the injections is estimated to be $600,000. Installation of additional groundwater monitoring wells and injection points is estimated to be $120,000. Remedial additive monitoring is estimated to be $100,000 per year, for the four annual events, with an estimated monitoring period of five years.

Based upon these assumptions, including project management, design, permitting, reporting cost estimates and a twenty percent contingency, the cost of this remedial alternative is estimated at approximately $2.01 million (see Table 2). Given the uncertainties regarding the number of injections necessary to achieve the RAO and associated groundwater monitoring that would be required to confirm remedy effectiveness, absolute costs to implement an ISCO remedy are highly variable. However, an ISCO remedy has the potential to be cost effective.

### 6.1.6 Land Use

Current and future use of OU-3 is restricted to Commercial Use by the environmental easement required by the Order.

## 6.2 In-Situ Chemical Reduction (ISCR)

The ISCR alternative would involve treating the DNAPL and associated impacted soil and groundwater via the degradation (i.e., dechlorination) of chlorinated compounds to non-toxic compounds such as ethene and chloride. ISCR would be performed by mixing the EZVI, composed of the selected emulsifier, water, and micro-scale ZVI particles at the surface and injecting the solution into the subsurface at various depth intervals via a network of injection wells. Encapsulating the ZVI in a hydrophobic membrane protects the iron from other groundwater constituents that otherwise would exhaust much of the iron's reducing capacity. This approach reduces the mass of EZVI required for treatment relative to unprotected ZVI.

Emulsified oil is not the only substrate that can be mixed or injected with ZVI to achieve both a biological and chemical reactive zone. Several commercial products (e.g., EHC® and ABC® Plus ZVI) provide a carbon substrate along with ZVI. In addition to combined products, ZVI can be mixed or injected separately with common substrates (lactate, molasses, alcohol) appropriate to the contaminant and hydrogeological setting (ITRC, 2011). These other products would be further evaluated during the design phase.

Similar to the ISCO alternative, ISCR would be applied to the source area within the limits of the area where dissolved-phase concentrations of TCA have been observed at concentrations greater than 10% of the single-component solubility of TCA. ISCR would be performed to depths of approximately 25 feet bgs, depending on location, within an area comprising approximately 3,480 $ft^2$, as indicated on Figure 6.

ISCR treatment would limit potential future impacts from DNAPL to groundwater by reducing or eliminating the amount of DNAPL present. Regular performance monitoring would be conducted to evaluate remedy effectiveness and assess the need for additional injections.

Prior to full-scale implementation, a pilot-scale study will be required to evaluate the effectiveness of various EZVI concentrations and optimal injection location spacing to achieve efficient solution distribution in the source area. In addition, different iron sources may be applied to assess cost benefits of the cost of iron and iron reactivity. These specific design details will be included as part of the remedial design based on the results of the pilot test.

### *6.2.1 Short-term Effectiveness*

During implementation of this alternative, onsite remedial construction workers may potentially be exposed to impacted saturated soil and groundwater during initial injection location and monitoring well installation activities. Potential exposure to chemical constituents by ingestion, dermal contact, and/or inhalation would be further minimized by the use of PPE and good housekeeping procedures specified in a remedy-specific HASP that would be developed during the remedial design. Air monitoring would be performed during implementation of this alternative to confirm that VOC vapors are within acceptable levels and to evaluate the need for additional engineering controls.

Public access, and therefore risk to the community, is minimized by restricted public access to the site and the 24-hour security provided. Building B001 is currently unoccupied and access to the treatment area would be obtained solely through authorized access provided by site security and building management.

### *6.2.2 Long-term Effectiveness*

Initial ISCR treatment activities may require several weeks to complete and may require multiple injections over a period of months or years. Initial concentrations of chlorinated VOCs in groundwater would decline rapidly. Long-term performance measures, including the monitoring of oxidation-reduction potential (ORP) values, would be necessary to evaluate complete source treatment (Macé et al., 2006). If TCA concentrations remain low after ORP levels have rebounded following complete iron solution consumption, source treatment may be said to be complete (Gavaskar et al., 2005). However, if the target DNAPL source area is not effectively treated, groundwater could become re-contaminated via back diffusion of VOCs from elevated concentrations in low-permeability units. In certain settings (aerobic aquifers), ZVI injection enhances anaerobic bioremediation of chlorinated VOCs in systems by shifting the redox condition of the aquifer to a more reducing regime, encouraging population increases for iron-reducing bacteria, sulfate-reducing bacteria, and nitrifying bacteria (Golder, 2009b). In addition to the abiotic degradation associated with the ZVI, EZVI injection will result in enhanced biodegradation of dissolved chlorinated ethenes because the vegetable oil and surfactant act as electron donors to promote anaerobic biodegradation processes (Glazier, et al., 2003). Similar to ISCO, additional EZVI injections may be required to address back-diffusion contamination and several years of monitoring and evaluation following final injection activities to evaluate the ultimate effectiveness of the remedy.

### 6.2.3 Reduction of Toxicity, Mobility, or Volume of Contamination

This technology has shown high potential for achieving mass removal, concentration reduction, mass flux reduction, reduction of source migration potential, and a substantial reduction in toxicity (ITRC, 2011). Previous applications of ZVI have shown greater than 95% reductions in average chlorinated solvent concentrations in groundwater after a single application (Gavaskar et al., 2005).

### 6.2.4 Implementability

Though the source area is largely located beneath Building B001, the space is currently unoccupied and access to the area for vertical drilling and treatment is not precluded. ZVI delivery mechanisms that minimize the volume of water injected along with the iron are preferable to methods that depend on larger volumes of water. Water from most sources contains oxygen and other oxidized species that may passivate the iron during injection (Gavaskar et al., 2005). When large volumes of water are necessary, the water should be de-oxygenated first, and this will require consideration in the final design.

Like other treatment technologies that involve injection of material into the subsurface, the effectiveness of ZVI can be limited by the technical challenge of delivering the treatment material to the impacted media. Multiple injections are generally necessary to ensure uniform delivery of the injected materials in the subsurface and complete destruction of the DNAPL source. The effectiveness of this technology for DNAPL removal and remediation of groundwater at the site would need to be tested using bench-scale and/or field (pilot-scale) treatability tests.

Similar to ISCO, limitations on the availability of personnel and material to implement an ISCR remedy, if selected, are not anticipated. Access to the treatment area, for which administrative protocols have been established in the Order, does not represent an impediment. However, redevelopment is anticipated and the potential need for multiple injections and the uncertainty in the timeline for completion are issues which must be considered in evaluating implementability of an ISCR remedy. No specific operating approvals, institutional or engineering controls are required prior to ISCR remedy implementation.

### 6.2.5 Cost Effectiveness

Bench and pilot-scale testing would be required to design and implement a full-scale ISCR treatment system. Past studies have determined that an iron-to-soil ratio of 0.004 is ideal to generate the desired ORP levels in the treatment area (Gavaskar et al., 2005). The bench-scale test would evaluate the reactivities of available products and the pilot test would evaluate the volume of ZVI necessary to achieve the desired iron-to-soil ration in the entire treatment area. The cost of a pilot test is estimated at approximately $150,000. For the purpose of this cost estimate, it is assumed that the full-scale treatment program would require four injections in a treatment area of approximately 63,000 cubic feet ($ft^3$).

Injections would be performed every six months, with quarterly groundwater monitoring to evaluate treatment effectiveness and adjust future injection plans. For the purpose of this cost estimate, it is assumed that full-scale treatment would require four separate mobilizations and injections. Injections would be conducted every six months and reaction progress monitored with regular (i.e., quarterly) groundwater sampling events. Based on this schedule it would require approximately two years to complete injections, with an additional two years of subsequent groundwater monitoring. The total cost for the injections is estimated to be $700,000. Installation of additional groundwater monitoring wells and injection points is estimated to be $110,000. Remedial additive monitoring is estimated to be $100,000 per year, for the four annual events, with an estimated monitoring period of five years.

Based upon these assumptions, including project management, design, permitting, reporting cost estimates and a twenty percent contingency, the cost of this remedial alternative is estimated at approximately $2.12 million (see Table 2). Given the uncertainties regarding the number of injections necessary to achieve the RAO and associated groundwater monitoring would be required to confirm remedy effectiveness, absolute costs to implement an ISCR remedy are highly variable. However, an ISCR remedy has the potential to be cost effective.

### 6.2.6 Land Use

Current and future use of OU-3 is restricted to Commercial Use by the environmental easement required by the Order.

## 6.3 In-Situ Thermal Desorption (ISTD)

The ISTD alternative would involve treating the DNAPL and associated impacted soil and groundwater via contaminant volatilization, enhancing soil vapor extraction efficiency, and increasing biological degradation and chemical dechlorination reaction rates. During the ISTD process, temperatures greater than 100°C would be generated at the heater wells, heating the treatment area via thermal conduction, and vapors generated would be removed and treated utilizing an SVE system.

ISTD would be applied to the source area within the limits of the area where dissolved-phase concentrations of TCA have been observed at concentrations greater than 25% of the single-component solubility of TCA. ISTD would be performed to depths of approximately 25 feet bgs, depending on location, within an area comprising approximately 2,532 $ft^2$, as indicated on Figure 6.

ISTD would be performed by installing the heater and heater/vacuum wells in the subsurface and constructing the heat exchanger and water/vapor extraction and treatment systems at the surface. ISTD would require a power distribution system be installed in proximity to the treatment area. Achieving the optimal treatment temperature is anticipated to require several weeks. Operation of the ISTD treatment system for approximately three to four months following attainment of optimal treatment temperature within the source area is anticipated to be sufficient to achieve the RAO. ISTD treatment would limit future impacts from DNAPL to groundwater by eliminating the DNAPL present. Specific design details will be addressed as part of the remedial design.

### 6.3.1 Short-term Effectiveness

During implementation of this alternative, onsite remedial construction workers may potentially be exposed to impacted soil and groundwater during initial heater and heater/vacuum well installation activities. Potential exposure to chemical constituents by ingestion, dermal contact, and/or inhalation would be minimized by the use of PPE and good housekeeping procedures specified in a remedy-specific HASP that would be developed during the remedial design. Potential vapor and dissolved-phase VOC migration out of the treatment area during remedy implementation is possible and will be considered in the remedial design and appropriate measures will be included to mitigate these issues. Air monitoring would be performed during implementation of this alternative to confirm that VOC vapors are within acceptable levels and to evaluate the need for additional engineering controls.

Public access to the site during remedy implementation activities would be limited by the installation of a perimeter security fence to restrict access to the treatment area exterior to Building B001, including any surface infrastructure installed in support of this remedy. Though Building B001 is currently unoccupied secured, a perimeter fence to secure the treatment area interior to Building B001 would also be constructed. In addition, risks to the community are minimized by the 24-hour security provided at the site.

### 6.3.2 Long-term Effectiveness

ISTD treatment implementation activities may require several weeks to complete. However, once the ISTD system is installed and operating, minimal oversight, operations and monitoring activities are required. The combined effectiveness of both heat and vapor flow yields greater than 95% horizontal and vertical coverage and is not impeded by changes in soil permeability. Compared to fluid injection processes, the conductive heating process is very uniform in its vertical and horizontal sweep. Furthermore, transport of the vaporized contaminants is improved by the creation of permeability, which results from drying and shrinking of the soil. Flow paths are created even in tight silt and clay layers, allowing escape and capture of the vaporized contaminants.

### 6.3.3 Reduction of Toxicity, Mobility, or Volume of Contamination

Laboratory treatability studies and field project experience have confirmed that the combination of high temperature applied for an appropriately determined duration results in high overall removal efficiency of even the high boiling point contaminants. In practice, most of the contaminants are destroyed in the soil before reaching the surface. Contaminants that have not been destroyed in-situ are removed from the produced vapor stream at the surface with an air pollution control system. With this system, DNAPL destruction and removal efficiencies in excess of 99.99% have been achieved (Stegemeir and Vinegar, 2001).

### 6.3.4 Implementability

Though the source area is largely located beneath existing Building B001, the space is currently unoccupied and access to the area for the installation of heater/extraction wells and the installation of an SVE system is not precluded. The time required to heat the formation is determined by the spacing of the heater wells, not the length of the heater interval. The time required to heat the formation is proportional to the square of the heater well spacing (Stegmeier and Vinegar, 2001), thus the denser the heater well array, the less time necessary to bring the treatment area up to the desired temperature. Treatment temperature is determined by type of contaminant or contaminants to be removed (i.e., the vaporization point of the contaminant). The amount of power necessary to achieve the desired temperature is controlled by the soil type and moisture content; the greater the moisture content, the more power necessary to achieve treatment temperature.

IBM will subcontract specialty contractors to implement this technology, however availability of personnel and material is not a limiting issue to implementation of an ISTD remedy. Access to the treatment area, for which administrative protocols have been established in the Order, does not represent an impediment. Air discharge permits would be required to discharge treated vapor effluent but are not expected to prevent implementation. No additional institutional or engineering controls would be required to effectively implement an ISTD remedy.

### 6.3.5 Cost Effectiveness

The cost of thermal conductance heating varies depending on the contaminant type and the level of remediation required (i.e., the RAO). Some factors that affect cost include the size of the treatment area, the cost of electricity, control of water recharge and temperature in the treatment area, depth below surface to the source area, and air discharge limitations. Cost estimates range between $50 and $250 per ton of soil to be treated. Using a conservative estimate for the treatment area of 50,000 cubic feet ($ft^3$) (i.e., a treatment area comprising 2,500 $ft^2$ and assuming a treatment area 20 feet thick) and assuming treatment requires three to four months of operation, costs are estimated to range between $1.9 and $2.5 million. Groundwater quality in and downgradient of the treatment are would be monitored biannually, beginning six months after completion of treatment. Remedial effectiveness monitoring is estimated to be $50,000 per year, for the two annual events, with an estimated monitoring period of two years.

Based upon these assumptions, including project management, design, permitting, reporting cost estimates and a twenty percent contingency, the cost of this remedial alternative is estimated at approximately $2.91 million (see Table 2). Given the likelihood of achieving the RAO within six months of remedy implementation and the resulting flexibility this schedule would provide for anticipated redevelopment, ISTD is considered to be cost effective.

### 6.3.6 Land Use

Current and future use of the site is restricted to Commercial Use by the environmental easement for OU-3 required by the Order.

## 7.0 RECOMMENDED REMEDIAL ALTERNATIVE

The three remedial alternatives retained for detailed evaluation, ISCO, ISCR, and ISTD, are considered capable of achieving the SWMU S RAO, and in general compare favorably in comparison to the evaluation criterion. However, IBM recommends implementation of ISTD. Although ITSD has the highest estimated cost, it provides the following benefits:

- ITSD has the shortest implementation schedule.
- ITSD is likely to achieve the RAO for SWMU S in a single treatment. While both ISCO and ISCR are considered capable of meeting the RAO, multiple rounds of treatment would likely be required.
- Through careful, conservative design, ITSD can typically be implemented without pilot testing.
- While long-term groundwater monitoring will be required at the site regardless of the alternative implemented, groundwater monitoring to assess the effectiveness of source elimination can be completed shortly after ITSD treatment. Multiple rounds of groundwater monitoring would be required to evaluate the effectiveness of each ISCO or ISCR treatment.

Following NYSDEC approval and community acceptance of the recommended remedial alternative, IBM will prepare a Remedial Action Work Plan (RAWP) that will describe pre-design investigation activities and remedial alternative design parameters including:

- A detailed description of the remedial action in sufficient detail for a contractor to design and install necessary treatment systems;
- The location and description of temporary treatment units necessary to implement the remedial action;
- A description of vapor control and air monitoring procedures to be implemented during remedial activities;
- A remedy-specific health and safety plan;
- A description of remedy performance and confirmation sampling;
- A description of procedures for dismantling and removing remedial structures and equipment and a site restoration plan;
- A cost estimate of the remedial action; and
- A proposed a schedule for remedy implementation.

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**TABLES**

**TABLE 1: REMEDIAL ALTERNATIVE EVALUATION SUMMARY**

| Category | Response Type | Remedial Alternative | RAO[1] Achieved | Comments | Schedule[2] | Evaluation |
|---|---|---|---|---|---|---|
| No Action | N/A | No Further Action | NO | DNAPL must be removed or treated if feasible. | N/A | Alternative not available |
| Administrative | Institutional Controls | Environmental Easement | NO | Restricts use to commercial and restricts future use of potable groundwater; protects human receptors. | 1 Year | Required by Order |
| Containment | Engineering Controls | Perimeter Control System (Groundwater Interception) | NO | Limits downgradient migration of VOC-impacted groundwater and protects environmental receptors. | N/A | Required by Order |
| Ex-situ Treatment | Physical Treatment | Excavation and Removal | YES | Source is in saturated zone beneath Building B001 and 25 feet of overburden; the use of sheet pile walls to secure the excavation, foundation supports to preserve the integrity of Building B001, and excavation dewatering and treatment would be required. | 1 Year | Not Recommended |
| In-situ Treatment | | Air Sparging | NO | Source is located in and on top of low-permeability units; not effective in substrates comprising moderate amounts of fine-grained sediments, injection beneath source inpractible. | N/A | Not Recommended |
| | | In-well Air Stripping (Groundwater Recirculation) | NO | DNAPL source present; flowing water is unable to flush DNAPL from low-permeability units. | N/A | Not Recommended |
| | Biological Treatment | Monitored Natural Attenuation | NO | Does not involve any active remedial measures; utilizes natural processes to treat impacts. DNAPL must be removed or treated if feasible. | N/A | Not Recommended |
| | | Enhanced Bioremediation | NO | Natural groundwater conditions not favorable to biodegradation, would require enhancement; low permeability of units would limit distribution of nutrients to subsurface and toxic nature of chlorinated NAPLs would inhibit efficacy. | N/A | Not Recommended |
| | Chemical Treatment | In-situ Chemical Oxidation | YES | Oxidant efficient in eliminating DNAPL sources and high dissolved-phase concentrations in groundwater; multiple injections typically necessary. Uniform delivery of oxidizing agent to subsurface primary technical challenge. | 3 Years | Feasible, Not Recommended |
| | | In-situ Chemical Reduction | YES | Reducing agents efficient in eliminating DNAPL sources and high dissolved-phase concentrations in groundwater; multiple injections typically necessary. Uniform delivery of reducing agent to subsurface primary technical challenge. | 2 Years | Feasible, Not Recommended |
| | Thermal Treatment | In-situ Thermal Desorption | YES | Application of heat to treatment area 99% effective in eliminating source DNAPL and associated dissolved-phase concentrations; 100% vertical and horizontal coverage of source zone. | 6 Months | Feasible, Recommended |

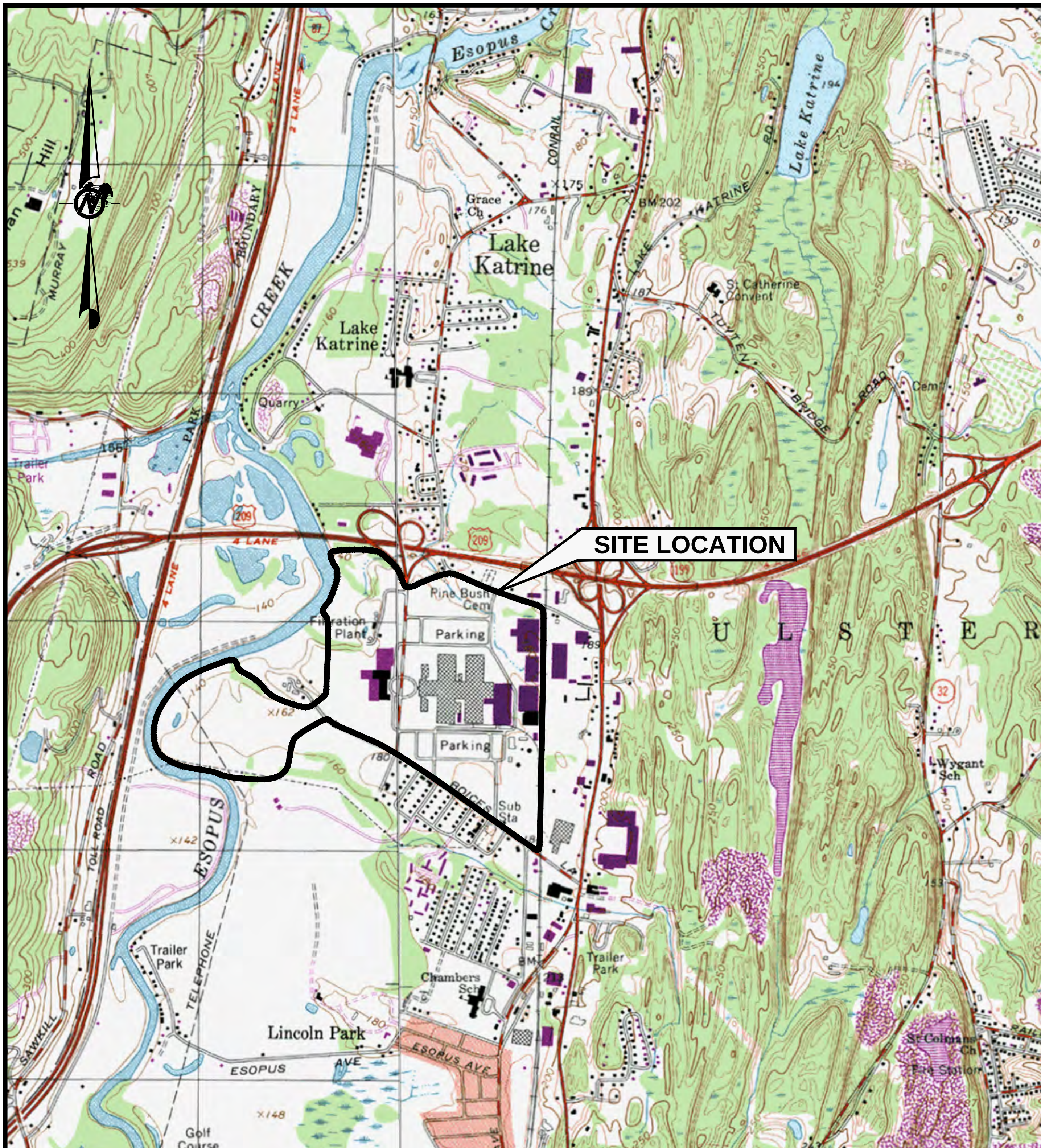
Notes:
1) Remedial Action Objective (RAO): Remove and/or treat DNAPL in the SWMU S area
2) Estimated time to implement and complete remedy; does not include remedy permanence groundwater monitoring following completion

## TABLE 2: REMEDIAL ALTERNATIVE COST COMPARISON

| Remedial Technology | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | 5 Year Total |
|---|---|---|---|---|---|---|
| In-situ Chemical Oxidation | $ 994,000 (1) | $ 399,000 (2) | $ 283,000 (3) | $ 167,000 (4) | $ 167,000 (4) | $2,010,000 |
| In-situ Chemical Reduction | $ 1,102,400 (5) | $ 517,400 (6) | $ 167,400 (7) | $ 167,400 (7) | $ 167,400 (7) | $2,122,000 |
| In-situ Thermal Desorption | $ 2,617,500 (8) | $ 292,500 (9) | $0 | $0 | $0 | $2,910,000 |

Notes:
1) The cost includes Total Cost of ISCO PDI (including pilot-scale test), Planning/Permitting/Reporting/Project Management, two oxidant injection events, and four groundwater monitoring events, plus 1/5 of 20% contingency.
2) The cost includes two oxidant injection events and four performance monitoring events, plus 1/5 of 20% contingency.
3) The cost includes one oxidant injection event and four performance monitoring events, plus 1/5 of 20% contingency.
4) The cost includes four performance monitoring events, plus 1/5 of 20% contingency.
5) The cost includes Total Cost of ISCR PDI (including pilot-scale test), Planning/Permitting/Reporting/Project Management, two ZVI injection events, and four groundwater monitoring events, plus 1/5 of 20% contingency.
6) The cost includes two ZVI injection events and four performance monitoring events, plus 1/5 of 20% contingency.
7) The cost includes four performance monitoring events, plus 1/5 of 20% contingency.
8) The cost includes Total Cost of ISTD infrastructure, power connection, Planning/Permitting/Reporting/Project Management, operational costs for 4 months, soil vapor extraction system installation and operation, demobilization, and two groundwater monitoring events, plus 1/2 of 20% contingency.
9) The cost includes two performance monitoring events, plus 1/2 of 20% contingency.

**FIGURES**




2000 0 2000
SCALE FEET

## REFERENCE

1.) BASE MAP TAKEN FROM USGS 7.5 MINUTE SERIES QUADRANGLES OF KINGSTON EAST, NY, DATED 1963, PHOTOREVISED 1980, AND KINGSTON WEST, NY, DATED 1997.

| REV | DATE | DES | REVISION DESCRIPTION | CADD | CHK | RVW |
|---|---|---|---|---|---|---|
| | | | | | | |

PROJECT

FORMER IBM FACILITY
KINGSTON, NEW YORK

TITLE

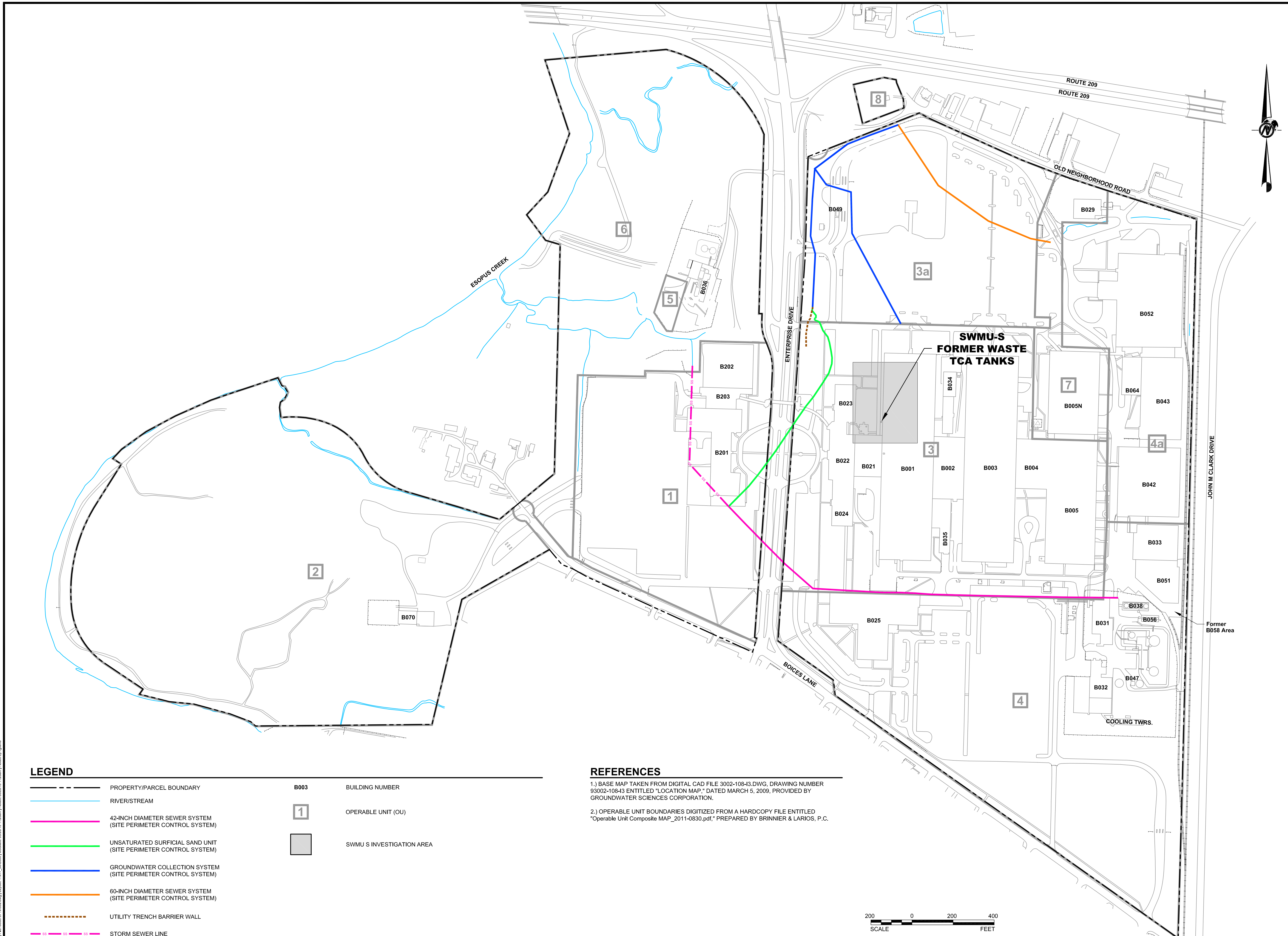
**SITE LOCATION MAP**

NJ Authorization #24GA28029100

Golder Associates
Newark, New Jersey

| | | | | |
|---|---|---|---|---|
| PROJECT No. | | 083-87071 | FILE No. | 08387071W001 |
| DESIGN | DPG | 03/20/13 | SCALE AS SHOWN | REV. 0 |
| CADD | RG | 03/20/13 | | |
| CHECK | CDH | 03/20/13 | **FIGURE 1** | |
| REVIEW | APTM | 03/20/13 | | |

Drawing file: 08387071W001.DWG Mar 20, 2013 - 11:25am




## LEGEND

| | |
|---|---|
| (black dash-dot line) | PROPERTY/PARCEL BOUNDARY |
| (light blue line) | RIVER/STREAM |
| (magenta line) | 42-INCH DIAMETER SEWER SYSTEM (SITE PERIMETER CONTROL SYSTEM) |
| (green line) | UNSATURATED SURFICIAL SAND UNIT (SITE PERIMETER CONTROL SYSTEM) |
| (blue line) | GROUNDWATER COLLECTION SYSTEM (SITE PERIMETER CONTROL SYSTEM) |
| (orange line) | 60-INCH DIAMETER SEWER SYSTEM (SITE PERIMETER CONTROL SYSTEM) |
| (brown dotted line) | UTILITY TRENCH BARRIER WALL |
| (magenta dashed line) | STORM SEWER LINE |
| B003 | BUILDING NUMBER |
| 1 | OPERABLE UNIT (OU) |
| (grey box) | SWMU S INVESTIGATION AREA |

## REFERENCES

1.) BASE MAP TAKEN FROM DIGITAL CAD FILE 3002-10843.DWG, DRAWING NUMBER 93002-108-43 ENTITLED "LOCATION MAP," DATED MARCH 5, 2009, PROVIDED BY GROUNDWATER SCIENCES CORPORATION.

2.) OPERABLE UNIT BOUNDARIES DIGITIZED FROM A HARDCOPY FILE ENTITLED "Operable Unit Composite MAP_2011-0830.pdf," PREPARED BY BRINNIER & LARIOS, P.C.

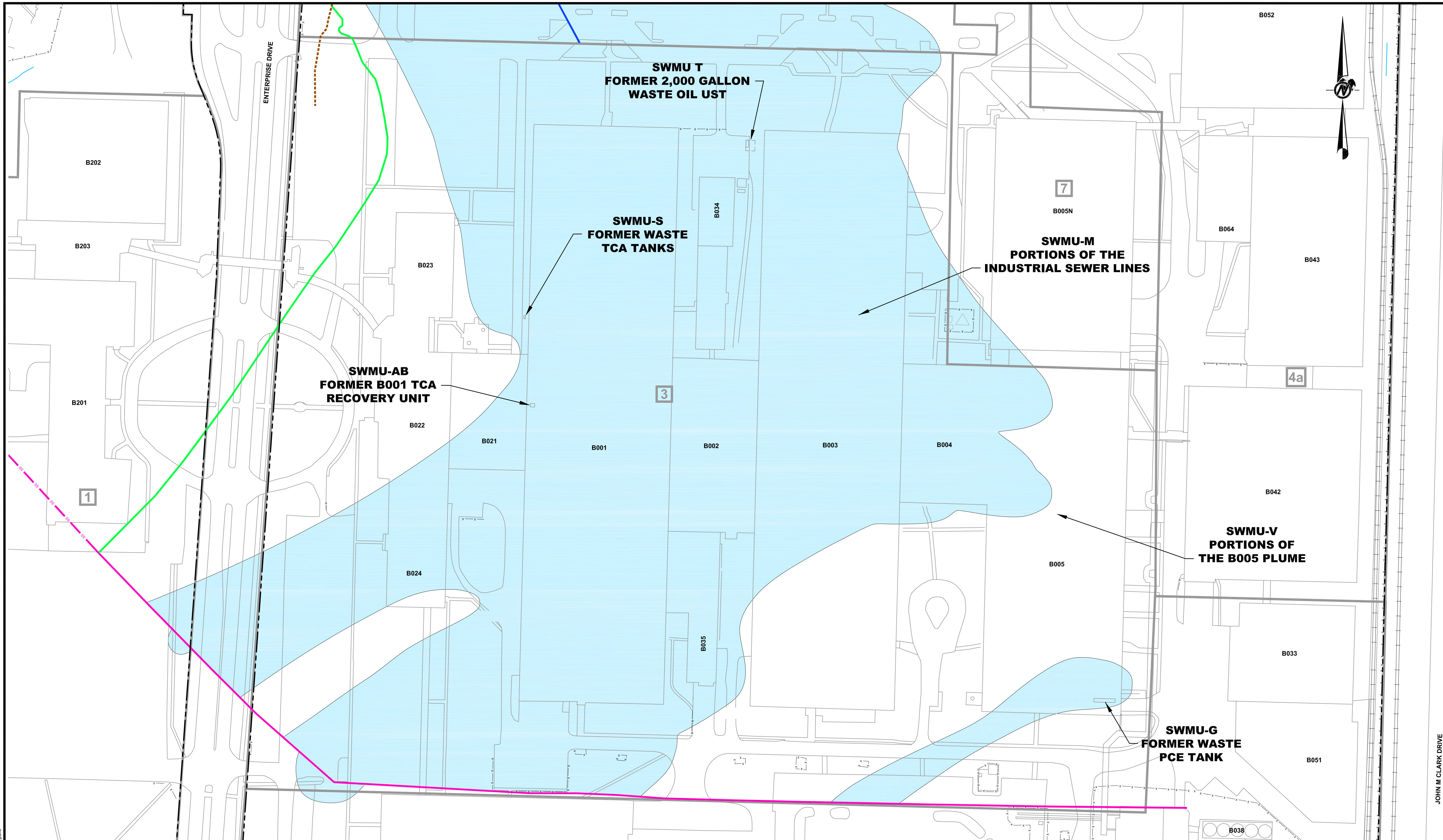
Golder Associates
Newark, New Jersey

PROJECT
FORMER IBM FACILITY
KINGSTON, NEW YORK

TITLE
SITE LAYOUT

| | | |
|---|---|---|
| PROJECT No. | | 083-87071 |
| FILE No. | | 08387071W002 |
| REV. 0 | SCALE | AS SHOWN |
| DESIGN | DPG | 03/20/13 |
| CADD | RG | 03/20/13 |
| CHECK | CDH | 03/20/13 |
| REVIEW | APTM | 03/20/13 |

FIGURE 2




## LEGEND

| | |
|---|---|
| | PROPERTY/PARCEL BOUNDARY |
| | RIVER/STREAM |
| | 42-INCH DIAMETER SEWER SYSTEM (SITE PERIMETER CONTROL SYSTEM) |
| | UNSATURATED SURFICIAL SAND UNIT (SITE PERIMETER CONTROL SYSTEM) |
| | GROUNDWATER COLLECTION SYSTEM (SITE PERIMETER CONTROL SYSTEM) |
| | UTILITY TRENCH BARRIER WALL |
| | STORM SEWER LINE |
| B003 | BUILDING NUMBER |
| 1 | OPERABLE UNIT (OU) |
| | GENERALIZED AREA OF VOC GROUNDWATER PLUME |

## REFERENCES

1.) BASE MAP TAKEN FROM DIGITAL CAD FILE 3002-108-43.DWG, DRAWING NUMBER 93002-108-43 ENTITLED "LOCATION MAP," DATED MARCH 5, 2009, PROVIDED BY GROUNDWATER SCIENCES CORPORATION.

2.) OPERABLE UNIT BOUNDARIES DIGITIZED FROM A HARDCOPY FILE ENTITLED "Operable Unit Composite MAP_2011-0830.pdf," PREPARED BY BRINNIER & LARIOS, P.C.

3.) GENERALIZED AREA OF VOC GROUNDWATER PLUME COMPILED FROM DIGITAL CONSTITUENT FILES FROM THE 2010 ANNUAL GROUNDWATER MONITORING REPORT, DATED MARCH 30, 2011, PREPARED BY GROUNDWATER SCIENCES CORPORATION.

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Newark, New Jersey

| REV | DATE | DES | REVISION DESCRIPTION | CADD | CHK | RVW |
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PROJECT

FORMER IBM FACILITY
KINGSTON, NEW YORK

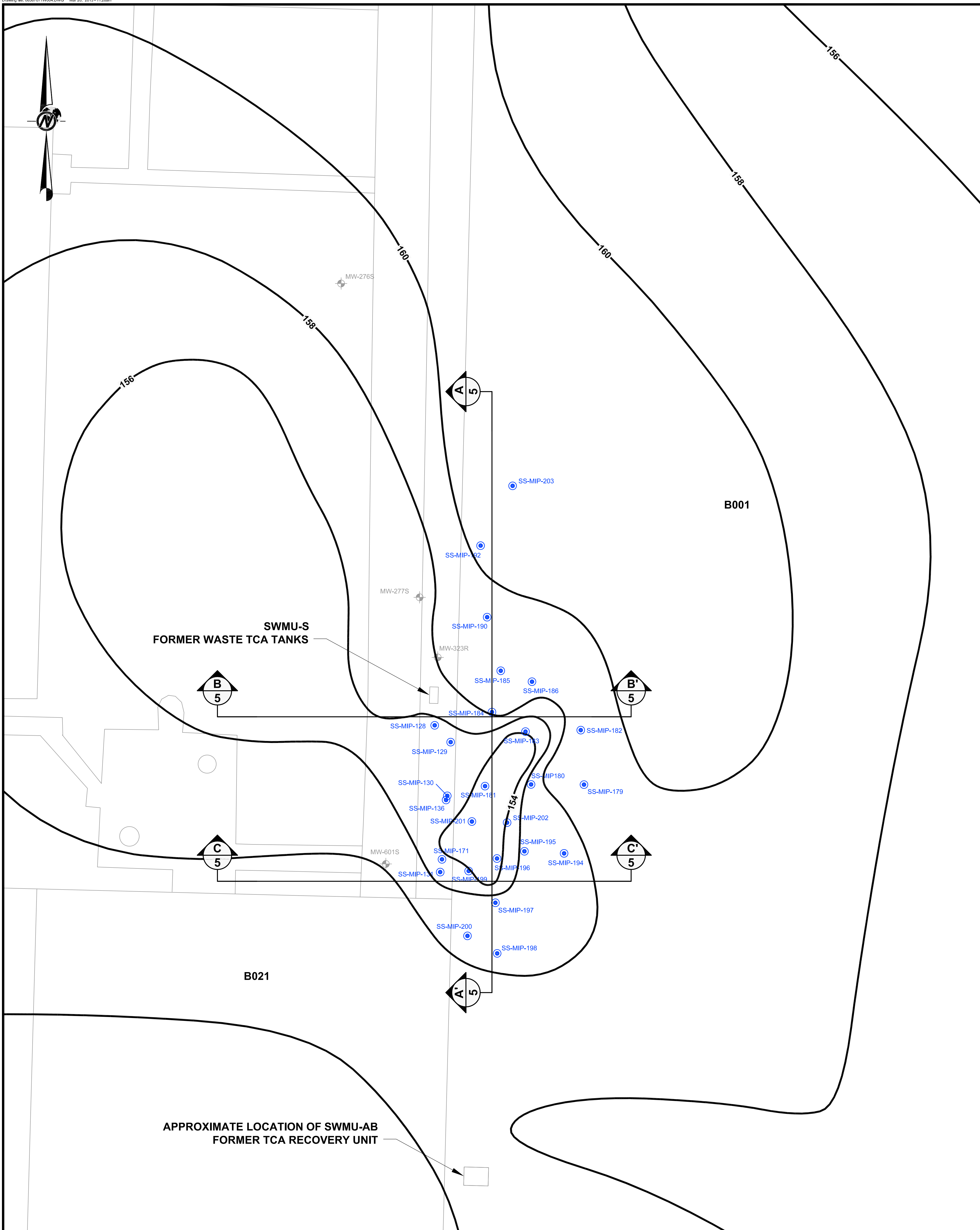
TITLE

OU-3 LAYOUT

| | | | |
|---|---|---|---|
| PROJECT No. | | | 083-87071 |
| FILE No. | | | 08387071W003 |
| REV. 0 | | SCALE | AS SHOWN |
| DESIGN | DPG | | 03/20/13 |
| CADD | RG | | 03/20/13 |
| CHECK | CDH | | 03/20/13 |
| REVIEW | APTM | | 03/20/13 |

FIGURE 3

Drawing file: 08387071W004.DWG Mar 20, 2013 - 11:28am




## LEGEND

| | |
|---|---|
| | PROPERTY/PARCEL BOUNDARY |
| B005 | BUILDING NUMBER |
| | EXISTING MONITORING WELL |
| | SWMU S MIP LOCATION |
| 170 | BASE OF SURFICIAL SAND CONTOUR (FT. MSL) |

## REFERENCES

1.) BASE MAP TAKEN FROM DIGITAL CAD FILE SITEMAP.DWG, DRAWING NUMBER 93002-SITEMAP/2 ENTITLED "SITE MAP," DATED MAY 9, 2005, PROVIDED BY GROUNDWATER SCIENCES CORPORATION.

2.) INACTIVE SUBSURFACE INDUSTRIAL WASTE LINES TAKEN FROM DIGITAL FILE 3002-108-I3.DWG, ENTITLED "LOCATION MAP," DATED MARCH 5, 2009, PREPARED BY GROUNDWATER SCIENCES CORPORATION.

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| REV | DATE | DES | REVISION DESCRIPTION | CADD | CHK | RVW |
|---|---|---|---|---|---|---|

PROJECT

FORMER IBM FACILITY
KINGSTON, NEW YORK

TITLE

**INTERPRETED BASE OF SURFICIAL SAND CONTOURS AND SWMU S AREA LAYOUT**

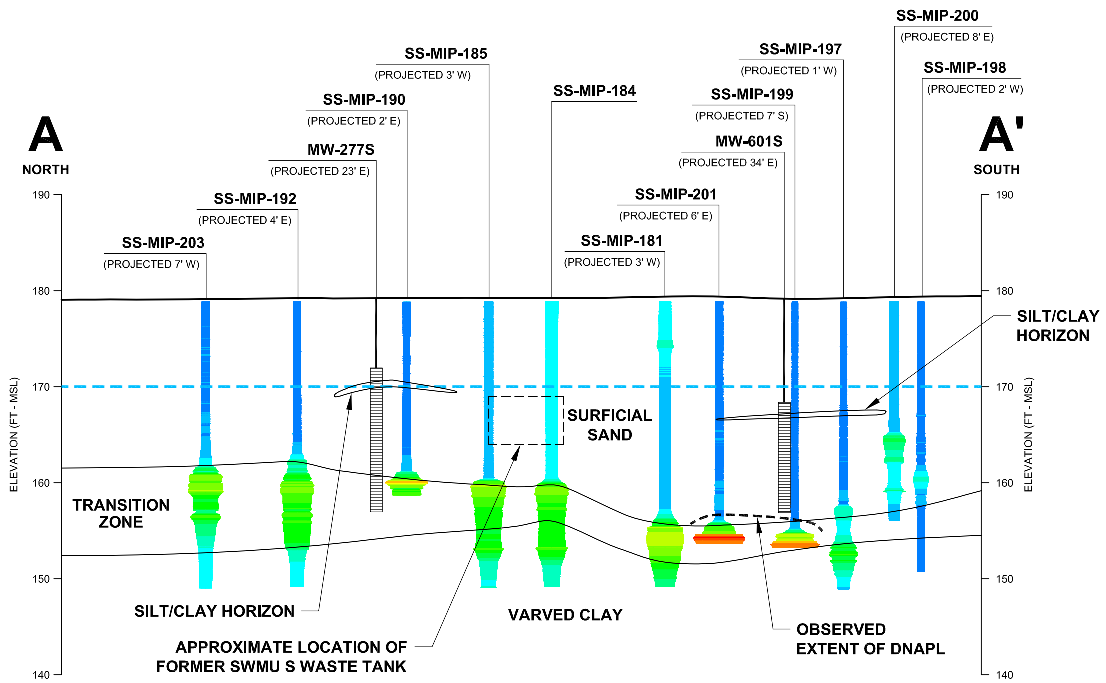
NJ Authorization #24GA28029100

Golder Associates
Newark, New Jersey

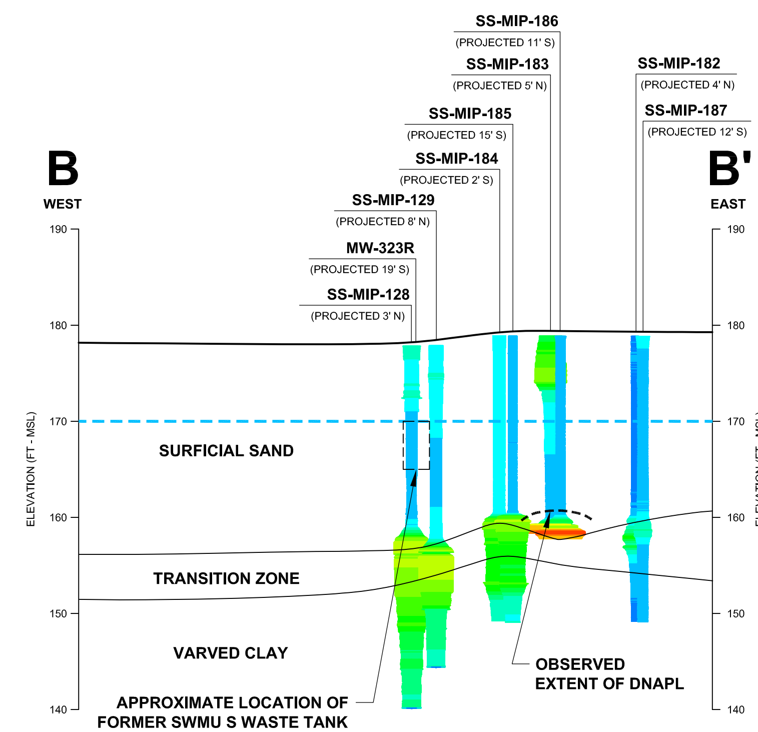
| | | |
|---|---|---|
| PROJECT No. | | 083-87071 |
| DESIGN | DPG | 03/20/13 |
| CADD | RG | 03/20/13 |
| CHECK | CDH | 03/20/13 |
| REVIEW | APTM | 03/20/13 |

FILE No. 08387071W004
SCALE AS SHOWN REV. 0

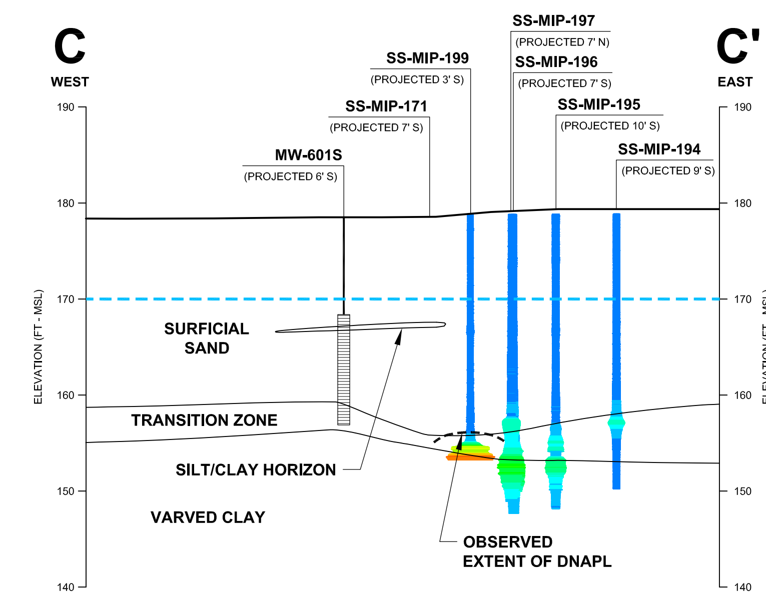
**FIGURE 4**




A
5
CROSS SECTION A-A'

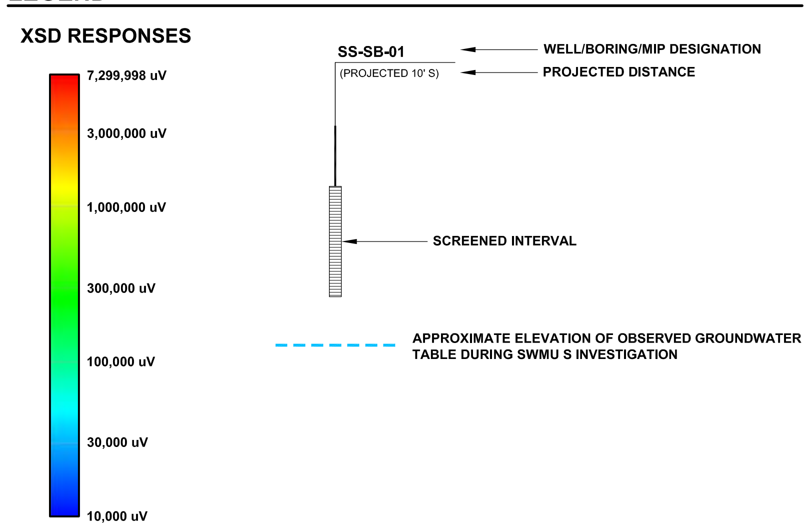



B
5
CROSS SECTION B-B'




C
5
CROSS SECTION C-C'

## LEGEND




## FIGURE NARRATIVE

THIS CROSS SECTION PRESENTS GOLDER'S INTERPRETATION OF THE SOIL STRATIGRAPHY BASED ON SOIL BORING LOG DESCRIPTIONS AND MIP DATA COLLECTED IN THE INVESTIGATION AREA. PROFESSIONAL JUDGMENT HAS BEEN USED TO DEVELOP THE CROSS SECTION. ACTUAL CONDITIONS WILL VARY FROM THOSE ILLUSTRATED. OTHER INTERPRETATIONS ARE POSSIBLE.

COLOR FLOOD AND DIAMETER OF THE DISCS SHOWN ON THE CROSS SECTION ARE INDICATIVE OF MIP XSD RESPONSES OBSERVED AT EACH LOCATION.

## NOTES

1.) CROSS SECTION AND MIP BORING PROFILES GENERATED BY EVS/MVS VERSION 9.22 RELEASED BY C TECH CORPORATION (2009) AND INTERPRETED BY GOLDER. SOIL BORING AND MEMBRANE INTERFACE PROBE INFORMATION PRESENTED IN THE SUPPLEMENTAL REMEDIAL INVESTIGATION REPORT: SOLID WASTE MANAGEMENT UNIT S: FORMER B001 WASTE TCA TANK (SWMU S SRIR) SUBMITTED TO NYSDEC ON OCTOBER 29, 2012."

2.) SOME MIP PROBE AND SOIL BORING LOCATIONS ARE PROJECTED OFF-SECTION.

3.) THE SIZE OF BORINGS AND WELLS SHOWN ARE EXAGGERATED.

4.) SEE FIGURE 4 FOR CROSS SECTION LOCATIONS.

20 0 20 40
HORIZONTAL SCALE FEET

10 0 10 20
VERTICAL SCALE FEET

VERTICAL EXAGGERATION X2

| REV | DATE | DES | REVISION DESCRIPTION | CADD | CHK | RVW |
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PROJECT

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KINGSTON, NEW YORK

TITLE

# INTERPRETED CROSS SECTIONS A-A', B-B', AND C-C'

NJ Authorization #24GA28029100

Golder Associates
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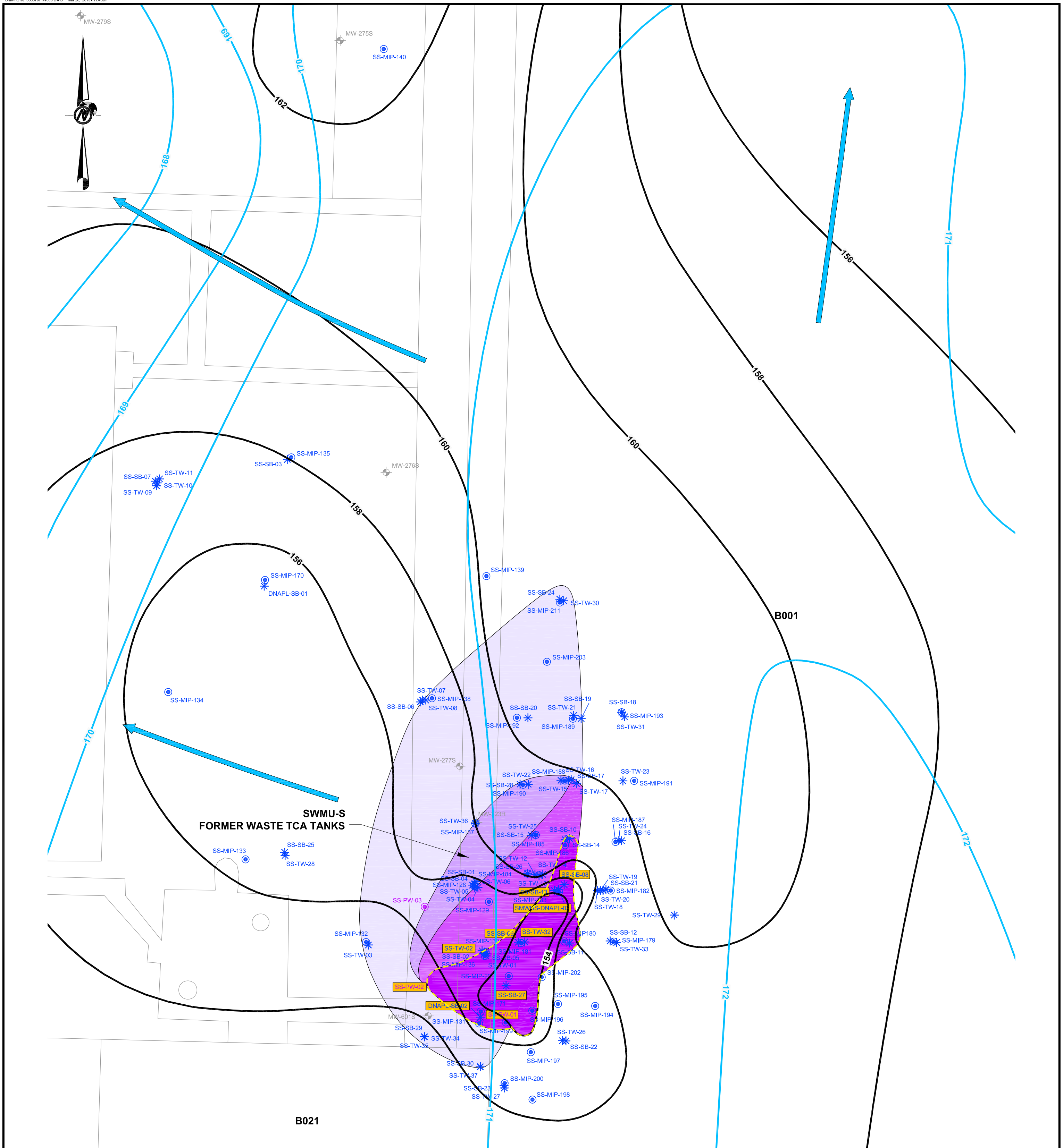
| PROJECT No. | | 083-87071 |
|---|---|---|
| DESIGN | RG | 03/20/13 |
| CADD | DPG | 03/20/13 |
| CHECK | CDH | 03/20/13 |
| REVIEW | APTM | 03/20/13 |

| FILE No. | 08387071W005 | | |
|---|---|---|---|
| SCALE | AS SHOWN | REV. | 0 |

**FIGURE 5**

Drawing file: 08387071W005.DWG Mar 20, 2013 - 11:42am

Drawing file: 0838707W006.DWG Mar 20, 2013 - 11:45am




## LEGEND

| | |
|---|---|
| | PROPERTY/PARCEL BOUNDARY |
| B005 | BUILDING NUMBER |
| | INACTIVE SUBSURFACE INDUSTRIAL WASTE LINES |
| | EXISTING MONITORING WELL |
| | SWMU S MIP LOCATION |
| | SWMU S SOIL BORING/TEMPORARY WELL LOCATION |
| | SWMU S NAPL EXPLORATORY WELL LOCATION |
| | LOCATION WHERE DNAPL OBSERVED |
| 170 | BASE OF SURFICIAL SAND CONTOUR |
| 170 | INTERPRETED GROUNDWATER TABLE ELEVATION CONTOUR |
| | INTERPRETED GROUNDWATER FLOW DIRECTION |
| | EXTENT OF OBSERVED DNAPL |

## DNAPL COMPONENT SOLUBILITY CONCENTRATIONS

> 1%

10-25%

25-50%

> 50%

## REFERENCES

1.) BASE MAP TAKEN FROM DIGITAL CAD FILE SITEMAP.DWG, DRAWING NUMBER 93002-SITEMAP/2 ENTITLED "SITE MAP," DATED MAY 9, 2005, PROVIDED BY GROUNDWATER SCIENCES CORPORATION.

2.) INACTIVE SUBSURFACE INDUSTRIAL WASTE LINES TAKEN FROM DIGITAL FILE 3002-108-I3.DWG, ENTITLED "LOCATION MAP," DATED MARCH 5, 2009, PREPARED BY GROUNDWATER SCIENCES CORPORATION.

15 0 15 30
SCALE FEET

| REV | DATE | DES | REVISION DESCRIPTION | CADD | CHK | RVW |
|---|---|---|---|---|---|---|

PROJECT

FORMER IBM FACILITY
KINGSTON, NEW YORK

TITLE

**DNAPL OCCURRENCE SOLUBILITY DISTRIBUTION MAP**

NJ Authorization #24GA28029100

Golder Associates
Newark, New Jersey

| | | | | |
|---|---|---|---|---|
| PROJECT No. | | 083-87071 | FILE No. | 0838707W006 |
| DESIGN | DPG | 03/20/13 | SCALE AS SHOWN | REV. 0 |
| CADD | RG | 03/20/13 | | |
| CHECK | CDH | 03/20/13 | | |
| REVIEW | APTM | 03/20/13 | | |

**FIGURE 6**