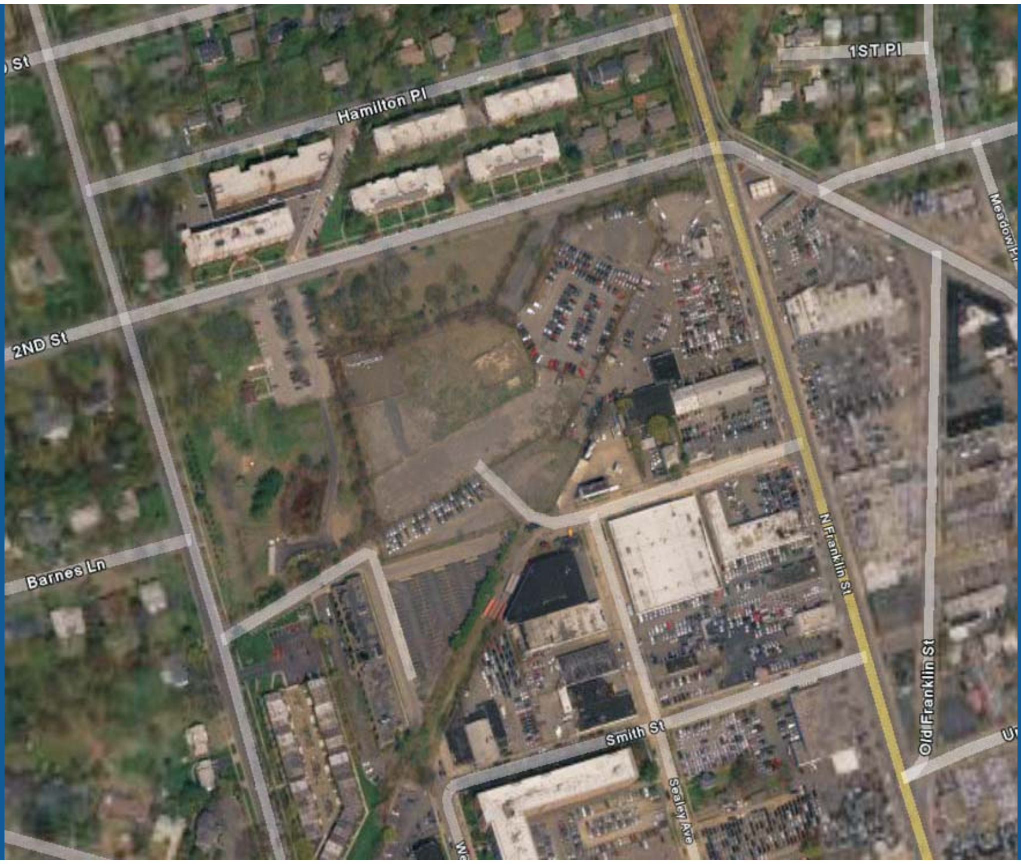
Feasibility Study/Remedial Action Plan for the Hempstead Intersection Street Former Manufactured Gas Plant Site

Villages of Garden City & Hempstead
Long Island, New York



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February 2008

FEASIBILITY STUDY/REMEDIAL ACTION PLAN FOR THE HEMPSTEAD INTERSECTION STREET FORMER MGP SITE VILLAGES OF GARDEN CITY AND HEMPSTEAD, LONG ISLAND NEW YORK

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LIST OF ACRONYMS AND ABBREVIATIONS

ASP	Analytical Services Protocol
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and total xylenes
CAMP	Community Air Monitoring Plan
C&D	construction and demolition
cf	cubic feet
cm/sec	centimeter/second
COPC	contaminants of potential concern
cy	cubic yard
DAR	Division of Air Resources
DER	Division of Environmental Remediation
DFW	Division of Fish and Wildlife
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOW	Division of Water
DSHM	Division of Solid and Hazardous Materials
EA	Human Health Exposure Assessment
FS	Feasibility Study
ft	feet
ft^3	cubic feet
FWIA	Fish and Wildlife Impact Analysis for Hazardous Waste Sites
gal	gallon
gpm	gallons per minute
HASP	health and safety plan
HDPE	high density polyethylene
HWR	Hazardous Waste Remediation
IRM	interim remedial measure
ISCO	in situ chemical oxidation
ISS	in situ solidification
ISTD	in situ thermal desorption

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

L/day	liters/day
LILCO	KeySpan predecessor company, Long Island Lighting Co.
LIRR	Long Island Railroad
LNAPL	light non-aqueous phase liquid
MDL	minimum detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MGP	manufactured gas plant
MNA	monitored natural attenuation
MW	monitoring well
NA	not applicable
NAPL	non-aqueous phase liquid
NCDH	Nassau County Department of Health
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
ND	not detected
NPDES	National Pollution Discharge Elimination System
NS	no standard
NYCRR	New York Code Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York Department of Health
OM&M	operation maintenance and monitoring
OSHA	Occupational Safety and Health Administration
PAHs	polycyclic aromatic hydrocarbons
PESH	New State Department of Labor's Public Employee Safety and Health
POTW	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
ppbv	parts per billion on a volume basis
PRAP	proposed remedial action plan
PRB	permeable reactive barrier

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

PS&S	Paulus, Sokolowski and Sartor Engineering
PVC	polyvinyl chloride
RAO	remedial action objective
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI	*Final Remedial Investigation Report*
RSCO	recommended soil cleanup objective
SB	soil boring
SCGs	standards, criteria, and guidance
sf	square feet
Site	Hempstead Intersection Street Former MGP Site
SPDES	State Pollution Discharge Elimination System
SVE	soil vapor extraction
SVOCs	semi-volatile organic compound
SWMU	Solid Waste Management Unit
TAGM	technical and administrative guidance memorandum
TCLP	toxicity characteristic leaching procedure
TMV	toxicity, mobility or volume
TOC	total organic carbon
TOGS	Technical and Operational Guidance Series
TPAHs	total polycyclic aromatic hydrocarbons
TPH	total petroleum hydrocarbon
UCS	unconfined compressive
µg/L	micrograms per liter
USEPA	United Stated Environmental Protection Agency
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

This report presents the Feasibility Study/Remedial Action Plan (FS/RAP) for the KeySpan Corporation Hempstead Intersection Street Former Manufactured Gas Plant (MGP) Site located in the Villages of Hempstead and Garden City, in the Town of Hempstead, Nassau County, Long Island, New York. This report was prepared by URS Corporation (URS) in accordance with the Order on Consent (#D1-0001-98-11) (the Order) with the New York State Department of Environmental Conservation (NYSDEC) and the NYSDEC Draft DER-10 Technical Guidance For Site Investigation and Remediation and meets remedial action objectives including the NYSDEC standards, criteria and guidance. The FS/RAP is to be used in conjunction with the Final Remedial Investigation Report (RI) prepared by Paulus, Sokolowski and Sartor Engineering, dated November 2006.

Historic releases of coal gasification related materials (i.e., coal tar) from former MGP processes have impacted soils and groundwater at and downgradient of the Site. Non-aqueous-phase liquid (NAPL) extends approximately 400 feet (ft) downgradient of the Site at the depth of the water table, approximately 30 ft below ground surface (bgs). A dissolved phase groundwater plume (50 – 100 micrograms per liter [µg/L] range) containing volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) extends approximately 3,000 feet downgradient of the Site. A majority of this lower concentration groundwater plume impacts the shallow water table aquifer that extends from approximately 30 ft bgs to 48 ft bgs. A small area of the intermediate aquifer (i.e., 48 to 95 ft bgs) is also impacted by dissolved phase constituents in the vicinity of the southwestern portion of the Site. The purpose of this FS/RAP is to define the remedial goal and remedial action objectives for remediation of MGP-related impacts which will be protective of public health and the environment, identify potential remedial technologies feasible for use at this MGP Site, and develop remedial alternatives that meet the remedial goals for the Site and surrounding impacted areas. Remedial alternatives are evaluated according to the criteria set forth by NYSDEC. A recommended remedy meeting the remedial goal and remedial action objectives is selected and a conceptual design is presented.

Remedial Goal

The Site Remedial Goal is:

> To remove or mitigate, to the extent practicable, the source of contamination, and eliminate or mitigate any significant threats to public health and the environment presented by Site-related contaminants in accordance with site cleanup objectives presented in 6 NYCRR Part 375 (Part 375).

Remedial Action Objectives

Remedial Action Objectives (RAOs) have been developed for the Site as follows:

Soil

> Eliminate or reduce, to the extent practicable, NAPL and MGP-related contamination sources that contribute to soil, air, soil vapor and groundwater contamination.
>
> Prevent, to the extent practicable, human exposure to MGP-related chemicals present in surface and subsurface soil at and around the site at levels exceeding applicable standards, criteria, and guidance (SCGs).

Air and Soil Vapor

> Prevent, to the extent practicable, potential inhalation of MGP-related chemicals exceeding SCGs in ambient and indoor air on and near the Site.
>
> Prevent, to the extent practicable, utility worker exposure to soil vapor off-site.

Groundwater/NAPL

> Reduce or mitigate NAPL, to the extent practicable, to decrease the source of chemicals that contribute to soil, air, soil vapor and groundwater contamination.
>
> Prevent or mitigate, to the extent practicable, off-site migration of groundwater contamination resulting from Site-related contaminants.
>
> To restore, to the extent practicable, groundwater impacted by Site related MGP contaminants of concern to meet ambient water quality standards and guidance values.

Interim Remedial Measure

An interim remedial measure (IRM) is proposed for implementation in 2008 that supports the RAOs for the Site. IRM activities include excavation of soil source material in the north-central portion of the Site. Excavated soil will be transported off-site to a thermal desorption facility for treatment/disposal. Excavated areas will be backfilled with clean soil. This area may then be used for construction support areas during site-wide remediation. IRM activities also include NAPL recovery in approximately 24 product recovery wells installed as part of the IRM within the NAPL plume. NAPL will be collected during regular visits to the recovery wells and in existing monitoring wells by hand bailing/pumping methods. NAPL recovery frequency will be adjusted based on observed NAPL recovery rates in individual wells. Collected NAPL will be properly disposed off-site.

Remedial Alternatives

Five remedial alternatives were developed for the site based on the areas and volumes of contamination estimated from the results of remedial investigations. The five alternatives include the full spectrum of no action, containment, and treatment of MGP-related contamination in soil, groundwater, and air/soil vapor. The list of remedial alternatives developed for the Site is as follows:

Alternative 1 – No Action, Monitored Natural Attenuation (MNA);

Alternative 2 – Excavation of Source Soil and Bioremediation of Dissolved Phase Plume;

Alternative 3 – Excavation of Shallow Source Soil, Product Recovery, In Situ Chemical Oxidation (ISCO), and Bioremediation of Dissolved Phase Plume;

Alternative 4 – Excavation of Shallow Source Soil, In Situ Solidification (ISS), and Bioremediation of Dissolved Phase Plume; and,

Alternative 5 – Excavation of Shallow Source Soil, Product Recovery, Source Area Containment With Treatment Gate using Ozone Injection, and MNA.

The five alternatives were evaluated against the NYSDEC criteria: Overall Protection of Public Health and the Environment; Compliance with Standards, Criteria and Guidance; Long-term

Effectiveness and Permanence; Reduction of Toxicity, Mobility and Volume with Treatment; Short-term Effectiveness; Implementability; and Cost.

Recommended Remedy

Based on the evaluation, Alternative 4 - Excavation of Remaining Shallow Source Soil, **In Situ Solidification**, and Bioremediation of the Dissolved Phase Groundwater Plume is the recommended remedy for the site. When combined with the vapor intrusion sampling and mitigation program, Alternative 4 incorporates proven technologies that are protective of public health and the environment, requires a shorter implementation time frame for construction than other alternatives, and meets remedial action objectives for the Site. It also eliminates remnant MGP structures and source material within the top 8 ft of the Site in accordance with Part 375 cleanup objectives.

In situ solidification, as applied to MGP Sites with NAPL, accomplishes the following during treatment:

- ISS achieves source control through encapsulation and soil hydraulic conductivity reduction;
- ISS minimizes long-term impacts to groundwater by markedly reducing the leaching of MGP-related constituents to groundwater;
- ISS eliminates mobile NAPL by homogenizing it with the surrounding soils, reducing its concentration to below its residual saturation point and blending the impacted soils with cementitious reagents, creating a low-hydraulic conductivity solidified monolith.

Solidification is an established technology that has been used for over 20 years to treat a variety of residual wastes at industrial sites. Solidification creates a large monolithic block with a hydraulic conductivity much less than the surrounding soil. Groundwater flows around the monolith, rather than through it, therefore there is no advective transport of contaminants from within the treated soil mass to the surrounding environment. Solidification has been applied to MGP sites since 1990. Since ISS was first used at an MGP site in 1990, the test methods and approaches have evolved over time as the collective understanding of the mechanisms involved in ISS are better understood by the remediation engineering, remedial construction, and academic communities.

A Conceptual Design of this recommended remedy is presented along with a description of additional pre-design investigations required.

1.0 PURPOSE

1.1 Introduction

This Feasibility Study/Remedial Action Plan (FS/RAP) report was prepared by URS Corporation (URS) for KeySpan Corporation (KeySpan), for the Hempstead Intersection Street Former Manufactured Gas Plant (MGP) Site (Site) located in the Villages of Hempstead and Garden City, in the Town of Hempstead, Nassau County, Long Island, New York. This FS/RAP was completed in accordance with the Order on Consent (#D1-0001-98-11) (the Order) with the New York State Department of Environmental Conservation (NYSDEC).

1.2 Scope of Feasibility Study/Remedial Action Plan

The Order requires that KeySpan prepare a Remedial Plan that evaluates on-site and off-site remedial actions. Based on the Remedial Action Plan proposed by KeySpan, NYSDEC will select a remedial response for the Site that meets the remedial goals developed herein.

This FS/RAP was developed to meet the requirements of a Remedial Plan set forth in the New York State Code Rules and Regulations (NYCRR) 6 NYCRR 375-1.1(c), NYSDEC Technical and Administrative Guidance Memorandum (TAGM) #4030, Selection of Remedial Actions at Inactive Hazardous Waste Sites and NYSDEC Draft DER-10 Technical Guidance For Site Investigation and Remediation. The FS/RAP is to be used in conjunction with the Final Remedial Investigation Report (RI) prepared by Paulus, Sokolowski and Sartor Engineering, dated November 2006.

This FS/RAP details the remedial goals for remediation, identifies potential remedial technologies feasible for use at this Site, and develops remedial alternatives that meet the remedial goals for the Site as a whole. Remedial alternatives are screened and evaluated according to the criteria set forth by NYSDEC. A recommended remedial alternative meeting the remedial goals for the Site is presented on a conceptual level.

An interim remedial measure (IRM) is proposed for completion in 2008 that supports the remedial action objectives (RAOs) for the Site. Proposed IRM activities include excavation of coal-tar containing soils in the north-central portion of the Site. Excavated soil will be transported off-site to a thermal desorption facility for treatment/disposal. Excavated areas will be backfilled with clean soil, which may then be used for construction support areas during site-wide remediation. IRM activities also include non-aqueous phase liquid (NAPL) recovery in existing monitoring wells and in approximately 24 new product recovery wells to be installed within the NAPL plume present at the water table. NAPL will be collected during regular visits by hand bailing/pumping methods. The frequency of collection may be adjusted as NAPL recharge rates at individual wells are assessed. Collected NAPL will be properly disposed off-site.

1.3 Report Organization

This document has been organized consistent with NYSDEC *Draft DER-10* and includes the following sections:

- Executive Summary;
- Purpose;
- Site Description and History including Nature and Extent of Contamination and Exposure Assessment;
- Remedial Goal and Remedial Action Objectives including remediation areas and volumes;
- Identification and Screening of Remedial Technologies including General Response Actions;
- Development, Screening, and Description of Alternatives;
- Detailed Analysis of Alternatives;
- Recommended Remedy; and
- Conceptual Design of Recommended Remedy including Recommended Additional Investigations.

2.0 SITE DESCRIPTION AND HISTORY

This section presents a description of the Site and a summary of Site conditions and history, and is based on information and data presented in the *RI*. The *RI* incorporated the results of previous investigations to establish Site conditions and the relationship between the historical Site operations and observed impacts to soil and groundwater. Investigations conducted prior to the RI include:

- Atlantic Environmental Services, Inc., Preliminary Investigation for Site of Former Hempstead Gas Plant, December 26, 1990.
- Weston, R.F., Final Baseline Risk Assessment Report LILCO – Hempstead Gas Plant, July 16, 1992.
- Weston, R.F., Final Field Investigation Report – Hempstead Gas Plant, October 1992.
- Grosser, P.W., Contaminant Fate Report – Hempstead Gas Plant, May 1995.
- Dvirka & Bartilucci Consulting Engineers, March 2003 Remedial Investigation Report, March 2003.
- Weston, R.F., Remedial Alternatives and Feasibility Analysis, November 1993.
- H2M Group, Village of Garden City and Village of Hempstead Clinton Street Water Supply Wells; Capture Zone Analysis Reports, November 2006.

Information collected during the course of the FS/RAP, such as NAPL thickness measurements and NAPL properties characterization, has been included in this report.

2.1 <u>Site Description</u>

The Site, located on Figure 2-1, is in the Villages of Hempstead and Garden City, Nassau County, New York. The majority of the approximately 7.5-acre site shown on Figure 2-2 is located within the Village of Garden City. The property is bordered to the north by Second Street and along the east by the Long Island Railroad (LIRR) inactive railroad right-of-way (ROW). Property to the west of the Site is owned by the Village of Garden City and contains a public parking lot, two public water supply wells and a recharge basin for those two wells. Residences and commercial businesses, including a Medical Office Building to the southwest, surround the Site.

An active natural gas regulator station is located on the northwestern portion. A 0.8-acre parcel in the southern portion is within the Village of Hempstead and is currently used to store vehicles. This portion was previously leased, and subsequently sold, by the Long Island Lighting Company (LILCO – a KeySpan predecessor company) in the early 1980's to an automobile dealer who is the current property owner. This parcel, identified as the Sold property, is considered to be on-site for the purposes of the FS/RAP. A second automobile dealership leases property in the upper northeastern corner. Oswego Oil Service Corporation (Oswego Oil) and an inactive fuel oil storage and loading facility are located immediately to the southeast.

The Site is defined in this document as the KeySpan former MGP property and the Sold property. Adjacent side-gradient and downgradient properties impacted by the Site are considered for remediation along with the Site in the identification of technologies and remedial alternatives. The Medical Office Building parking lot generally delineates this off-site area.

The Site and surrounding area are generally flat, sloping gently to the west and southwest. A perimeter fence secures the Site. Site access is through the Sold property. The northern two-thirds of the Site, as well as the eastern portion, is unpaved ground covered with either vegetation or crushed stone. The southern third of the Site is paved with asphalt. Limited grass, shrubs and trees serve as a buffer extending across the northern portion of the Site along Second Street.

The Site is zoned industrial with the exception of the Sold property, which is zoned business "C", the definition of which includes warehouse storage, light manufacturing, and car dealer's vehicle storage and repair. Properties immediately to the north of the Site across Second Street are zoned for multi-family residential apartment housing. Properties immediately to the east are zoned as general commercial. The property to the west is designated parkland. Property to the south is zoned business "C."

2.2 Site History

MGP operations began in the early 1900's in the southern portion of the Site and expanded north as the demand for gas increased. LILCO acquired the Site in the early 1930's. Following the start of natural gas availability in the early 1950's, the MGP served as a peak/emergency facility to ensure gas supply until gas manufacturing operations ceased in the mid 1950's. The on-site plant was subsequently demolished by LILCO. In 1998, LILCO merged with Brooklyn Union Gas forming KeySpan Corporation. Following this merger, all but the previously sold automobile dealer property became KeySpan property.

Figure 2-2 shows the locations of former MGP structures, portions of which remain on-site, generally below the ground surface. The majority of structures were located on the Sold property, currently used by the owner for vehicle storage. Located in this southern portion of the Site were the 340,000-cubic foot (cf) storage holder, the 250,000-cf relief holder and a 140,000-gallon gas oil tank. Located in the southeastern corner of the Site was the former gas generator house. Other structures located in the southernmost portion of the Site included an effluent water treatment facility, tar separators, skimming basins and various tar and tar emulsion storage and settling tanks. A series of gas purifying structures including oxide purifier boxes, tar extractors and an electric precipitator house straddled the boundary between the Villages of Garden City and Hempstead.

A coal storage area was located in the northeastern portion of the Site. Tar and oil storage tanks were located in the eastern portion adjacent to the LIRR ROW. A large tar separator and an associated cesspool were located in the south-central portion. Cooling spray ponds were located in the north-central portion. Immediately east of the former spray ponds were four 30,000-gallon liquid propane tanks. The concrete foundations for the propane tanks currently exist at the Site. Three drip oil tanks with capacities of 12,000, 7,300, and 9,500 gallons (gal), along with a paint house, were located near the western property line.

A "cut and plug" IRM Program was undertaken at the Site during the winter of 1999. The objective of the IRM was to locate underground piping associated with historic MGP operations so that each pipe could be cut, drained of any fluids and plugged in order to limit the potential for any off-site migration of MGP-related constituents. The IRM was completed in Summer 2000.

An IRM has been proposed for completion in 2008, as discussed in Section 3.4 of this report.

2.3 Geology and Hydrogeology

From the ground surface through the subsurface, the four primary geologic units present at the Site include:

- Fill/topsoil;
- Glacial sediments;
- Upper Magothy formation; and
- Lower Magothy formation.

The fill/topsoil unit encountered throughout and adjacent to the Site is highly variable in character and thickness. It consists of brown to black sands, silts and gravels with varying amounts of concrete, brick, coal, bluestone, clinker, vesicular slag and wood. The unit is not continuous throughout the Site; where present it ranges in thickness from approximately 0.5 feet (ft) to 16 ft. The unit appears to be thickest in the central-western portion of the Site within the area of the former drip oil tanks, and is up to 8 ft thick near the former tar separator. It is possible that following removal of these former MGP structures, excavations were backfilled with fill material. With the exception of a thin layer of topsoil, the fill unit does not appear to extend a significant distance south of the Site. A thin layer of fill does appear to be present at several soil borings located west of the Site within the Village of Garden City property.

Underlying the fill/topsoil layer are relatively porous glacial outwash deposits consisting of yellow to light brown, fine to coarse sand with varying amounts of gravel, having excellent water transmitting properties. The thickness of these sediments ranges from 60 to 70 ft within the Site to over 95 ft south of the Site. Zones and lenses of silty sand and silt were identified within the glacial unit at a number of boring locations. The majority of the silt-sand lenses were encountered from ground surface to a depth of approximately 20 ft with the exception of one area just south of the southern tip of the Medical Office Building parking lot (i.e., MW-08D) where up to 32 ft of silt and silty sand was observed. The silty sand lenses appear to limit the vertical movement of groundwater and NAPL. Additionally, a number of gravel-rich sand lenses were found from approximately 30 to 50 ft below ground surface (bgs), especially in the western half of the Site and off-site to the west and south. Where present below the water table, these gravel zones may act as preferential flow paths for groundwater and NAPL. Also observed in the glacial sediments unit were zones or lenses of silty fine sand, which, where present, limit the vertical migration of groundwater and NAPL due to a lower permeability as compared to adjacent coarse sand deposits.

Total organic carbon (TOC) data collected during the RI indicate that the glacial outwash deposits are relatively poor in organic matter, having an average TOC content of approximately 0.5%. The organic content fraction in soil is the dominant characteristic affecting the adsorption capacity of non-ionic organic compounds such as benzene, toluene, ethylbenzene, and total xylenes (BTEX) and polycyclic aromatic hydrocarbons (PAHs) onto the soil matrix (Suthersan, 1997). Soil with a very low fraction of organic content will have a limited ability to adsorb and therefore immobilize organic compounds. Rather, continued migration of compounds through the groundwater system through advection, dissolution, and diffusion will occur.

Underlying the glacial outwash sediments is the upper subunit of the Magothy formation that is characterized by a sequence of sand, silt and clay layers. Its thickness ranges between 49 and 110 ft at the Site. Because of its diverse stratigraphy and heterogeneous distribution of sediment types and zones, the upper subunit is highly anisotropic with the vertical hydraulic conductivity several orders of magnitude less than the horizontal hydraulic conductivity. The lower subunit of the Magothy formation, found from 118 ft bgs and below, is characterized by a low permeability silty fine sand and stiff clay. Due to the high clay content of the lower subunit, it acts as an effective confining layer limiting the vertical migration of groundwater.

The water table is at a depth of approximately 30 ft bgs. Groundwater flow within the glacial outwash sediments (Upper Glacial aquifer) is in a south-southwesterly direction, with a hydraulic gradient on the order of 0.0001 ft/ft.

Based on literature sources, hydraulic conductivities of the Upper Glacial aquifer and the upper subunit of the Magothy formation are estimated to be on the order of 1 x 10^{-1} cm/sec, and on the order of 1 x 10^{-2} to 5 x 10^{-2} cm/sec, respectively; while the corresponding horizontal-to-vertical anisotropies of these two units are approximately 1:10 and 1:100. The lower subunit of the Magothy formation is characterized by very low hydraulic conductivity. Two Site-specific laboratory tests provided estimates of the vertical hydraulic conductivity on the order of 1x 10^{-7} cm/sec.

2.4 Potable Water Supply and Recharge Basin Assessment

Locations of private water supply wells potentially downgradient of the Site are shown on Figure 2-3. These wells are screened in the Upper Glacial and Magothy aquifers, as indicated on *RI* Table 1-2**.** Based on the completed private well surveys and NYSDEC records, it was determined that of the 17 wells identified, none are used for drinking water purposes. Water from these wells is reportedly used for irrigation, cooling, auto washing, and laundry. The nearest private well to the Site is well N-4406 identified in the *RI* as used for cooling water at the Medical Office Building. In December 2007, the New York State Department of Health (NYSDOH) visited this property and verified that the well is closed.

There are two public water supply wells located approximately 200 ft west (side gradient) of the Site as shown on Figure 2-3. These wells are operated by the Village of Garden City and are screened at depths of 439 to 541 ft, and 489 to 570 ft, within the Magothy aquifer. Due to the low permeability of sediments in the upper portion of the Magothy aquifer and previously described horizontal-to-vertical anisotropies, the potential for site-related contaminants to reach the wells is limited. Analytical results from water samples collected from these wells on a routine basis by the Nassau County Department of Health (NCDH) confirm this.

Two additional public water supply well fields that may be potentially downgradient were identified in the *RI*. These two well fields are approximately 1.3 miles southeast and 1.6 miles southwest. Both are screened in the Magothy aquifer between 450 and 625 ft bgs. Given the depth of the well screens and the distance from the Site, it was determined that it is unlikely that site-related contaminants could impact water quality in these wells.

On behalf of KeySpan, H2M Group analyzed groundwater flow in the vicinity of the Site relative to the Village of Garden City's public water supply wells located approximately 200 ft west, and the Village of Hempstead Clinton Street public water supply wells located approximately 4,000 ft east of the Site. Modeling results indicate that the area of Site-related impacts determined during the RI is outside of the groundwater capture zone of these water supply wells, assuming normal pumping rates.

A recharge basin for the Village of Garden City water supply wells is located immediately west of the Site. Recharge to this basin from the water supply wells is to the ground surface in an approximately 10-foot deep fenced-in depression, and is episodic during cleaning operations of the supply wells. PS&S performed an analysis on the potential impact of water pumped into the basin and determined that periodic discharges to the basin during well cleaning operations are not expected to result in a state of constant infiltration and therefore, is considered to have a low potential for causing a downward hydraulic driving force of any significant consequence.

2.5 Nature and Extent of Contamination

2.5.1 Soil

Areas of soil contamination were presented in the *RI* based on field (visual and olfactory) observations, total PAH concentrations, and total BTEX concentrations.

Surface and near-surface soils containing site-related contaminants are predominately in areas associated with former MGP structures and areas of operation. Field observations for these areas included tar-like odors, staining and/or sheens, as well as blebs, tar/oil droplets and/or NAPL both on- and off-site. *RI* Drawing 6A identified the locations and depths of NAPL-saturated soils as evidenced through field observations.

Figures providing the locations and depths of total BTEX and total PAHs (TPAHs) based on sampling and laboratory analysis were presented in the *RI* for soils in 8 to 10-foot depth intervals between 0 to 8 ft bgs, 8 to 16 ft bgs, 16 to 24 ft bgs, 24 to 34 ft bgs, and below 34 ft bgs.

Based on information provided in the *RI*, source areas are identified as significant zones of NAPL-saturation in soils and the presence of NAPL in groundwater along with areas of high concentrations of PAHs and BTEX. These source areas are shown on Figure 2-4 for the 0 to 8-foot depth, Figure 2-5 for the 8 to 16-foot depth, Figure 2-6 for the 16 to 24-foot depth, and Figure 2-7 for the 24 to 34-foot depth. Boring logs and test pits within the relief holder, storage holder, and gas oil tank indicated that remnant MGP structures were present to a depth of 6.5 ft; therefore, these areas were included as source areas on Figure 2-4 for the 0 to 8-foot depth.

Below 34 ft bgs, NAPL migration vertically has been impeded by capillary forces and by soil gradation changes, resulting in isolated stringers of NAPL migrating vertically to depths greater than 70 ft bgs in isolated areas as shown on *RI* Figures 4F through 4I and 6B. These stringers represent a relatively low mass of contaminants as compared to the source areas between 0 to 34 ft bgs.

2.5.2 Air

Fifteen soil vapor probe samples collected during the RI on- and off-site indicated the presence of BTEX compounds in soil vapor. The maximum total BTEX soil vapor concentration on-site was 32,720 parts per billion on a volume basis (ppbv). The maximum total BTEX concentration off-site was within the Medical Office Building parking lot at 779 ppbv. Naphthalene, the compound most generally associated with MGP sites, was not detected in any of the 15 soil vapor samples.

Results of one ambient outdoor air sample collected at the approximate center of the Site indicated trace levels of BTEX compounds. One indoor air sample within the Medical Office Building, and one outdoor air sample across Wydler Place north of the Medical Office Building, were collected. Of the 61 volatile organic compounds (VOCs) analyzed, 43 were reported as not detected. Chemicals detected ranged from 0.50 ppbv to 10 ppbv. It was noted that the room adjacent to the indoor air sampling point was painted one week prior to sampling, and varnishing occurred in the building one-week prior. Naphthalene was not detected in either sample.

Soil vapor intrusion sampling was performed during the time that the FS/RAP was being developed. Sampling results were presented in separate reports by GEI Consultants (GEI). To date, there have not been any MGP site-related soil vapor intrusion issues identified by GEI.

2.5.3 Groundwater

Shallow groundwater extends from the water table at an approximate depth of 30 ft, to a depth of 48 ft bgs. Monitoring wells screened within this depth interval are designated with the letter “S”. Intermediate groundwater extends from a depth of 48 ft to 95 ft bgs. Monitoring wells screened within this depth interval area designated with the letter “I”. Deep groundwater is encountered below 95 ft bgs but above the top of the Lower Magothy found between 118 and 270 ft bgs. The letter “D” designates monitoring wells screened within this interval.

Shallow Groundwater

The highest concentrations of BTEX and TPAHs in shallow groundwater were detected in the vicinity of former MGP structures. Figure 2-8 shows the location of the plume (from 2003 monitoring data) where concentrations of either BTEX or TPAH exceed 1,000 parts per billion (ppb) in shallow groundwater. Outside this near-site plume area, concentrations drop off quickly to 100 ppb or less indicating that natural processes are effectively reducing contaminant concentrations. Figures 2-9 and 2-13 show the location of the groundwater plume (50-100 ppb range) based on monitoring conducted in 2003 and 2007. Figure 2-10 (April 2007), Figure 2-11 (July/August 2007), and Figure 2-12 (October 2007) show the plume configuration based on three monitoring episodes performed in 2007.

Intermediate Groundwater

Elevated concentrations of BTEX and TPAHs were present at former MGP structures at the western edge of the Site. Figure 2-8 shows the location of the plume where concentrations of either BTEX or TPAH exceed 1,000 ppb in intermediate groundwater. Outside this near-site plume area, concentrations drop off quickly indicating that natural processes are effectively reducing contaminant concentrations. Figures 2-9 and 2-13 show the location of the groundwater plume (50-100 µg/L range) based on monitoring conducted in 2003 and 2007. Figure 2-10 (April 2007), Figure 2-11 (July/August 2007), and Figure 2-12 (October 2007) show the plume configuration based on three monitoring episodes performed in 2007.

Deep Groundwater

Concentrations of BTEX and TPAHs were present in the vicinity of former MGP structures at significantly lower concentrations as compared to shallow and intermediate groundwater.

Dissolved Plume

A plume of dissolved phase BTEX and PAHs exists in groundwater both on-site and downgradient in the shallow and intermediate groundwater zones. Figure 2-13 presents a profile view of the approximately 600-foot wide plume, defined as the 100 ppb concentration, which extends in a southerly direction consistent with the natural flow of groundwater in the Upper Glacial aquifer. The maximum width of the plume was estimated to be approximately 800 ft immediately downgradient of the Site. The overall length of the plume based on 2007 monitoring well data is estimated to be approximately 3,000 ft. The highest levels of contamination are at or near the water table. The elongated plume shape is typical of relatively soluble chemicals, such as BTEX and low-molecular weight PAHs, migrating through moderately to highly transmissive aquifers.

Downgradient migration is being retarded by low permeability layers, naturally occurring organic carbon present in the soil matrix, and dilution and dispersion in the aquifer. During the RI, a comparison of measurements of dissolved oxygen (DO) was made between upgradient areas and within the plume area. The comparison indicated that a significant reduction in dissolved oxygen occurs. The lowest concentrations of DO were present in areas where the highest concentrations of total BTEX and PAHs were detected. This suggests the presence of active aerobic biodegradation of contaminants in the subsurface.

A comparison of groundwater monitoring data between 2003 and 2007 is provided on Figures 2-9 and 2-13. The figures show the plume as an area where the concentration of either total BTEX or total PAHs was greater than 100 ppb. In 2003, the concentration of BTEX in the downgradient-most monitoring well cluster (HIMW-15) was 111 ppb; therefore the plume was interpreted as extending to just past HIMW-15, which is located approximately 3,800 feet from the site. In 2007, concentrations in HIMW-15 were between not detected (ND) and 30 ppb; therefore the plume was interpreted as extending 3,000 feet from the site. Based on this data, it is concluded that the plume is stable and has reached its maximum extent, fluctuating in response to climatic factors such as precipitation and water levels. This observation is supported by considering the velocity of contaminant migration and the time when the source originated. The aquifer materials are very coarse and permeable, indicating high groundwater flow velocities, and the adsorption of contaminants onto the matrix is probably low given the low TOC. Therefore, the velocities of contaminant transport, which are directly proportional to groundwater flow velocities and inversely proportional to adsorption, are probably high. The age of the source is on the order of 100 years. During that time, and under high migration velocities, the theoretical front of the plume would have migrated far beyond the point where the actual front is observed today. This indicates that attenuation processes such as dispersion and degradation have limited the extent of the plume.

Private Well Sampling

Water sample results from two private irrigation wells were reported as less than the laboratory detection limits for the sample parameters VOCs, semi-volatile organic compounds (SVOCs), total cyanide and free cyanide for well N-7734, and for VOCs for well N-7529. Locations are provided on Figure 2-3.

2.5.4 NAPL

Measurable amounts of DNAPL and sheens of LNAPL were observed during monitoring well sampling efforts in 2007 and during the RI in both on-site and off-site monitoring wells. NAPL thicknesses were measured during the RI on December 3, 2001 and during development of the FS/RAP in 2007. Results are presented on Table 2-1. During the RI and FS/RAP, DNAPL was removed from the monitoring wells by hand bailing and/or use of a submersible pump. A DNAPL plume delineation map updated from the *RI* is shown on Figure 2-14 and identifies the migration pathway of NAPL that extends approximately 450 ft downgradient to the south.

2.6 Qualitative Human Exposure Assessment

A Qualitative Human Health Exposure Assessment (EA) was presented in the *RI*. Included in the EA are future use scenarios considering that the Site and/or adjacent areas may be used for commercial purposes including commercial structure construction. Based on the assessment of both current and future scenarios on-site and off-site, the following potential exposure pathways have been identified for soil and air:

- Exposure to surface and subsurface soil;
- Exposure to ambient air;
- Exposure to indoor air; and
- Exposure to soil vapor (for future off-site utility worker only).

The EA did not identify a completed exposure pathway for human receptors to groundwater for the following reasons: (1) groundwater is present at approximately 30 ft below ground surface; (2) results from a private well survey and associated groundwater sampling and analysis support no significant potential for exposure; and (3) the Site is not considered to be within the capture zone of the two nearby public water supply well fields.

2.7 Fish and Wildlife Resources Impact Analysis

A Fish and Wildlife Resources Impact Analysis was included in the *RI*. The analysis concluded that the Site does not pose a risk to fish and wildlife because only transient species and a few individual animals would utilize the industrial/commercial area that provides minimal habitat areas; and the frequency and duration of exposure would be limited.

No federally- or state-listed species were identified as occurring on the Site. Due to the distance and the fate and transport mechanisms involved, no significant effects on downgradient wetlands were expected.

2.8 Conceptual Site Model

The following Conceptual Site Model (CSM) is based on Section 6.0 of the *RI*.

The CSM describes the relationship between former MGP operations and the observations of physical impacts (i.e., NAPL, staining, sheen and odors), detected chemical constituents, migration pathways, and potential exposure pathways as identified in the *RI*. The observed MGP-related NAPL and site hydrogeologic conditions support a CSM summarized as follows:

1. NAPL associated with the former MGP Site accumulated in the shallow Site soils around the identified source areas until their sorbtive capacity was exceeded and the NAPL migrated vertically downward. The heaviest NAPL, which has a tar consistency, did not tend to migrate out of the shallow soils. NAPL and NAPL residual remain at or near saturated conditions in the shallow soil beneath the former source areas.

2. The vertical migration of NAPL from the near-surface source area soils appears to have occurred via isolated and relatively thin pathways. These vertical pathways can be envisioned as vertical columns extending down from the mass of material accumulated in the near-surface source area soils. This is based on encountering significantly fewer instances of NAPL saturation in the deeper soils from 8 to 24 ft bgs. In contrast to the shallow source area soils, the soils in the 8 to 24-foot zone exhibited isolated occurrences of near-saturated residual NAPL. This is because the vertical migration pathways are likely narrow and isolated, and as a result of this the borings did not frequently intercept these vertical pathways.

3. The vertical migration of the NAPL was impeded when it encountered the soils at and just above the water table and NAPL has accumulated to saturated and near-saturated levels. Based on the observed conditions, the majority of the NAPL-saturated soils occur just below 24 ft bgs and extend down to the water table encountered an average of 30 ft bgs. Although beneath the former source areas some NAPL penetration into the saturated zone has occurred, NAPL has preferentially migrated horizontally along the slope of the water table extending approximately 450 ft beyond the southern Site boundary. The NAPL saturation extending south of the Site occurs as a thin (0 to 6-inch thick) layer at the water table interface. The NAPL in this zone exists in saturated or near-saturated conditions as indicated by the fact that, although very viscous, it flows into wells screened in this area. While the NAPL is a DNAPL, it has preferred to migrate horizontally along the water table as evidenced by only isolated observations of NAPL penetration deeper into the water table primarily beneath the source area.

4. The thickness of the NAPL-saturated soils decreases significantly away from the source areas. In particular, the thickness of NAPL-saturated soils off-site in the central potion of the

Medical Office Building parking lot is less than 1 foot as compared to multiple-foot thickness near the southern property line.

5. The saturated and near-saturated NAPL soils in the shallow source areas and at or just above the water table are sources of dissolved phase chemical constituents (BTEX and PAHs). This has resulted in the plume of dissolved phase constituents, in the shallow zone, that extends approximately 3,800 ft [2003 data] from the Site in a southwestern direction.

6. The plume of dissolved phase contamination undergoes natural attenuation by means of one or more physical processes (dispersion, dilution, and/or adsorption) and biological processes (microbial degradation).

2.9 Potentially Applicable Standards, Criteria, and Guidance

Standards, Criteria and Guidance (SCGs) are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, or location. Guidance values include non-promulgated criteria and guidelines that are not legal requirements but should be considered if determined to be applicable to the Site. SCGs are categorized as chemical-specific, location-specific, or action-specific. SCGs developed for the Site, and which are considered potentially applicable, are presented on Table 2-2.

3.0 REMEDIAL GOAL AND REMEDIAL ACTION OBJECTIVES

3.1 Remedial Goal

The NYSDEC's *Draft DER-10 Technical Guidance for Site Investigation and Remediation* identifies the following generalized remedial goals for site remediation:

- At a minimum the remedy will eliminate or mitigate all significant threats to public health and the environment presented by the contaminants disposed at the Site.
- Where an identifiable source of contamination exists at a site, it should be removed or eliminated, to the extent feasible, regardless of presumed risk or intended use of the site.

The current use of the Hempstead Intersection Street Site and adjacent impacted areas are commercial, industrial, and/or residential. These land use types are defined in Part 375 (3.0) as:

- "Commercial use" which is a land use for the primary purpose of buying, selling or trading of merchandise or services. Commercial use includes passive recreational uses, which are public uses with limited potential for soil contact; and
- "Industrial use" which is a land use for the primary purpose of manufacturing, production, fabrication or assembly process and ancillary services. Industrial uses do not include any recreational component.
- "Residential use" which is a land use category that allows a site to be used for any use other than raising livestock or producing animal products for human consumption. Restrictions on the use of groundwater are allowed, but no other institutional or engineering control would be allowed. This is the land use category that will be considered for single family housing.
- Restricted-residential use" which is a land use category that shall only be considered when there is common ownership or a single owner/managing entity of the site. Restricted residential use
    - Shall, at a minimum, include restrictions which prohibit:

      (1) Any vegetable gardens on a site, although community vegetable gardens may be considered with Department approval; and

(2) Single family housing; and

- Includes active recreational uses, which are public uses with a reasonable potential for soil contact;

Further, land use may be unrestricted or restricted as defined in Part 375 (3.0):

- "Unrestricted use" which is a use without imposed restrictions, such as environmental easements or other land use controls; and
- "Restricted use" which is a use with imposed restrictions, such as environmental easements, which as part of the remedy selected for the site require a site management plan that relies on institutional controls or engineering controls to manage exposure to contamination remaining at a site.

In consideration of the existing use of the Site and the presence of MGP-related contaminants, the Site Remedial Goal is:

> To remove or mitigate, to the extent practicable, the source of contamination, and eliminate or mitigate any significant threats to public health and the environment presented by site-related contaminants in accordance with Part 375 site cleanup objectives.

3.2 Remedial Action Objectives

In order to meet the remedial goal for the Site, RAOs were developed to protect public health and the environment and provide the basis for selecting appropriate technologies and developing remedial alternatives. RAOs were developed on the basis of contaminated media identified at the Site, SCGs identified as potentially applicable, and results of the qualitative human health exposure assessment and fish and wildlife resources impact analysis. The RAOs for the Site are as follows:

Soil

- Eliminate or reduce to the extent practicable NAPL and MGP-related contamination sources that contribute to soil, air, soil vapor and groundwater contamination.

- Prevent, to the extent practicable, human exposure to MGP-related chemicals present in surface and subsurface soil at and around the Site at levels exceeding SCGs.

Air and Soil Vapor

- Prevent, to the extent practicable, potential inhalation of MGP-related chemicals exceeding SCGs in ambient and indoor air on and near the Site.
- Prevent, to the extent practicable, utility worker exposure to soil vapor off-site.

Groundwater/NAPL

- Reduce or mitigate NAPL, to the extent practicable, to decrease the source of chemicals that contribute to soil, air, soil vapor and groundwater contamination.
- Prevent or mitigate, to the extent practicable, off-site migration of groundwater contamination resulting from Site-related contaminants.
- To restore, to the extent practicable, groundwater impacted by Site related MGP contaminants of concern to meet ambient water quality standards and guidance values.

3.3 Remediation Areas and Volumes

3.3.1 Soil

Based on information in the *RI,* areas defined by the field observations of NAPL-saturated soils, containing MGP remnant structures, and exhibiting the highest concentrations of TPAHs and BTEX were presented on Figure 2-4 for the 0-8-foot depth, Figure 2-5 for the 8-16-foot depth, Figure 2-6 for the 16-24-foot depth, and Figure 2-7 for the 24-34-foot depth. These individual depth layers are combined on Figure 3-1 and are considered soil source material, presenting the greatest potential for risk via direct contact with the soils, release of volatile organic vapors and the potential for continuing release of NAPL and dissolved phase constituents to groundwater. The areas and volumes of soil source material based on RI data by depth interval are summarized on Figure 3-1**.** The extent of soil source material illustrated on Figure 3-1 is primarily confined to the Site and Medical Office Building parking lot, consistent with site hydrogeological characteristics. Minor fringe areas of source material have been identified west of the Site adjacent to the recharge basin, east of the Site on the LIRR ROW, and west, and south of the

Medical Office Building parking lot. Collectively, these fringe areas represent less than 3% of the overall source material identified at the Site and off-site areas. These fringe areas will require additional lateral delineation prior to implementation of a Site-wide remedy.

An estimated 18,250 cy (25%) of the source material is at the shallow depth of 0 to 8 ft and an estimated 48,200 cy (68%) is found straddling the water table in a smear zone between 24 to 34 ft bgs with approximately 4,550 cy (7%) between 8 and 24 ft. Additional limited areas of contamination are identified in the RI below a depth of 34 ft; however, they represent a relatively minor volume of source material, were encountered intermittently, and were found to be discontinuous both vertically and horizontally. The identification of technologies and development and evaluation of remedial alternatives for the Site presented in the remaining sections of the FS/RAP address the primary source material areas which occur in the 0 to 34-foot bgs zone. The feasibility for remediation to depths greater than 34 ft will be discussed for each remedial alternative in Section 5.

It should be noted that contaminated soil identified in the area of the Oswego Oil tanks is not considered to be source material for the purposes of Site remediation. RI data show that contaminated groundwater and soil in the area of the Oswego Oil may be a separate source area attributable to operations at the Oswego Oil petroleum facility. The facility has documented #2 Fuel Oil spills as referenced in the RI. Total petroleum hydrocarbon (TPH) fingerprint analysis performed during the RI from two samples adjacent to, and downgradient from, the Oswego Oil property, as well as one LNAPL sample obtained during the FS/RAP from MW-11S, showed that the contamination is characteristic of diesel fuel and is not MGP-related.

Additional monitoring wells will be installed and data collected as part of delineation in this area. This delineation and evaluation is ongoing, and results will be presented separately following an assessment of the additional data to be collected.

3.3.2 Groundwater

The highest levels of groundwater contamination are at or near the water table at a depth of approximately 30 ft in the Upper Glacial aquifer, near the southern boundary of the Site. This area is delineated by the 1,000 ppb concentration contours for BTEX and TPAHs in shallow and intermediate groundwater as shown on Figure 2-8. Outside this plume area, concentrations drop off quickly indicating that natural processes such as retardation by low permeability layers, naturally occurring organic carbon present in the soil matrix, dilution and dispersion in the aquifer, and naturally-occurring aerobic biodegradation are effectively reducing contaminant concentrations. Source area groundwater remediation would be performed in the shallow and intermediate groundwater zones that contain the highest levels of contamination, which are shown on Figure 2-8.

Groundwater modeling for the Site was performed to estimate extraction rates within the plumes. Results are presented in Appendix A and summarized as follows. It is estimated that approximately 110 to 160 gpm of groundwater would have to be extracted to contain the shallow groundwater source plume. The corresponding extraction rate for intermediate groundwater source plume is 50 to 320 gpm. If a vertical barrier keyed into the low-permeability lower Magothy surrounded the soil source material area, the extraction rate needed for containment would be approximately 5 to 10 gpm. However, this assumes high-quality barrier construction to the depth of approximately 130 feet.

3.3.3 NAPL

Section 2.5.4 presented a discussion of the location and thickness of NAPL detected in monitoring wells. Figure 2-14 illustrates that the DNAPL plume has migrated off-site to the southern tip of the Medical Office Building parking lot. Efforts to collect NAPL should be concentrated within this plume area.

The primary DNAPL plume is located in the shallow aquifer that is represented by "S" zone monitoring wells. However, two intermediate wells (MW-01I and MW-16I) also exhibited DNAPL. The observation of DNAPL in MW-16I is unexpected due to the observation of no DNAPL impacts in MW-06I in the intermediate zone just upgradient, and the absence of NAPL impacts in the 25 to 60-ft bgs zone in the soil boring adjacent to MW-16I.

In April 2007 NAPL was collected from monitoring wells where product had been previously measured and analyzed for viscosity, water content, and specific gravity. A fingerprint analysis was performed on LNAPL from MW-11S. Results are presented in Appendix B and summarized on Table 3-1. At the ambient groundwater temperature of 55 degrees Fahrenheit, the specific gravity of DNAPL ranges from 1.05 to 1.09 and viscosity ranges from 65 to 844 centistokes. There appears to be a general correlation between specific gravity and viscosity that may reflect varying degrees of DNAPL weathering. In general, NAPL viscosities above 100 centistokes can present difficulties in recovering the DNAPL, which is also dependent on the permeability of the soil and the interfacial surface tensions of the soil matrix. As indicated on Table 2-1, it does not appear that full recovery of the product thickness occurs over a one month period in many of the wells, so product recovery may be slow. This could be due to viscosity limitations posed by well materials (i.e., sandpack and well screen slot size), or a combination of factors. The data in Table 3-1 also indicate that a temperature increase can reduce the DNAPL viscosity and possibly enhance recovery. This factor will be considered in evaluating remedial technologies where heat is applied or generated as a direct or indirect result of treatment application. Table 3-1 also presents the results of water and sediment content analysis of NAPL samples. Overall, the samples had a low water and sediment content, indicating that NAPL flowing into the wells is not mixed with substantial amounts of water and that NAPL collection methods are not resulting in emulsification of water and product. Minimizing the collection of water with product is beneficial to minimize excess disposal volumes.

3.4 Proposed IRM

A Remedial Action Work Plan for an IRM was prepared in November 2007 for IRM implementation in 2008. IRM activities include excavation of approximately 10,500 cy (measured in place as delineated based on interpretation of the 2006 RI data) of soil source material in the north-central portion of the Site within the areas shown on Figure 3-2. Excavation will generally be to a depth of 8 ft with the possible addition of areas where source soils extend to a depth of 24 ft. A combination of excavation support (sheet piling and open cut method), and odor control structures (sprung structures) are proposed. Excavated soil will be transported off-site to a thermal desorption facility for treatment/disposal. Excavated areas will be backfilled with clean soil. These IRM areas may then be used for construction support and lay down areas during site-wide remediation implementation.

Proposed IRM activities also include NAPL recovery in approximately 24 product recovery wells to be installed as part of the IRM within the DNAPL plume that is present at the water table. Locations are shown on Figure 3-2. NAPL will be collected during regular visits to the recovery wells. The frequency of NAPL recovery will be adjusted as necessary based on the observed recharge rates in individual wells. NAPL will also be collected from existing monitoring wells by hand bailing or submersible pump methods on the same regular basis. Collected NAPL will be properly disposed off-site.

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

Remedial technology identification and screening described in this section consists of: identifying general response actions to satisfy the remedial action objectives (RAOs); identifying site-specific remedial technologies that fall within the general response categories; and screening those technologies with respect to their effectiveness in meeting the objectives for the site, technical implementability and relative cost. Technologies identified for this MGP Site have been selected from the host of technologies considered potentially effective for use at MGP sites in general, and include primarily those technologies that have been previously implemented successfully at MGP sites. The most promising technologies are retained and carried forward into the development of alternatives for the Site as a whole.

4.1 General Response Actions

General response actions are broad categories of remediation capable of satisfying the RAOs for the Site. Some response actions may be sufficiently broad to be able to satisfy all RAOs for the media of soil, groundwater, air, and NAPL at the Site. Other response actions must be combined to satisfy RAOs for all media. Remedial technologies are evaluated according to the general response actions of no action, exposure point mitigation, containment, groundwater collection, NAPL recovery, groundwater treatment, NAPL disposal, excavation, and in situ treatment. Table 4-1 provides a summary of the technology identification and screening process. General Response Actions for the Site are as follows:

- **No Action -** The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requires that a no action alternative be evaluated as part of the Feasibility Study process. This alternative will be used as the baseline for comparison with other alternatives.
- **Exposure Point Mitigation** – Remedial measures may be implemented at the point of exposure to mitigate exposure to contaminated material and provide adequate protection to human health and the environment.
- **Containment** – Containment measures are those remedial actions whose purpose is to contain and/or isolate contaminants. These measures provide protection to human health and the environment by reducing exposure or migration of contaminants.

- **Groundwater Collection and NAPL Recovery -** Groundwater collection and NAPL recovery technologies provide protection to human health and the environment by removing contamination from groundwater limiting the migration of contaminants and NAPL.
- **Groundwater Treatment -** Collected groundwater could be treated on-site prior to discharge, or disposed of off-site at a permitted facility.
- **NAPL Disposal -** Recovered NAPL would be transported off-site for treatment at a permitted facility.
- **Excavation -** Excavation of contaminated soil is a remedial action whose purpose is to remove contaminants from the Site. Combined with off-site treatment through thermal desorption, excavation provides protection to human health and the environment.
- **In Situ Treatment –** Treatment measures include technologies whose purpose is to reduce the toxicity, mobility, or volume of contaminants by directly altering, isolating, or destroying those contaminants. Soils that are not excavated may be treated in place (in situ). Soil treatment technologies could potentially utilize biological, chemical, stabilization/solidification (physical), or thermal processes to alter, isolate, or destroy contaminants.

4.2 Identification and Screening of Remedial Technologies for Air and Soil Vapor

4.2.1 Exposure Point Mitigation

Exposure point mitigation is used to mitigate exposure to contaminated media and provide protection to human health at individual receptors. This includes installation and operation of sub-slab depressurization systems located at selected occupied buildings as part of the vapor intrusion mitigation program. The systems collect soil gasses from beneath the buildings and vent them to the atmosphere. By maintaining a slight vacuum below the basement slab, contaminant vapors are prevented from migrating through cracks and other openings in the basement slab and infiltrating into the indoor air.

A soil vapor intrusion sampling program will be used to monitor soil gas levels at adjacent buildings and assess the need for any mitigation system installations.

Effectiveness: Monitoring and installation of sub-slab depressurization systems are effective in reducing and controlling exposure to vapor-phase contaminants within the adjacent buildings (receptors).

Implementability: Monitoring and sub-slab depressurization systems are readily implementable at individual buildings impacted by soil gas.

Cost: The cost of monitoring and individual units is relatively low.

Conclusion: Monitoring and vapor intrusion mitigation units will be retained for use for air and soil vapor.

4.3 Identification and Screening of Remedial Technologies for Groundwater

4.3.1 Monitored Natural Attenuation

Monitored natural attenuation (MNA) is a technology that combines natural processes to achieve remedial action objectives with a comprehensive monitoring program. According to USEPA guidance (USEPA, 1999), the most important considerations regarding the suitability of MNA as a remedy include: whether the contaminants are likely to be effectively addressed by natural attenuation processes; the stability of the groundwater contaminant plume and its potential for migration; and the potential for unacceptable risks to human health or environmental resources by the contamination.

Based on Site data, the natural attenuation processes that are occurring include physical processes such as hydrodynamic dispersion and dilution by infiltration, and microbial degradation, which transforms the contaminants into typically less toxic daughter products and, ultimately, to carbon dioxide and water.

Given sufficient time, a plume undergoing natural attenuation will stabilize after reaching a size where all of the mass delivered by the source is either diluted to very low concentrations or destroyed. The plume at the Site is stable and appears to have reached its maximum extent, fluctuating in response to climatic factors such as precipitation and water levels as discussed in Section 2.5.3. If the source is removed or isolated from the aquifer through remediation, natural attenuation will likely cause the remaining plume to collapse with time, as the contaminant mass residing within the plume is diluted and destroyed, assuming no new mass is introduced. If the source of contamination remains in place, natural attenuation can limit migration.

MNA consists of periodic sampling of existing monitoring wells, and analysis for both contaminants of concern (total BTEX and total PAHs) and indicator parameters, such as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, and pH.

Effectiveness: MNA may result in the stabilization of the plume at the current size, or, if combined with source control measures, in the eventual collapse of the plume.

Implementability: Sampling and analysis for contaminants of concern and indicator parameters is easy to implement.

Cost: The annual cost for the sampling, analysis, and reporting would be relatively low. However, considering the time scales required to make an assessment of the effectiveness of this measure (possibly on the order of a decade or more), the present worth cost would be moderate.

Conclusion: MNA is considered to be feasible at this Site.

4.3.2 Groundwater Containment

Containment methods are used to prevent or reduce the migration of contaminants and prevent exposure. Containment methods include capping, vertical barriers, and active hydraulic controls including collection. Vertical barriers are structures that include sheet pile walls, bentonite and soil cement walls, and grout injection. The vertical barrier would have to be keyed into a low permeability zone. The lower subunit of the Magothy formation, which may be considered as a low permeability unit, is located at a depth of approximately 130 ft.

Effectiveness: Construction of an asphalt or low permeability cap may reduce infiltration to the subsurface; however, the majority of groundwater recharge is from upgradient areas. Vertical barriers may be effective for groundwater containment if properly installed. These technologies have been utilized at numerous remediation projects.

Implementability: An asphalt or low permeability cap over areas of contaminated soil would not be difficult to construct; however, it would limit the future use of the Site. Given the depth to an impermeable unit and the areal extent of the plume through areas containing subsurface utilities, vertical barriers would be difficult to construct within the impacted area.

Cost: The cost of an asphalt cap would be low; a low permeability cap would be moderate. Due to the anticipated depth and areal extent required, the relative cost of vertical barriers is expected to be high.

Conclusion: An asphalt cap and vertical barriers are retained for consideration at this Site.

Funnel and gate and containment and gate technologies are a variation of containment and involve construction of a vertical barrier extending through the entire depth of the aquifer and around the sidegradient and downgradient sections of Site perimeter (funnel), or surrounding the Site (containment). The vertical barrier is keyed into low permeability deposits at the bottom of the aquifer. An opening in the vertical barrier is constructed at the most downgradient point, where a subsurface treatment facility is installed (gate). Groundwater flowing across the Site is directed by the vertical barrier into the treatment area. Contaminants are removed in situ, and treated water flows downgradient. Vertical cutoff can be provided by a steel sheet pile wall, bentonite or soil cement walls, or grout injection.

Effectiveness: The effectiveness of the system depends on the hydrogeology of the Site and surrounding area, and the ability of the in situ treatment facility to treat contaminants.

The funnel and/or containment constrict the flow of groundwater into an area that is narrower than the flow area occurring under undisturbed conditions. As a result, the amount of flow that can pass through the Site decreases. The system compensates in two ways. Part of the ‘clean’ flow entering the funnel at the upstream side is redirected backwards and sidegradient, and moves out of the funnel and around the Site. In addition, the hydraulic head inside the funnel increases, and part of the flow may be redirected over or underneath the vertical barrier to off-site areas. Containment of the area would limit the amount of inflow and hydraulic head buildup within the area. The elements influencing the final flow pattern are the size, shape and leakage through the barriers, hydraulic conductivity and hydraulic gradient in the aquifer, vertical gradient and the vertical conductance of the low permeability layer, recharge, and the ability of the in situ treatment facility to conduct water. It is not clear whether the low-permeability layer is continuous and that a desirable flow pattern could be established at the Site with a funnel as opposed to a containment system.

A permeable reactive barrier (PRB) could be used as a vertical barrier installed downgradient of the funnel, comprising the gate. As contaminated groundwater flows through the PRB, contaminants react with the materials inside the gate and are either broken down into non-toxic products or immobilized by precipitation or sorption. The advantage of this in situ technology is that it requires no pumping. Biological walls may be considered; however, the most common type of permeable barrier wall for application at MGP sites utilizes activated carbon adsorption. A PRB utilizing activated carbon is not considered to be effective on the relatively high levels of BTEX and PAHs present.

A gate utilizing ozone injection may be effective on the contaminants at the Site. Since contaminants would have to flow toward the gate with groundwater, the contact area between the ozone and contaminants would be relatively small and require a long time for remediation. Remediation would not be effective in the unsaturated zone within the fence. Off-gasses would have to be collected from the surface of the gate area.

Implementability: The barrier would have to be keyed into a low permeability zone. The lower subunit of the Magothy formation, which may be considered as a low permeability unit, is located at a depth of approximately 130 ft. Also, because of the nature of the flow pattern that typically develops around the funnel, the vertical barrier would have to extend a significant distance upgradient of the containment area, and the entrance to the funnel would have to be much wider than the dimensions of the Site. Therefore, the barrier would have to be extended beyond the Site. Construction of substantial lengths of a vertical barrier across underground utilities and through residential and commercial/industrial areas would be difficult and vibration and noise considerations could be significant.

Since the remediation area is triangularly shaped, there is limited area along the downgradient edge of the fence for the gate. If ozone were used, off-gasses would have to be collected over a long time period at the downgradient end.

Cost: Given the anticipated depth and the areal extent required, the relative cost of a funnel and gate or containment and gate system is expected to be high.

Conclusion: A containment and gate system using ozone injection is retained.

4.3.3 Groundwater Collection

Active hydraulic control methods include groundwater collection trenches and vertical extraction wells that are used for groundwater collection.

Effectiveness: The glacial outwash deposits present at the Site are already relatively permeable. Construction of collection trench within these deposits would provide limited additional effectiveness in collecting groundwater.

Implementability: Due to the anticipated depth and length required, this technology would be more difficult to implement than extraction wells.

Cost: The relative cost of a groundwater collection trench is expected to be moderate.

Conclusion: A groundwater collection trench will not be retained for use at this Site.

Groundwater could be extracted within the plume through a series of extraction wells individually located to any depth around existing structures.

Effectiveness: Extraction wells could be located to control the migration of contaminants in groundwater and extract groundwater for treatment. They have been utilized at numerous remediation projects. When combined with appropriate treatment, groundwater extraction would be effective at the Site.

Implementability: Installation of extraction wells in appropriate locations and to appropriate depths would be implementable.

Cost: The relative cost of extraction wells is low to moderate depending on the number required and flow rates.

Conclusion: Extraction wells are considered feasible for use at the Site.

4.3.4 Groundwater Treatment

Treatment technologies may be used to reduce the toxicity of contaminants present in groundwater in situ (e.g., bioremediation), or once extracted (e.g., above-ground treatment facility). Treatment technologies pertaining to extracted groundwater include pumping to either an above-ground treatment facility constructed specifically for use at this Site, or transporting to an existing facility willing and capable of accepting contaminated water. Regardless, groundwater treatment is expected to consist of volatiles removal, semi-volatiles (PAH) removal, and potentially metals removal, as there is currently insufficient data available to discount the need for metals removal.

Groundwater Bioremediation

Bioremediation is the general practice of supporting contaminant degradation by native (i.e., naturally existing) or introduced microorganisms (i.e., bioaugmentation). Certain types of contaminants can be consumed or co-metabolized through biodegradation and are ultimately transformed into innocuous compounds as part of the metabolic processes of the established microbial community. Biodegradation is often the result of a microbial consortium (i.e., the actions of multiple organisms) rather than one isolated species (Vidali, 2001).

Bioremediation may require the addition of a rate-limiting substrate (such as oxygen for aerobic processes); biostimulation, which is the addition of amendments and/or nutrients to create an environment that will support microbial growth; or bioaugmentation, which is the introduction of microbes to degrade target contaminants or strengthen an existing microbial community. Thus far, bioremediation has been successfully applied within dissolved phase groundwater plumes for contaminant treatment including for those contaminants present at the Site. Recent research has been performed on the potential for source area biodegradation; however, this would be fairly innovative considering the mass of NAPL-phase contaminants present at this Site. Bioremediation has been retained for the dissolved phase groundwater plume in combination with source area remediation.

In general, bioremediation can include aerobic (i.e., oxygen present) or anaerobic (i.e., in the absence of oxygen) biodegradation processes. BTEX and PAH compounds present in the groundwater plume are degraded by both processes, although aerobic biodegradation occurs at a much faster rate. Therefore, only technologies that promote aerobic conditions will be considered.

Aerobic bioremediation could include the introduction of gaseous oxygen or air or an oxygen releasing amendment introduced as a solid or slurry (e.g., Oxygen Release Compound [ORC®] or EHC-OTM) via injection wells, in well inserts (i.e., socks) or in open boreholes. Aerobic bioremediation is generally compatible with other remedial alternatives such as chemical oxidation. Chemical fixation or stabilization methods located upgradient of an aerobic bioremediation system might necessitate aquifer-buffering amendments to maintain neutral aquifer conditions. Additional microbial cultures can be introduced to the subsurface if determined necessary based upon evaluation of the naturally occurring microbial community.

As discussed in Section 2.5.3, it appears that aerobic biodegradation is currently ongoing in the dissolved phase groundwater plume. Bench-scale testing may be required to fully evaluate the extent of ongoing bioremediation and if any amendments would be required for efficient contaminant degradation. Additionally, depending upon the alternative selected, a subsequent evaluation of potential impacts may be required.

As with other in situ applications, subsurface distribution is a key component in the potential success of bioremediation. In general, microbial communities do not necessarily move with groundwater and are fixed to the soil matrix. Additionally, once a hospitable aquifer is established, microbes may 'bloom' or grow randomly in all directions, which can increase subsurface distribution where surface access is limited or unavailable (i.e., below buildings, utilities, etc.).

Effectiveness: Enhanced aerobic biodegradation has been proven to be effective on BTEX and PAHs. The technology would not likely be applied to treat source area soils due to the volume of soil source material, the presence of NAPL, and the high concentrations of contaminants present. The technology would be more effective in the dissolved phase plume. Enhanced aerobic bioremediation has the potential to reduce contaminant mass within the dissolved phase groundwater plume within a shorter time frame than MNA alone.

Implementability: Field and laboratory testing can be used to evaluate aquifer conditions and determine if amendments and/or additional microbial cultures are needed.

The need for and level of field and laboratory testing is somewhat dependent on the selected technology and the performance criteria established (e.g., numeric standards versus contaminant concentration reduction). Subsurface distribution is required for contaminant treatment. Surface access is required for delivery of materials to enhance biodegradation. Installation of delivery wells and introduction of amendments, if required, should not be difficult given Site lithology. However, injection wells located downgradient and off-site would have to be installed such that minimal disruptions would occur in residential neighborhoods.

Cost: The cost is considered to be low to moderate depending on the operation period and any licensing or patent fees associated with biostimulation and/or bioaugmentation (if required) that would increase the cost of materials.

Conclusion: This technology is retained for consideration within the dissolved phase plume, with potential applicability to some of the off-site source areas.

Groundwater Treatment System

An above-ground Site-specific groundwater treatment system could be designed to accommodate the levels of contaminants and flow rates anticipated from groundwater extracted at the Site. As shown on Figure 4-1, the treatment facility is anticipated to minimally include:

- An oil/water separator for the collection of any free product, and the settling of suspended solids.
- An air stripper for the removal of volatile organic contaminants.
- An aqueous phase carbon adsorption system and/or organophylic clay for the removal of the semi-volatile (PAH) contaminants.
- A chemical feed system(s) to prevent iron fouling and scaling of the air stripper and/or adjustment of the water pH as required for metals precipitation.
- A filtration system (e.g., bag filters) for the removal of solids and metals that are precipitated by the air stripper.
- An air treatment system for the removal of contaminants in the air stream off the air stripper. The air treatment would consist of either vapor phase carbon adsorption, or

thermal treatment such as catalytic oxidizer and include an approximately 10-12-foot stack.

- Various storage tanks, pumps, and other appurtenances as required for the efficient operation of the other treatment units.
- Conveyance of treated water through a force main to the local sewer system.

Effectiveness: A properly designed treatment system could effectively treat collected groundwater. Treatment would have to meet the appropriate levels for subsequent discharge to the local water treatment facility. The air stripper would have to meet air emissions limitations.

Implementability: A treatment system would require a secure location, preferably on the property, and considering the location of the nearest sewer line. Preliminary discussions between KeySpan and the local water treatment facility indicate that the facility is capable of, and may accept treated water. The proximity to residences and other buildings may require that the air discharge be through a stack that may visually impact the residents.

Cost: Relative costs are assumed to be moderate to high considering the quantity of groundwater expected, the fact that treatment of water and air will have to meet appropriate standards, and the unknowns associated with the need for additional components. If metals removal is required, the treatment cost would increase.

Conclusion: An on-site above-ground treatment facility designed and constructed for treatment of extracted groundwater with discharge to the local water treatment facility will be retained.

Extracted groundwater could be conveyed by direct discharge line or tanker to an appropriate water treatment facility capable and willing to accept the levels of contamination and volume of water without pretreatment.

Effectiveness: An appropriate existing off-site treatment system could effectively treat collected groundwater.

Implementability: Given the high flow rate and levels of contamination, it most likely would be difficult to identify a treatment facility capable of full treatment and willing to accept untreated collected water. Unless the facility was in the immediate vicinity of the Site, transporting such large quantities either via a direct connection or tanker trucks would not be feasible.

Cost: The relative costs are assumed to be high considering the quantity of groundwater and levels of contamination expected.

Conclusion: Off-site treatment of extracted groundwater will not be retained since implementation would be difficult and the relative cost is anticipated to be high.

4.4 Identification and Screening of Remedial Technologies for NAPL

Technologies that would meet the RAO of removing NAPL from the subsurface and considered implementable at this Site are the use of existing groundwater monitoring wells and passive NAPL recovery using hand bailing, and/or installing new recovery wells to intercept the NAPL plume using active NAPL recovery pumps.

NAPL was collected during the RI from the existing (2-inch diameter) monitoring wells by hand bailing. NAPL recovery performed in 2007 from existing monitoring wells has used a combination of hand-bailing and portable submersible pumps.

Effectiveness: Product has been recovered from groundwater monitoring wells at the Site through hand bailing and portable submersible pumps. Continued recovery efforts would be effective in removing small quantities of NAPL from the subsurface.

Implementability: Monitoring wells are already constructed and hand bailing/pumping efforts have been shown to be feasible.

Cost: The cost of hand bailing/pumping (passive recovery) is low.

Conclusion: Passive recovery in existing monitoring wells will be retained.

Installation of new large diameter product recovery wells may be more effective at increasing the amount of NAPL removed from the groundwater system.

Effectiveness: Additional large diameter NAPL recovery wells may be more effective at increasing the amount of NAPL removed from the subsurface. Effectiveness is dependent on the lithology and NAPL characteristics. Approximately 24 additional NAPL recovery wells are proposed as part of the IRM. Site-specific effectiveness will be determined following installation.

Implementability: Construction and maintenance of NAPL recovery wells (with options for pumps) would not be difficult.

Cost: The capital cost of active NAPL recovery would be greater than passive recovery, but a comparison of long-term operation and maintenance costs between active and passive recovery systems would be dependent on the assumed timeframes.

Conclusion: This technology will be retained and its effectiveness will be further assessed during IRM implementation.

Once collected through either passive or active recovery, NAPL would be transported off-site for disposal. This technology is retained.

4.5 Identification and Screening of Remedial Technologies for Soil

4.5.1 Containment

Containment methods to prevent or reduce the migration of contaminants and prevent exposure to contaminated soil are similar to containment methods for groundwater. Containment methods include capping and vertical barriers. Vertical barriers are structures that include sheet pile walls, bentonite or soil cement walls, and grout injection. The barrier would have to be keyed into a low permeability zone. The lower subunit of the Magothy formation, which may be considered as a low permeability unit, is located at depths of approximately 130 ft.

Effectiveness: Construction of an asphalt or low permeability cap would eliminate direct contact and reduce infiltration to the subsurface; however, the majority of groundwater recharge is from upgradient areas. Vertical barriers may be effective for containment if properly installed. These technologies have been utilized at numerous remediation projects.

Implementability: An asphalt or low permeability cap over areas of contaminated soil would not be difficult to construct; however, it would limit the future use of the Site. Given the depth to an impermeable unit and the areal extent of the plume through areas containing subsurface utilities, vertical barriers would be difficult to construct within the impacted area and there would be vibration and noise considerations. Sheet piling and grout injection would be the most implementable through the glacial outwash materials.

Cost: The cost of an asphalt cap would be low; a low permeability cap would be moderate. Due to the anticipated depth and areal extent required, the relative cost of vertical barriers is expected to be high.

Conclusion: Low permeability caps and vertical barriers are retained for consideration at this Site.

4.5.2 Excavation

Excavating contaminated soil is a proven and reliable technology for contaminant removal. Excavation would require the use of a temporary enclosure (i.e., sprung structure) to minimize impacts to the surrounding community during remediation.

Effectiveness: Excavation of contaminated soil, and NAPL where encountered, and off-site treatment at a thermal desorption facility, would be effective in removing the source of contamination and meeting the remedial action objectives for soil and on-site NAPL.

Implementability: This technology is widely used for remediation and would be implementable at the Site. Slope stability measures would have to be undertaken to excavate at depth, and dewatering would be required for saturated soils. Excavation in areas with subsurface utilities would be difficult.

Cost: The cost of excavating contaminated soil to an appropriate depth, including depths below the water table, using proper health and safety measures, and treating the soil off-site is considered to be relatively high.

Conclusion: Excavation and off-site treatment of contaminated soil and on-site NAPL could be an effective and implementable technology. Excavation will be retained.

4.5.3 <u>In Situ Chemical Treatment</u>

Treatment using in situ chemical oxidation (ISCO) involves the delivery of a chemical oxidant to contaminated media to enhance product recovery and destroy target contaminants and convert them to non-toxic compounds. In some case studies at MGP sites, ISCO application has also been shown to enhance NAPL recovery efforts, either through reducing surface tensions, lowering NAPL viscosity, or by partially oxidizing the NAPL, or other physical/chemical mechanisms. The rate and extent to which organics can be degraded using chemical oxidation are dictated by the properties of the contaminants and their susceptibility to oxidation. In addition, soil and groundwater conditions (e.g., pH, temperature) and the concentration of other oxidant-consuming substances, such as natural organic matter and reduced minerals, affect the transport, distribution, and reactions for the oxidant and target contaminants. Any chemical fixation or stabilization methods located upgradient of an ISCO system might necessitate aquifer amendments. Chemical oxidation reactions occur only with dissolved phase contaminant materials and require contact between the oxidant and the contaminant. Therefore, ISCO is heavily dependent upon subsurface distribution and contact with target contaminant mass. For this Site, delivery wells, as conceptualized on Figure 4-2, would be spaced on approximately 30-foot centers and consist of nested five- to ten-foot vertical screens, covering the vadose or saturated zones. For the unsaturated zone, an infiltration gallery could be used.

For chemical oxidants, bench-scale and/or field-scale pilot testing would be recommended. Bench-scale pilot testing may include an analysis of the soil buffering capacity and/or the potential for metals leaching. During the application of ISCO materials, secondary effects to the aquifer such as a change in the oxidation-reduction potential or pH can contribute to a localized mobilization of metals. Typically, due to the natural soil buffering capacity (e.g., ability of the aquifer to re-establish neutral conditions), these effects are transitory and very localized within the target treatment area. As influent groundwater enters, or treated groundwater leaves the treatment zone, metals will re-precipitate upon contact with native groundwater conditions.

Three potential chemical oxidants used for remediation of petroleum and MGP site-related compounds, including BTEX and PAHs, are Fenton's reagent (i.e., peroxide and chelated iron), ozone, and activated persulfate. Permanganate, also used for ISCO, is not considered effective on BTEX, and will not be considered further for use at this Site. Oxidants are typically added to the subsurface through a series of injection wells. Space limitations in off-site locations may require a mobile mixing and delivery system. Groundwater treatment using ISCO at this Site does not require groundwater extraction, but could be paired with an extraction system for additional contaminant removal, hydraulic control, or to induce a more pronounced hydraulic gradient in the treatment area.

In general, based upon oxidative potential of the oxidation reactions, Fenton's chemistry is the strongest of the three, followed by activated persulfate and ozone the weakest. All three chemical oxidants used for remediation of petroleum and MGP site-related compounds, including BTEX and PAHs are evaluated below. All three oxidants could be delivered using nested injection or infiltration (gravity feed) delivery wells. Each well could be screened to target a five- to ten-foot vertical section of vadose or saturated zone material. Depending on the location, construction of the injection or infiltration delivery wells should not be difficult considering the Site lithology. By incorporating low-pressure injection rates (e.g., less than 30 pounds per square inch gauge) or gravity feed (e.g., no active pressure upon the system) delivery of oxidant materials also should not be difficult given Site lithology.

Fenton's Reagent

Conventional Fenton's chemistry reactions are produced when hydrogen peroxide (H_2O_2) is applied with an iron catalyst (Fe^{2+}), creating a number of free radicals (i.e., hydroxyl, superoxide, and perhydroxyl and radicals) capable of oxidizing complex organic compounds including petroleum, BTEX, and PAHs. Fenton's chemistry requires the delivery of two solutions, a liquid or solid peroxide solution and an iron catalyst solution, that must adequately mix within the subsurface for the free radical reactions to occur. Equations 1, 2, and 3 display the production of the free radicals associated with Fenton's chemistry, hydroxyl, superoxide, and perhydroxyl radicals, respectively.

$H_2O_2 + Fe^{2+} \rightarrow {}^{\bullet}OH + OH^- + Fe^{3+}$ Equation 1

$H_2O_2 + Fe^{3+} \rightarrow {}^{\bullet}O_2^- + H^+ + Fe^{2+}$ Equation 2

${}^{\bullet}OH + H_2O_2 \rightarrow {}^{\bullet}HO_2 + 2\ H_2O$ Equation 3

In the equations above, H_2O_2 is hydrogen peroxide, Fe^{2+} is ferrous iron (i.e., the catalyst), ${}^{\bullet}OH$ is the hydroxyl free radical, OH^- is an hydroxide ion, Fe^{3+} is ferric iron, ${}^{\bullet}O_2^-$ is the superoxide radical, H^+ is the hydrogen ion, ${}^{\bullet}HO_2$ is the perhydroxyl radical, and H_2O is water.

Residual hydrogen peroxide (H_2O_2) decomposes into water and oxygen in the subsurface and any remaining iron precipitates out of groundwater as ferric iron (Fe^{3+}). In addition, the hydroxyl radical ($^\bullet OH$) reacts with natural organic material to form carbon dioxide and chloride. All three free radicals produced in Fenton's chemistry are short lived (i.e., decompose within approximately 2 to 24 hours).

There are two forms of Fenton's reagent applied in environmental remediation: traditional Fenton's requires a step to acidify the aquifer (e.g., pH 3 to 6) and uses higher concentrations of hydrogen peroxide (e.g., approximately 30%); and modified Fenton's reagent, which can be performed under neutral groundwater conditions and uses a lower concentration of hydrogen peroxide (e.g., approximately 4 to 17%). For modified Fenton's applications, the use of a lower concentration of liquid hydrogen peroxide solution minimizes heat generation and reduces the production of oxygen gas generated during the reaction. Solid peroxides can also be used to further minimize heat and oxygen gas production during implementation and provide an increased peroxide persistence following delivery (e.g., multiple weeks to one month).

Effectiveness: ISCO using traditional and modified Fenton's reagents could be effective for remediation of petroleum and MGP site-related compounds in groundwater. ISCO may be less effective on source area soils due to the high organic carbon content and heterogeneous conditions that are present. Modified Fenton's reagent using liquid or solid peroxides would not require pH adjustment prior to implementation for effective treatment.

Implementability: ISCO reactions are aqueous in nature and adequate subsurface distribution is required for contaminant treatment. Surface access is required to allow adequate delivery of materials. Vadose zone applications can be limited by soil moisture, requiring additional liquids for sufficient oxidation reactions to occur, or tighter spacing of injection wells for adequate subsurface distribution. Modified Fenton's chemistry using low concentrations of liquid or solid peroxide would minimize the production of oxygen gas, which can cause surfacing and therefore prevent additional subsurface distribution during implementation. Installation of delivery wells and introduction of oxidant materials should not be difficult considering Site lithology.

Cost: The relative costs of all ISCO processes are assumed to be moderate to high depending on the effectiveness and the number of injection events that are required. The costs associated with the chelated iron formulation used with modified Fenton's reagent and liquid peroxide may require licensing or patent fees that would increase the cost of materials. Solid peroxide formulas may also require increased material costs depending upon the selected vendor.

Conclusion: ISCO using traditional Fenton's chemistry will not be retained. ISCO using modified Fenton's chemistry incorporating liquid and/or solid peroxides will be retained.

Ozone

Ozone gas (O_3) is a strong oxidant capable of destroying petroleum and MGP site-related contaminants directly or through the formation of hydroxyl radicals. The ozone direct oxidation and hydroxyl free radical formation reactions are shown below in Equations 4 and 5, respectively.

$O_3 + 2H^+ + 2e^- \rightarrow O_2 + H_2O$ Equation 4

$O_3 + H_2O \rightarrow O_2 + 2\ {}^{\bullet}OH$ Equation 5

In the equations above O_3 is ozone, H^+ is a proton, e^- is an electron, H_2O is water, O_2 is oxygen gas, and ${}^{\bullet}OH$ is the hydroxyl radical.

Ozone is typically generated electrically on-site and is immediately delivered to the subsurface through wells, eliminating the need for oxidant storage and handling. Treatment with ozone generally requires that the gas be generated in close proximity to the treatment area, and that wells are closely spaced. Ozone has a half-life of several hours in air (vadose zone) in low concentration, and several minutes in water, however, the reaction rate of ozone is typically much faster than its decomposition rate. A conceptual ozone injection process is shown on Figure 4-3.

Effectiveness: ISCO using ozone has been proven to be effective in lowering the toxicity and volume of petroleum and MGP site-related compounds in soil and groundwater. Due to the rapid degradation of ozone, achieving adequate subsurface distribution could be challenging.

Implementability: Due to ozone's high reactivity and instability, ozone must be produced on-site. Increased injection volumes and/or field durations versus other oxidants may be required. Its gaseous nature and gases produced during the reaction would require a vapor extraction system at the ground surface due to the volatilization of contaminants. Installation of delivery wells and introduction of oxidant materials should not be difficult considering Site lithology.

Cost: The relative costs of all ISCO processes are assumed to be moderate. If increased injection volumes and/or field durations are required for ozone versus other oxidants, the cost of materials and/or field implementation may be greater than for other oxidants.

Conclusion: ISCO utilizing ozone will not be retained for overall Site use in an ISCO system; however it appears to be the most promising technology for use in a containment and gate system.

Activated Persulfate

Injection of activated persulfate solutions for environmental remediation is an emerging technology for the in situ oxidation of a wide range of organic compounds. Laboratory testing and limited field testing have shown that activated persulfate can oxidize a wide range of environmental contaminants including petroleum and MGP site-related compounds, though the field application of activated persulfate does not yet appear to have been optimized. Activated persulfate has a very strong oxidation potential similar to that of modified Fenton's chemistry, and involves the delivery of both the persulfate and a catalyst for activation. The activated persulfate reaction produces very minimal heat and gas by-products, therefore minimizing volatilization of the contaminants and/or surfacing issues.

Persulfate salts are water-soluble, crystalline solids that, when catalyzed (i.e., activated), react to form persulfate radicals. These radicals are strong oxidants that may react with contaminants as well as non-target compounds such as natural organic matter and other soil species susceptible to oxidation, as shown below in Equations 6 and 7.

$S_2O_8^{2-} \xrightarrow[\text{catalyst}]{} 2\ {}^{\bullet}SO^-_4$ Equation 6

${}^{\bullet}SO^-_4 + e^- \rightarrow SO_4^{2-}$ Equation 7

In the equations above, $S_2O_8^{2-}$ is the persulfate ion, $^{\bullet}SO^{-}_4$ is the persulfate radical, e^- is the electron, and SO_4^{2-} is the sulfate ion.

Activation of persulfate may be accomplished either with heat or by using a transition metal-based catalyst, such as iron. Heat activation can be achieved by introducing both heat and the oxidant, for example, by pairing thermal resistive heating with the delivery of persulfate solution to the vadose and/or saturated zone. Lower temperatures may be employed as compared to treatment using thermal resistive heating alone (e.g., 30 to 40 degrees Celsius for persulfate activation). An iron catalyst can be introduced in combination with the persulfate solution, although it is also possible that background transition metal concentrations could be sufficient for effective oxidation. Persulfate is effective at near-neutral pH, so acidification of the treatment solution or the aquifer is not necessary.

Recent laboratory and field data attempting to enhance ISCO have combined activated persulfate and co-solvent and/or surfactant materials to increase the contaminant mass available in the aqueous phase. Field-scale testing data indicates promising results with the application of ISCO (using activated persulfate) and co-solvent and/or surfactant mixtures for both vadose and saturated zone contaminants. As with activated persulfate, where the oxidant and catalyst (activator) must be adequately mixed within the subsurface and be in contact with the contaminants, adding co-solvent and/or surfactant materials also requires adequate mixing with the activated oxidant material and target contaminants. Therefore subsurface mixing and distribution remain primary implementation challenges.

Effectiveness: Activated persulfate is a relatively new oxidant for environmental purposes, although in laboratory studies and recent field applications it has been found to effectively treat petroleum and MGP site-related compounds. Persulfate has the potential as a strong oxidant as well as being relatively persistent within the subsurface. Enhanced ISCO using activated persulfate and co-solvent and/or surfactant materials may also increase the availability of the target contaminants for oxidation with the vadose and/or saturated zones.

Implementability: ISCO reactions are aqueous in nature and adequate subsurface distribution is required for contaminant treatment. Surface access is required to allow adequate delivery of materials. Vadose zone applications can be limited by soil moisture, requiring additional liquids for sufficient oxidation reactions to occur, or tighter spacing of injection wells for adequate subsurface distribution. Heat generation or gas production should not be an issue for activated persulfate. Installation of delivery wells and introduction of oxidant materials should not be difficult considering Site lithology. Subsurface mixing and distribution are the primary implementation challenges with activated persulfate and enhanced ISCO using activated persulfate and co-solvent and/or surfactant mixtures.

Cost: The relative costs of all ISCO processes are assumed to be moderate to high depending on the number of injection events that are required. The costs associated with persulfate and associated chelated iron materials for activation may require licensing or patent fees that would increase the cost of materials. The costs associated with enhanced ISCO using persulfate, the associated chelated iron materials for activation, and the co-solvent and/or surfactant materials may require licensing or patent fees that would increase the cost of materials.

Conclusion: ISCO using activated persulfate using a chelated iron catalyst will be retained. Enhanced ISCO using activated persulfate in combination with a co-solvent and/or surfactant material will be retained.

4.5.4 In Situ Biological Treatment

Naturally occurring microorganisms in the soil promote the breakdown and detoxification of organic contaminants. Aerobic biodegradation has been shown to be ongoing based on analytical results from Site groundwater monitoring wells. In situ biological treatment such as bioremediation may enhance that process in soil as well as in groundwater as discussed in Section 4.3.4. Water enhanced with oxygen and other amendments, if necessary, is delivered to contaminated soil to enhance biological degradation of target contaminants. An infiltration gallery or injection wells can be utilized for the saturated and unsaturated zones.

Effectiveness: This technology has been proven to be effective on PAHs. However, given the volume of soil source material, the presence of NAPL, and the high concentrations of contaminants present, bioremediation would require a long time period to effectively remediate Site soils.

Implementability: Construction of an infiltration gallery or injection wells would not be difficult given Site hydrogeology. Delivery of materials should not be difficult given the Site lithology.

Cost: The cost is considered to be moderate to high depending on the operation period.

Conclusion: This technology is retained only for consideration as a second-step technology after contaminant source concentrations have been reduced.

4.5.5 In Situ Solidification

In situ solidification (ISS), as applied to MGP sites, is the process of mechanical injection of a solidification mixture into the contaminated subsurface soils in order to immobilize and contain the contaminants in a low permeability monolith. The solidification mixture is typically a combination of Portland cement and ground-granulated blast furnace slag, with other additives to improve pumpability, auger lubrication, or cohesive soil shearing evaluated on a site-specific basis. Contaminants are immobilized primarily by incorporating contaminated soil and NAPL into a low permeability mass, reducing groundwater flow through the soils, and by reaction chemistry and physical homogenization that eliminates NAPL as a separate phase (i.e., reduces its concentration to well below its residual saturation point such that NAPL is not observable and solidified soils do not produce a sheen) and binds the contaminants in a soil-cement matrix. The overall mass of contaminants is contained within the solidified mass, the mobility of NAPL is eliminated, the vaporization potential is significantly reduced, and the dissolution of contaminants to groundwater is largely eliminated. Volatilization of VOCs during treatment can be controlled with a vapor recovery and treatment system if necessary.

ISS most commonly consists of a crane-operated auger system which pumps the grout mixture into a large diameter mixing blade that blends the grout with subsurface soils as the blade is turned. A grout batch plant is constructed on-site where the grout is formulated from dry reagents and water and delivered to the auger system. A conceptual schematic of ISS is shown on Figure 4-4. Individual mix columns are overlapped to provide complete coverage and the up and down stroke mixing provides homogenization of contaminated soils to improve the solidification process. Permeabilities of treated soils are typically less than 10^{-6} cm/sec, with the goal of achieving several orders of magnitude reduction in permeability as compared to surrounding soils. Solidified soil strengths are typically between 50 and 250 pounds per square inch (psi) unconfined compressive strength, which is capable of supporting a wide variety of post-remediation development construction, yet remains excavatable and drillable for the purpose of utility installation or support pile installation. Other methods of ISS include pressure injection and mixing using jet grouting, use of excavator blender heads, and use of excavator buckets. The choice of ISS application equipment is typically determined on a site-specific basis considering depth of treatment, utilities and/or obstructions, proximity to receptors, and risk of unknown subsurface obstructions, among others.

Effectiveness: This technology would be effective in reducing the mobility of the Site-related contaminants in soil. The process improves the soil bearing capacity. Long-term monitoring is required to evaluate the effectiveness. This technology has been applied to MGP sites nationwide, including in New York State. Bench-scale testing is necessary to develop a Site-specific mix design.

Implementability: Soil solidification to reduce mobility is easier to implement than constructing a soil barrier wall. Dewatering and/or groundwater control would not be required. There is a depth limitation of approximately 70 feet in coarse-grained soils. An increase in the volume of the mixture occurs requiring appropriate site grading and potentially some off-site disposal of swell material. VOCs present in the subsurface may be released to the atmosphere during treatment; however, this can be mitigated with vapor collection systems on the solidification equipment. Implementation of this technology would require the removal of the majority of subsurface abandoned MGP infrastructure, and existing active utilities would require relocation or alternate solidification application methods in close proximity.

Cost: The cost is considered to be moderate to high depending on the operation period and the volume of clean soils above the contaminated soils that are incidentally treated.

Conclusion: Solidification is retained.

4.5.6 In Situ Thermal Treatment

In situ thermal desorption (ISTD) is a technology by which MGP wastes can be remediated without excavation. ISTD uses subsurface heating elements installed in a manner similar to wells to heat contaminated soil by thermal conduction, as conceptualized on Figure 4-4. The heat induces several remedial processes that, depending on the level of heating, soil and groundwater conditions, and the nature of the wastes, can partially or fully remediate the wastes. Among other processes, it can break down or volatilize the organic compounds, and it can reduce the viscosity of the remaining product (while heated) to allow it to be more easily captured. Vacuum extraction wells are installed within the heating wells to collect any steam or contaminant vapors generated during heating. For optimal effectiveness, groundwater inflow should be minimized within the treatment area.

Effectiveness: Under favorable conditions, ISTD can remediate MGP sites to typical clean-up criteria. The permeability of the soils at this Site, however, will limit the effectiveness of the technology at and below the water table without groundwater containment. The presence of groundwater limits the effectiveness of this technology to an "enhanced-remediation" level. It will drive off lighter-weight VOCs but it will not destroy the heavier-weight PAHs. Instead, it will lessen the viscosity of the remaining compound (while heated) to allow it to be physically captured and removed more easily, and, once cooled, the remaining product will be substantially less mobile due to the absence of the VOCs, have a lower viscosity, and reduced solubility (i.e., mobility) of higher molecular weight PAHs.

Implementability: The technology is implementable at the Site assuming that adequate power sources are available. In order to increase the effectiveness of ISTD below the water table, groundwater containment would have to be included to reduce heat loss within the treatment zone. Groundwater containment through vertical barriers would be difficult to implement.

Cost: The cost is estimated to be high due to the drilling and power requirements.

Conclusion: To be fully effective at this Site, this technology is retained with the inclusion of groundwater containment.

4.6 Summary of Retained Technologies

Table 4-1 provides a summary of the technology identification and screening process. Technologies retained for use in the development of alternatives are:

- Vapor Intrusion Mitigation Units
- Monitored Natural Attenuation
- Asphalt cap
- Vertical barriers
- Containment and Gate using Ozone Injection
- Extraction Wells
- Bioremediation for Dissolved Phase Plume
- Groundwater Treatment On-Site
- Passive and/or Active NAPL Recovery
- Off-Site NAPL Disposal
- Excavation and Off-Site Treatment
- In situ Chemical Oxidation
- In situ Solidification
- In situ Thermal Desorption with Groundwater Containment.

5.0 DEVELOPMENT, SCREENING, AND DESCRIPTION OF ALTERNATIVES

This section combines the remedial technologies considered feasible for each media (soil, groundwater/NAPL, air/soil vapor) into a list of remedial alternatives for the Site as a whole. Remedial alternatives are then screened, and those best meeting the remedial goal and remedial action objectives developed for the Site are described.

5.1 Development of Alternatives

The No Action Alternative is the baseline for the Site and includes only monitored natural attenuation.

In addition to the No Action Alternative, four remedial alternatives have been developed for the Site and are described below. These four alternatives include the proposed IRM proceeding independently of the remedial alternatives such that soil source material in the north-central portion of the Site will be removed and product recovery wells will be installed with ongoing regular NAPL removal. IRM implementation will effectively meet the RAO for soil to prevent, to the extent practicable, human exposure to MGP-related chemicals present in surface and subsurface soil at levels exceeding SCGs in the northern area of the Site. It will further help to meet the second RAO for soil to eliminate or reduce to the extent practicable NAPL and MGP-related contamination sources that contribute to soil, air, soil vapor and groundwater contamination. Product recovery will also help to meet the remedial action objective for groundwater/NAPL to reduce or mitigate NAPL, to the extent practicable, to decrease the source of chemicals that contribute to soil, air, soil vapor and groundwater contamination.

Alternatives 2 through 5 all include removal (excavation and off-site treatment/disposal) of the remaining shallow soil source material to a depth of 8 ft shown on Figure 3-1 including soil and MGP-remnant structures (storage holder, relief holder and gas oil tank) on the Sold property. This removal will effectively prevent human exposure to MGP-related chemicals present in surface and subsurface soil across the Site for current and future uses, and reduces the MGP-related contamination sources. Bioremediation of the dissolved phase groundwater plume has been included in alternatives without groundwater treatment.

Soil vapor intrusion testing and an evaluation of the need for any mitigation system installations are being conducted in parallel to the FS/RAP. The vapor intrusion sampling program will evaluate soil vapor intrusion at adjacent buildings and assess the need for exposure point mitigation system installations. Should monitoring results indicate that exposure point mitigation is required, it will be become a component of the recommended remedy. This could include installation and operation of sub-slab depressurization systems as part of the vapor intrusion mitigation. The systems collect soil gas from beneath the buildings and vent them to the atmosphere. By maintaining a slight vacuum below the basement slab, contaminant vapors can be prevented from migrating through cracks and other openings in the basement slab and infiltrating into the indoor air.

This technology would meet the RAOs for air and soil vapor, and be the same for all alternatives, including the No Action Alternative. All alternatives include exposure point mitigation to monitor and mitigate exposure to contaminated media and provide protection to human health at individual receptors. The cost for this technology is unknown until monitoring results are known; however, a cost is included in the alternative cost estimates that include air monitoring and the installation of one sub-slab depressurization unit on a yearly basis.

From the retained list of remedial technologies, the following list of remedial alternatives has been developed for the Site:

No Action, Monitored Natural Attenuation (MNA).

Excavation of Remaining Shallow Source Soil and Product Recovery**, Source Containment,** On-Site Groundwater Treatment, MNA.

Excavation of Remaining Shallow Source Soil and Product Recovery, **Hydraulic Containment**, On-Site Groundwater Treatment, MNA.

Excavation of Remaining Source Soil, Bioremediation of Dissolved Phase Plume.

Excavation of Remaining Shallow Source Soil and Product Recovery, **In Situ Chemical Oxidation**, Bioremediation of Dissolved Phase Plume.

Excavation of Remaining Shallow Source Soil and Product Recovery, **In Situ Thermal Desorption** with Vapor and Product Collection, Groundwater Containment (either Source Containment or Hydraulic Containment), Bioremediation of Dissolved Phase Plume.

Excavation of Remaining Shallow Source Soil, **In Situ Solidification,** Bioremediation of Dissolved Phase Plume.

Excavation of Remaining Shallow Source Soil and Product Recovery, **Containment and Gate** using Ozone Injection, MNA.

5.2 Screening of Alternatives

Alternatives that include above-ground groundwater treatment in a constructed treatment system would be difficult to implement considering the need for long-term (i.e., 30 years) operation and maintenance of a groundwater treatment system, and the continued discharge to a local water treatment facility. Preliminary cost estimates for groundwater collection and treatment for 5 gpm (Source and Groundwater Containment Alternatives) and 500 gpm (Hydraulic Containment Alternative) are detailed in Appendix C and summarized below.

	Groundwater Collection and Treatment (5 gpm)	**Groundwater Collection and Treatment (500 gpm)**
Capital Costs	$598,000	$2,320,000
Annual OM&M	$601,900	$1,873,400
Present Worth of OM&M	$9,251,300	$28,795,000
Total Present Worth	$9,849,300	$31,115,000

Due to the cost and time frame required for groundwater collection and treatment, alternatives that include an above-ground water treatment facility are removed from further consideration. Five remedial alternatives are presented for the Site as described in Section 5.3.

5.3 Description of Alternatives

5.3.1 Alternative 1 - No Action, Monitored Natural Attenuation (MNA)

Alternative 1 consists of MNA which includes periodic sampling and analysis for contaminants of concern (BTEX and PAHs) as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity. Remaining existing monitoring wells which may be included in the post-remediation groundwater monitoring program are: HIW-03S,I,D; HIMW-05S,I,D; HIMW-08S,I,D; HIMW-12S,I,D; HIMW-13S,I,D; HIMW-14I,D; HIMW-15I,D. The list of parameters may be modified following data review of monitoring results.

Size and Configuration

- Figure 5-1 identifies the monitoring wells for MNA.
- Annual sampling and analysis for BTEX and PAH compounds, as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity would be performed in monitoring wells.
- An annual report and Five-Year Review would evaluate OM&M activities.

Time for Remediation

- For the purpose of this report, a 30-year period is assumed for MNA.

Spatial Requirements

- There are no spatial requirements.

Options for Disposal

- No disposal will be required for this alternative.

Permit Requirements

- No permits will be required for this alternative.

Limitations

- The time frame to continue MNA is unknown at this time.

Ecological Impacts

- This alternative is not anticipated to have any significant impacts on fish and wildlife resources.

5.3.2 Alternative 2 – Excavation of Remaining Source Soil Bioremediation of Dissolved Phase Plume

This alternative includes excavating all soil source material that has not been previously excavated during the IRM. The areas would be backfilled with clean soil. Since the majority of source material (soil and NAPL) would be removed, natural processes would continue to reduce contaminant concentrations outside the limits of remediation, and only limited additional long-term monitoring would be required as compared to other alternatives. Bioremediation would be performed within the dissolved phase groundwater plume and monitoring would assess the reduction of contaminant concentrations in groundwater outside of the source area.

Size and Configuration

- A conceptual layout for Alternative 2 is presented on Figure 5-2.
- Approximately 171,000 cy of soil source material, much of which would contain NAPL, would be excavated to depths of up to 34 ft requiring adequate shoring and sprung structures for dust, vapor and odor control. Excavation of soil to depths greater than 34 ft would be more difficult to implement.
- Excavated soils would be transported off-site for treatment/disposal at a thermal desorption facility.
- Excavated areas would be backfilled with clean soil and properly compacted.
- Dewatering and product collection, especially in saturated soils, would be required. Collected water would be treated on-site in a temporary water treatment unit, and product transported off-site for treatment.
- Appropriate health and safety procedures and shoring would be required during construction.
- Confirmatory analytical sampling would be performed to determine the limits of excavation.
- Air monitoring would be performed on- and off-site, and appropriate measures such as a sprung structure will be used to control vapors, odors, and/or dust.
- Field-scale testing may be required to support the design of a groundwater bioremediation system.
- Bioremediation wells could be installed within the downgradient groundwater plume for introduction of oxygen and/or amendment materials, if required, to the saturated zone. Potential well location areas are shown on Figure 5-6.
- Groundwater monitoring would be performed within the downgradient plume following implementation of the groundwater bioremediation system. The initial monitoring frequency could potentially be monthly, which might be adjusted based

upon system performance and aquifer conditions. At a minimum, annual groundwater sampling and analysis would be performed. Parameters monitored might include BTEX and PAH compounds and their associated degradation products, dissolved gasses, dissolved oxygen, pH, temperature, microbial species, alkalinity, and total organic carbon.

- An annual report and Five-Year Review would evaluate OM&M activities.

Time for Remediation

- Excavation of soil source material is anticipated to require 2 ½ years.
- The groundwater bioremediation system is anticipated to require 9 to 12 months to design, construct, and operate.

Spatial Requirements

- Adequate on-site area is available for remedial activities including staging, storage, and construction support and operation areas. The Sold property would be unavailable to its current occupants during remediation. The parking lot of the Medical Office Building would be unavailable during remediation in this area.
- Nearby areas and traffic would be affected during construction activities. Subsurface, and potentially above-ground, utilities would have to be temporarily or permanently re-located due to construction. Disruption of residences, businesses and utility service would have to be minimized through appropriate controls.
- Bioremediation wells would require access for installation. Due to access limitations in the downgradient plume area, the wells could be located along sidewalks, public access areas, and at the edge of parking lots or streets, where possible.
- Any required mechanical and electrical components of the bioremediation system would be located in close proximity to the wells and secured with a fence.

Options for Disposal

- It is assumed that options for treatment/disposal of the volume of excavated soil source material and water collected during dewatering are available.

Permit Requirements

- Substantive technical permit requirements to be considered include air emissions during excavation, and off-site transportation and disposal of excavated soil that is contaminated. These requirements are not expected to limit the effectiveness or implementability of this alternative.
- An inventory of amendment materials to be delivered to the subsurface may be required by the USEPA.

Limitations

- Deep excavation in the area of the Natural Gas Regulator Station and along the gas line(s) would require substantial health and safety requirements.
- Excavation to depths greater than 34 ft would be difficult.
- The effectiveness of bioremediation on Site-specific contaminants and concentration levels could be confirmed during the design phase and after implementation. Surfacing and/or gas production would also be considered during the design. Impacts from remediation in the source area would require an evaluation of contaminant mass removal.

Ecological Impacts

- This alternative is not anticipated to have any significant impacts on fish and wildlife resources.

5.3.3 Alternative 3 – Excavation of Remaining Shallow Source Soil and Product Recovery, In Situ Chemical Oxidation, Bioremediation of Dissolved Phase Plume

Remaining shallow soil source material will be excavated and transported off-site for treatment/disposal. The areas will be backfilled with clean soil. This alternative includes ISCO using modified Fenton's reagent (with liquid or solid peroxides), activated persulfate, and/or enhanced ISCO incorporating activated persulfate and a co-solvent and/or surfactant mixture. The application of either ISCO alone or enhanced ISCO materials requires a delivery system targeting the vadose and saturated zones. Delivery wells would be spaced on approximately 30-foot centers and consist of nested 5- to 10-ft vertical screens, covering the vadose or saturated zones from 16 to 34 ft bgs, or deeper if deemed necessary. The delivery wells would be located based upon target concentrations. Product removal would continue as necessary to decrease the amount of oxidant required for treatment.

Bioremediation would be performed within the dissolved phase groundwater plume and monitoring would be conducted to assess the reduction of contaminant concentrations in groundwater outside of the source area.

Size and Configuration

- A conceptual layout for Alternative 3 is presented on Figure 5-3 (ISCO area) and Figure 5-6 (groundwater bioremediation wells).
- Remaining source material to a depth of 8 ft. would be excavated and transported off-site for treatment/disposal at a thermal desorption facility.
- Excavated areas would be backfilled with clean soil and properly compacted.
- Appropriate health and safety procedures would be required during construction.
- Product would be recovered regularly from product and monitoring wells.
- Soil and groundwater sampling would be conducted to support bench-scale and field-scale pilot testing. Bench- and field-scale pilot testing will be conducted to support the design of the oxidant delivery system.
- Field-scale pilot testing of delivery wells would be conducted to support the design of the oxidant delivery system.
- Approximately 100+ delivery wells would be installed for introduction of oxidant materials to the vadose and saturated zones to address source material within the 16 to 34-foot depth ranges, or deeper if deemed necessary. Wells in the vadose zone would simulate an infiltration gallery.
- Groundwater monitoring for BTEX and PAH compounds, as well as other groundwater parameters, would be conducted on a weekly and/or monthly frequency following the implementation of the oxidant delivery system to assess performance. The frequency of monitoring events will be adjusted based upon system performance and aquifer conditioning with delivery of oxidant materials.

- Soil and/or soil gas samples would be collected and analyzed to evaluate system performance. BTEX and PAH compounds would be analyzed within the one to two quarters following implementation of the oxidant delivery system. Additional samples may be required based upon system performance.
- Field-scale testing may be required to support the design of a groundwater bioremediation system.
- The groundwater bioremediation system would include wells installed within the downgradient groundwater plume for injection of oxygen in gaseous or solid/slurry phase. Other amendments, if required, would also be applied. Potential well location areas are shown on Figure 5-6
- Groundwater monitoring would be performed within the downgradient plume following implementation of the groundwater bioremediation system. The initial monitoring frequency could potentially be monthly, which might be adjusted based upon system performance and aquifer conditions. At a minimum, annual groundwater sampling and analysis would be performed. Parameters monitored might include: BTEX and PAH compounds and their associated degradation products, dissolved gasses, dissolved oxygen, pH, temperature, microbial species, alkalinity, and total organic carbon.
- An annual report and Five-Year Review would evaluate OM&M activities.

Time for Remediation

- Soil source excavation and backfill are anticipated to require 4 months of field work.
- Bench-scale pilot testing is anticipated to require a minimum of 3 months for sample collection and laboratory testing.
- Field-scale pilot testing is anticipated to require 6 months for implementation and subsequent performance monitoring.
- Construction of the oxidant delivery system and oxidant applications in 3 events are anticipated to require approximately 6 months.
- Additional monitoring specific to the performance of the oxidant delivery system may require an additional 3 to 6 months.

- Performance monitoring would be ongoing during construction.
- The groundwater bioremediation system is anticipated to require 9 to 12 months to design, construct, and operate.
- Total source remediation is anticipated to require approximately 5 years.

Spatial Requirements

- Adequate on-site area is available for remedial activities including staging, storage, and construction support and operation areas. The Sold property would be unavailable to its current occupants during remediation. The parking lot of the Medical Office Building would be unavailable during remediation, unless the delivery wells were constructed below the ground surface.
- An on-site oxidant mixing area would be required for system construction or footprint for mobile mixing unit(s).
- Feed lines from oxidant mixing equipment to delivery wells may be temporarily installed above or below grade, based upon oxidant mixing system construction (i.e., stationary or mobile) and location. Multiple smaller oxidant mixing systems may be employed if determined more cost effective and/or to reduce field time and/or number of field personnel.
- Groundwater bioremediation wells would require access for installation. Considering access limitations in the downgradient plume area, the injection wells would be located along sidewalks, public access areas, at the edge of parking lots or streets, where possible.
- Any required mechanical and electrical components for the bioremediation system would be located in close proximity to the wells and secured with a fence.

Options for Disposal

- Options for disposal of the recovered product are readily available.
- Options for treatment/disposal of excavated soil source material are readily available.

Permit Requirements

- While close regulatory review would be performed, there are no substantive technical permit requirements during ISCO that are expected to limit the effectiveness or implementability of this alternative. An inventory of oxidant materials to be delivered to the subsurface may be required by the USEPA.

Limitations

- Contamination in areas between the depths of 8 to 16 ft is not proposed for remediation with ISCO. ISCO may not be as effective between the depths of 8 to 16 ft; however, a mixing of oxidant with soil may be feasible in these areas.
- The effectiveness of ISCO on Site-specific contaminants must be evaluated and/or confirmed with bench-scale pilot testing. Additional parameters such as required oxidant dosing, natural oxidant demand, soil buffering capacity (i.e., to buffer metals leaching), and oxidant persistence should also be evaluated using bench-scale pilot testing.
- Subsurface mixing and distribution using the proposed delivery method (i.e., low pressure injection or gravity feed infiltration) must be evaluated with field-scale pilot testing. Additional parameters evaluated in bench-scale pilot testing would also be considered during field-scale pilot testing. Surfacing and heat and/or gas production would also be considered during field-scale pilot testing.
- ISCO in the area of the Natural Gas Regulator Station and along existing subsurface utility lines would be difficult to implement.
- The effectiveness of groundwater bioremediation on Site-specific contaminants and concentration levels would be evaluated during field-scale testing. The potential for vapor migration and/or gas production would also be considered during field-scale testing. Impacts from the implemented Site remediation in the source area would require evaluation of contaminant mass removal.

Ecological Impacts

- This alternative is not anticipated to have any significant impacts on fish and wildlife resources.

5.3.4 Alternative 4 – Excavation of Remaining Shallow Source Soil, In Situ Solidification, Bioremediation of Dissolved Phase Plume

Remaining shallow soil source material would be excavated and transported off-site for treatment/disposal. These areas would be partially backfilled with clean soil, or, depending on the estimated volume increase and depth of solidification, ISS may be conducted from a lower excavation platform (i.e. elevation). This alternative includes ISS of soil source material that has not been excavated. Cement and blast furnace slag (to increase the percentage of fines) would be mixed into subsurface soil. The majority of source material (soil and NAPL) would be rendered immobile, and natural processes would continue to reduce contaminant concentrations in soil and groundwater outside the limits of remediation. Following ISS, the entire Site would be re-graded and backfill added as necessary in light of the soil volume increase due to the solidification process. Bioremediation of the dissolved phase groundwater plume is proposed and monitoring would assess the reduction of contaminant concentrations in groundwater outside of the source area.

Size and Configuration

- A conceptual layout for Alternative 4 is presented on Figure 5-4 (ISS area) and Figure 5-6 (groundwater bioremediation wells).
- Remaining soil source material to a depth of 8 ft would be excavated and transported off-site for treatment/disposal at a thermal desorption facility. Existing MGP infrastructure would require removal in order to implement ISS.
- Appropriate health and safety procedures would be required during construction.
- Air monitoring would be performed on- and off-site, and if necessary due to vapors, odors, and/or dust, appropriate measures may be taken such as a sprung structure.
- Excavated areas would be partially backfilled with clean soil to establish a level working platform.
- Bench-scale testing would be performed to determine an appropriate mixture to reduce the leachability of contaminants from Site soils.
- In situ solidification of subsurface source soil from the top of the source area, including small areas at multiple depths, to a depth of 34 ft would be conducted by

mixing soil with a combination of cement and blast furnace slag (to add fines to the subsurface). Jet grouting methods of solidification may be required to remediate beneath un-removed structures and/or utility lines.

- Approximately 171,000 cy of soil source material (including clean soils above source material that must be passed through to solidify deeper soils) would be solidified. Remediation could be implemented to depths greater than 34 feet.
- Confirmatory analytical sampling would be performed during remediation to assess the effectiveness of the solidification process.
- Due to the anticipated volume increase in Site soils, re-grading of the Site and possible off-site disposal of excess solidified swell material may be necessary.
- Depending on the selected system, field-scale testing may be required to support the design of a groundwater bioremediation system.
- The groundwater bioremediation system would be installed within the downgradient groundwater plume for injection of oxygen in gaseous or solid/slurry phase. Other amendments, if required, may also be applied. Potential well location areas are shown on Figure 5-6.
- Groundwater monitoring would be performed within the downgradient plume following implementation of the bioremediation system. The monitoring frequency could potentially be monthly, which might be adjusted based upon system performance and aquifer conditions. At a minimum, annual groundwater sampling and analysis would be performed. Parameters monitored would include: BTEX and PAH compounds and their associated degradation products, dissolved gasses, dissolved oxygen, pH, temperature, microbial species, alkalinity, and total organic carbon.
- An annual report and Five-Year Review would evaluate OM&M activities.

Time for Remediation

- Soil excavation and ISS is anticipated to require approximately 2 years.
- The groundwater bioremediation system is anticipated to require 9 to 12 months to design, construct, and operate.

Spatial Requirements

- Adequate on-site area is available for remedial activities including staging, storage, and construction support and operation areas. The Sold property may be unavailable to its current occupants during remediation. The parking lot of the Medical Office Building may be unavailable during remediation in this area. However, implementation can be staged such that specific areas are remediated and restored for temporary use while other non-KeySpan-owned areas are remediated.
- Nearby areas and traffic would be affected during construction activities. Subsurface and potentially above-ground utilities would have to be temporarily or permanently re-located due to construction. Disruption to residences, businesses and utility service would have to be minimized through appropriate controls.
- Bioremediation wells would require access for installation. Due to access limitations in the downgradient plume area, the wells would be located along sidewalks, public access areas, at the edge of parking lots or streets, where possible.
- Any required mechanical and electrical system components for the bioremediation system would be located in close proximity to the wells and secured using a fence.

Options for Disposal

- Options for treatment/disposal of excavated soil source material are readily available.

Permit Requirements

- There are no substantive technical permit requirements during solidification that are expected to limit the effectiveness or implementability of this alternative.
- An inventory of amendment materials to be delivered to the subsurface may be required by the USEPA.

Limitations

- The volume increase due to the solidification process would result in changes in Site topography, or, some swell material may need to be disposed off-site.
- All shallow obstructions including MGP remnant structures would have to be removed prior to mixing.

- Solidification in the area of the Natural Gas Regulator Station and along existing subsurface utility lines would be difficult to perform. An alternate delivery method to mixing (e.g., jet grouting) would have to be utilized.
- Solidification would be difficult to implement to depths greater than 60 to 70 ft.
- Solidified subsurface soil may restrict future Site construction and use.
- Solidified subsurface soil and the resulting temporary pH increase in the vicinity of the remediated areas could have a negative effect on existing native microorganisms that contribute to natural attenuation and may temporarily delay the ability to stimulate bioremediation.
- The coarse-grained character of soils and the high permeability present at the Site presents difficulties in auger mixing (i.e., torque requirements) that can be overcome with specific grout additives. Developing a cost-effective mix design to achieve a 1×10^{-6} cm/sec permeability may be difficult or require additional additives (e.g., bentonite); however, for a highly permeable aquifer such as exists at the Site, achieving a 2 to 3-order of magnitude permeability reduction may be sufficient to immobilize source material.
- Without a cap over the entire solidified area, or groundwater control, influent water could reduce the effectiveness of the stabilized soil, allowing contaminants to leach into the groundwater system over the long-term. During the design phase, this issue may be addressed by either sloping the top of ISS surface and/or the addition of a drainage layer where applicable.
- The effectiveness of bioremediation on Site-specific contaminants and concentration levels will be evaluated during the design phase and confirmed after implementation. The potential for vapor migration and/or gas production will also be considered during field-scale pilot testing. Impacts from the source area Site remediation would require evaluation of contaminant mass removal.

Ecological Impacts

- This alternative is not anticipated to have any significant impacts on fish and wildlife resources.

5.3.5 Alternative 5 – Excavation of Remaining Shallow Source Soil and Product Recovery, Containment and Gate, MNA

Remaining shallow soil source material will be excavated and transported off-site for treatment/disposal. The areas will be backfilled with clean soil. The objective of a containment and gate system is to contain source material and treat contaminated groundwater before it migrates outside the containment area. Containment would include a vertical barrier circumventing the soil source material, minus a small treatment area at the downgradient end, to an estimated depth of approximately 130 ft, where the relatively impermeable lower Magothy subunit is present. Contaminated soil and the majority of contaminated groundwater would be contained inside the vertical barrier. The alternative does not include groundwater extraction; but includes in situ groundwater treatment using injected ozone in the gate area. Ozone injection wells would be space on approximately 8- to 10-foot centers in three rows to make an injection curtain. Screens would be 2 to 3 ft in length with multiple points per well. Wells would extend to a depth of 70 ft. Off-gas monitoring, and collection if necessary, would be performed in the injection area.

Since groundwater flow through the treatment area would be acceptable, a site cap is not included with the alternative. Flow through the gate would be from infiltration through the site surface and leakage through the vertical barrier. Significant mounding within the containment area, or along the outside edge of the upgradient barrier, may cause contaminated groundwater to flow outside of the gate area. A Site-specific groundwater flow model and system design would be necessary to develop an appropriate configuration of vertical barriers and treatment area.

This alternative includes recovery of product within the containment area. NAPL extraction would result in the gradual removal of a portion of the contaminant mass present in groundwater. Hydraulic containment would separate the dissolved phase plume from its source, which would gradually decrease in both extent and concentration. Over time, the plume would collapse and become non-detectable in areas downgradient of the Site. However, soil contamination and residual NAPL contamination would persist in the source area. Long-term monitored natural attenuation would assess the reduction of contaminant concentrations in groundwater outside of the remediation area.

Size and Configuration

- A conceptual layout for Alternative 5 is presented on Figure 5-5.
- Remaining soil source material to a depth of 8 ft would be excavated and transported off-site for treatment/disposal at a thermal desorption facility.
- Excavated areas would be backfilled with clean soil and properly compacted.
- Product would be recovered regularly from recovery and monitoring wells.
- Vertical barriers would be installed circumventing the source material, minus a small treatment area at the downgradient end, over a length of approximately 1,850 ft and to a depth of approximately 130 ft, the anticipated depth of the relatively less permeable layer.
- Bench/pilot-scale testing would be required to determine the effective and optimal ozone injection rates.
- Ozone injection wells spaced on approximately 8- to 10-foot centers in three rows would constitute the injection curtain. Screens would be 2 to 3 ft in length with multiple points per well. Wells would extend to a depth of 70 ft.
- Off-gas monitoring, and collection if necessary, would be performed in the injection area.
- Annual sampling and analysis for BTEX and PAH compounds, as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity would be performed in monitoring wells.
- An annual report would evaluate OM&M activities.

Time for Remediation

- Construction is anticipated to require 1 ½ years.
- For the purpose of this report, a 30-year period is assumed for ozone injection, product recovery and MNA.

Spatial Requirements

- Adequate on-site area is available for remedial activities including staging, storage, and construction support and operation areas. The Sold property may be unavailable to its current occupants during remediation. The parking lot of the Medical Office Building may be temporarily unavailable during construction in this area. The southern tip of the parking lot, where the treatment area was located, would be unavailable over the long term.
- The vertical barrier would be installed across both on-site and off-site properties. Nearby areas and traffic would be affected during construction activities. Subsurface, and potentially above-ground, utilities would have to be temporarily or permanently re-located due to construction of the vertical barrier. Disruption to residences, businesses, and utility service would have to be minimized through appropriate controls.

Options for Disposal

- Options for disposal of the recovered product are readily available.
- Options for treatment/disposal of excavated soil source material are readily available.

Permit Requirements

- Substantive technical permit requirements to be considered include air emissions during treatment, which may require vapor collection systems to be installed. These requirements are not expected to limit the effectiveness or implementability of this alternative.

Limitations

- Construction of a vertical barrier across the gas lines to the Natural Gas Regulator Station would be necessary for this alternative, but would be difficult with respect to health and safety.
- A groundwater flow model and Site-specific system design would have to be performed to determine if, given the Site hydrogeology, an adequate configuration of vertical barriers and treatment area could be developed which would not negatively affect the surrounding groundwater flow system.

- The gate area would require permanent property easements or acquisition.
- Re-paving the Medical Office Building parking lot would limit infiltration and reduce the amount of water flowing through the gate.

Ecological Impacts

- This alternative is not anticipated to have any significant impacts on fish and wildlife resources.

6.0 DETAILED ANALYSIS OF ALTERNATIVES

6.1 Description of Evaluation Criteria

Each of the alternatives is subjected to a detailed evaluation with respect to the criteria outlined in 6 NYCRR Part 375 and described below. This evaluation aids in the selection process for remedial actions in New York State.

Alternatives 1 through 5 will all include exposure point mitigation (discussed in Section 5.1) to monitor and mitigate exposure to contaminated media and provide protection to human health at individual receptors. This technology will be the same for all alternatives with respect to the evaluation criteria and overall will be protective of public health and the environment. Therefore, exposure point mitigation will not be included in the following discussions on evaluation criteria comparisons.

Overall Protection of Public Health and the Environment

This criterion is an assessment of whether the alternative meets requirements that are protective of human health and the environment. The overall assessment is based on a composite of factors assessed under other evaluation criteria, particularly long-term effectiveness and performance, short-term effectiveness, and compliance with SCGs. This evaluation focuses on how a specific alternative achieves protection over time and how site risks are reduced. The analysis includes how the source of contamination is to be eliminated, reduced, or controlled.

Compliance with Standards, Criteria, and Guidance (SCGs)

This criterion determines whether or not each alternative complies with applicable environmental laws, and standards, criteria, and guidance (SCGs) pertaining to the chemicals detected in contaminated media, the location of the Site, and relating to proposed technologies. .

Long-Term Effectiveness and Permanence

This criterion addresses the performance of a remedial action in terms of its permanence and the quantity/nature of waste or residuals remaining at the Site after implementation. An evaluation is made on the extent and effectiveness of controls required to manage residuals remaining at the Site and the operation and maintenance systems necessary for the remedy to remain effective. The factors that are evaluated include permanence of the remedial alternative, magnitude of the remaining risk, adequacy of controls used to manage residual contamination, and the reliability of controls used to manage residual contamination.

Reduction of Toxicity, Mobility or Volume with Treatment

This criterion assesses the remedial alternative's use of technologies that permanently and significantly reduce toxicity, mobility, or volume (TMV) of the contamination as their principal element. Preference is given to remedies that permanently and significantly reduce the toxicity, mobility, or volume of the wastes at the site.

Short-Term Effectiveness

This criterion assesses the effects of the alternative during the construction and implementation phase with respect to the effect on human health and the environment. The factors that are assessed include protection of the workers and the community during remedial action, environmental impacts that result from the remedial action, and the time required until the remedial action objectives are achieved.

Implementability

This criterion addresses the technical and administrative feasibility of implementing the alternative and the availability of various services and materials required during implementation. The evaluation includes the feasibility of construction and operation, the reliability of the technology, the ease of undertaking additional remedial action, monitoring considerations, activities needed to coordinate with regulatory agencies, availability of adequate equipment, services and materials, off-site treatment, and storage and disposal services.

Cost

Capital costs and operation, maintenance, and monitoring costs are estimated for each alternative and presented on a present worth basis based on a 5% discount rate. Cost estimates for each remedial alternative are presented in Appendix C and summarized on Table 6-1.

Community and State Acceptance

Concerns of the State and the Community will be addressed separately in accordance with the public participation program developed for this Site.

6.2 Alternative 1 – No Action, MNA

The majority of source material would remain on-site in its present condition as residual contamination under Alternative 1. Monitored natural attenuation would assess the reduction in contaminant concentrations in the dissolved phase groundwater plume and assess the degree to which natural processes were having an effect on the concentrations of contaminants. Deed restrictions would have to be implemented to limit Site access, development, and groundwater use.

6.2.1 Overall Protection of Public Health and the Environment

Although this alternative poses few short-term risks during monitoring, it does not comply with SCGs, and is not effective in the long term. This alternative would not be protective of human health or the environment.

6.2.2 Compliance with SCGs

Since contamination would remain on-site, this alternative would not meet SCGs for media at the Site.

6.2.3 Long-Term Effectiveness and Permanence

Contaminant migration from soil to groundwater and potential exposure to contaminants would continue due to residual contamination. The potential risks to human health caused by contaminated soil, groundwater, and air on-site could be addressed through deed restrictions limiting Site access and use, and prohibiting extraction of groundwater for potable purposes. Such restrictions off-site would be difficult to implement. This alternative is not considered effective or permanent in the long term.

6.2.4 Reduction of Toxicity, Mobility and Volume with Treatment

Reduction of the toxicity, mobility, and volume of contaminants would occur slowly through natural attenuation.

6.2.5 Short-Term Effectiveness

As there is no construction associated with this alternative, there would be minimal impact to workers or the community. Remedial action objectives would not be met.

6.2.6 Implementability

Monitoring and deed restrictions could be implemented; however, this does not meet the remedial goal for the Site.

6.2.7 Cost

Estimated capital and operation, maintenance, and monitoring (OM&M) costs for Alternative 1 are presented on Table 6-1.

6.3 Alternative 2 – Excavation of Remaining Source Soil, Bioremediation of Dissolved Phase Plume

6.3.1 Overall Protection of Public Health and the Environment

This alternative would meet the SCGs for soil and groundwater at the Site. Soil source material would be removed and the downgradient groundwater plume would be remediated through bioremediation. RAOs would be met. Minimal residual contamination would remain which could be adequately controlled.

6.3.2 Compliance with SCGs

Soil source material removal would comply with SCGs for soil. Once the source was removed, bioremediation would commence and SCGs would be reached in groundwater downgradient of the source area.

6.3.3 Long-term Effectiveness and Permanence

Soil source material excavation would result in minimal residual soil contamination at depths greater than 34 feet. Contaminated groundwater and NAPL within the excavation limits would be collected and treated during remediation. Contaminant concentrations present in the downgradient dissolved phase groundwater plume would be reduced over time to SCGs through bioremediation.

6.3.4 Reduction of Toxicity, Mobility and Volume with Treatment

Soil source material excavation would remove the majority of contaminated soil volume from the Site. This volume to be excavated would include soil, NAPL, and groundwater collected during dewatering operations. Bioremediation would reduce the mass and toxicity of contaminants within the dissolved phase plume.

6.3.5 Short-term Effectiveness

Alternative 2 includes substantial excavation of soil source material. Significant efforts would have to be undertaken during implementation to minimize impacts to human health and the environment with respect to air emissions, odor control, noise, dust suppression, and transportation/traffic in nearby areas. The groundwater bioremediation wells would have to be located such that there are minimal effects to human health and the environment during construction and operation. The time required for construction is 2 ½ years; bioremediation would continue for 10 years. Once construction was complete and the Site Management Plan implemented, including temporary groundwater use restrictions, RAOs for soil, soil vapor, and groundwater would be met.

6.3.6 Implementability

Excavation and off-site disposal/treatment of substantial quantities of contaminated soil source material would be difficult during construction activities. Substantial quantities of contaminated water from dewatering activities may be collected and require off-site treatment. Truck traffic would be of concern to nearby businesses and residences. Soil treatment facility capacity could result in schedule delays. The groundwater bioremediation wells would have to be located such that there are minimal effects to human health and the environment during construction and operation.

6.3.7 Cost

Estimated capital and operation, maintenance, and monitoring (OM&M) costs for Alternative 2 are presented on Table 6-1.

6.4 Alternative 3 – Excavation of Remaining Shallow Source Soil and Product Recovery, In Situ Chemical Oxidation, Bioremediation of Dissolved Phase Plume

6.4.1 Overall Protection of Public Health and the Environment

ISCO would destroy contaminants in the remediated area and comply with SCGs for all media. Once the source was treated, the downgradient groundwater plume would be remediated through bioremediation and SCG levels would be reached. RAOs would be met; residual contamination could be adequately controlled.

6.4.2 Compliance with SCGs

ISCO would destroy contaminants in the remediated area and comply with SCGs for all media. Once the source was remediated, bioremediation would commence and SCGs would be reached in groundwater downgradient of the source area.

6.4.3 Long-term Effectiveness and Permanence

Soil source material removal is proposed for depths between 0 to 8 ft resulting in no residual contamination to a depth of 8 ft. ISCO is proposed for soil depths between 16 and 34 ft. Residual soil contamination between 8-16 ft and below 34 ft may exist. Residual contaminant concentrations present in the downgradient dissolved phase groundwater plume would be reduced over time.

6.4.4 Reduction of Toxicity, Mobility and Volume with Treatment

ISCO would reduce the toxicity of contaminants in soil and groundwater in the soil source material area through destruction. Bioremediation would reduce the mass and toxicity of contaminants within the dissolved phase plume. Product recovery would reduce the volume of NAPL present on-site.

6.4.5 Short-term Effectiveness

Alternative 3 includes excavation of substantial quantities of soil source material during which time a sprung structure would be utilized to minimize impacts to human health and the environment with respect to air emissions, odor control, noise, and dust suppression. ISCO air emissions will be monitored, and steps undertaken during implementation to minimize impacts to human health and the environment. The groundwater bioremediation wells would have to be located such that there are minimal effects during injection events to human health and the environment during construction and operation. The time required for construction and implementation is 2 years; bioremediation would continue for 10 years. Once construction and implementation were complete, RAOs for soil, soil vapor, and groundwater would be met.

6.4.6 Implementability

Installation of an injection gallery and wells would not be difficult to the required depths. If necessary, ISCO could be performed below a depth of 34 ft. Bench and pilot-scale tests are required prior to full-scale implementation to document treatment effectiveness. This process requires multiple ISCO and bioremediation events followed by monitoring well sampling and analysis. The groundwater bioremediation wells would have to be located such that there are minimal effects to human health and the environment during construction and operation.

6.4.7 Cost

Estimated capital and operation, maintenance, and monitoring (OM&M) costs for Alternative 3 are presented on Table 6-1.

6.5 Alternative 4 – Excavation of Remaining Shallow Source Soil, In Situ Solidification, Bioremediation of Dissolved Phase Plume

6.5.1 Overall Protection of Public Health and the Environment

Contaminants present in soil would be immobilized to meet RAOs. The contaminants would remain in the solidified soil mass below 8 ft bgs. The downgradient groundwater plume would be remediated through bioremediation and SCG levels would be reached in groundwater.

6.5.2 Compliance with SCGs

Immobilized contaminants would remain within the solidified soil mass beneath 8 ft bgs. Groundwater SCGs would be reached both on-site and downgradient of the source area after ISS is completed and the groundwater bioremediation system is installed and operated

6.5.3 Long-term Effectiveness and Permanence

Soil source material removal is proposed for depths between 0 to 8 ft resulting in no residual contamination to a depth of 8 ft. Containment of source material in a solidified, low permeability monolith would result in contaminant concentrations in the downgradient dissolved phase groundwater plume reducing to SCGs over time through bioremediation.

6.5.4 Reduction of Toxicity, Mobility and Volume with Treatment

Solidification would reduce the mobility of contaminants in soil and groundwater present within the soil source material area. Bioremediation would reduce the mass and toxicity of contaminants within the dissolved phase plume.

6.5.5 Short-term Effectiveness

Alternative 4 includes excavation of soil source material during which time a sprung structure would be utilized to minimize impacts to human health and the environment with respect to air emissions, odor control, noise, and dust suppression. Air emissions during the solidification process will be monitored, and steps under taken during implementation to minimize impacts to human health and the environment. The groundwater bioremediation wells would have to be located such that there are minimal effects during injection events to human health and the environment during construction and operation. The time required for construction and implementation is 2 years; bioremediation could continue for 5 to 10 years. Once construction was complete and the Site Management Plan implemented including groundwater use restrictions, RAOs for soil, soil vapor, and groundwater would be met.

6.5.6 Implementability

Solidification at depth would not be difficult to implement; any shallow obstructions would have to be removed. Solidification at depths greater than 60 to 70 feet in coarse-grained soils can be difficult; however, grout additives can be formulated to reduce torque requirements, or pre-excavation of overlying clean soils can be implemented to reduce solidification column depths. Bench-scale testing would be performed to determine appropriate mixtures to reduce leachability and to enhance bioremediation following source material treatment. Solidification requires confirmatory analytical sampling to assess the effectiveness of the processes. Bioremediation requires continuous operation or multiple injection events followed by monitoring well sampling and analysis. The groundwater bioremediation wells would have to be located such that there are minimal effects to human health and the environment during construction and operation.

6.5.7 Cost

Estimated capital and operation, maintenance, and monitoring (OM&M) costs for Alternative 4 are presented on Table 6-1.

6.6 Alternative 5 – Excavation of Remaining Shallow Source Soil and Product Recovery, Containment and Gate, MNA

6.6.1 Overall Protection of Public Health and the Environment

This alternative would not meet the SCGs for media at the Site. It relies on restrictions both on-site and off-site to control risks posed by residual contamination and to meet RAOs.

6.6.2 Compliance with SCGs

Since soil contamination would remain on-site with containment, this alternative would not meet the SCGs for soil at the Site. Over time, infiltration would cause groundwater to migrate from the Site through the treatment area. With the source cut off, the downgradient plume would collapse and SCGs would eventually be reached in groundwater downgradient of the contained area.

6.6.3 Long-term Effectiveness and Permanence

Soil source material removal is proposed for depths between 0 to 8 ft resulting in no residual contamination to a depth of 8 ft. Contaminant migration from soil to groundwater would continue due to residual contamination. Potential risks caused by residual contaminated soil, groundwater, and soil vapor on-site would be addressed through deed restrictions limiting Site access and use within the containment area, and prohibiting extraction of groundwater for potable purposes. Such restrictions off-site would be difficult to implement. Ozone treatment of groundwater would require a long time period for remediation.

6.6.4 Reduction of Toxicity, Mobility and Volume with Treatment

Source containment would reduce the mobility of contaminants in soil and groundwater present within the soil source material area. Ozone injection would reduce the toxicity of contaminants in groundwater. Product recovery would reduce the volume of NAPL present on-site.

6.6.5 Short-term Effectiveness

Alternative 5 includes excavation of soil source material during which time a sprung structure would be utilized to minimize impacts to human health and the environment with respect to air emissions, odor control, noise and dust suppression. Installation of the vertical barrier would not negatively impact human health and the environment. The time required for construction is 1 ½ years. Operation of the ozone injection system would have to continue long term. Once construction was complete and the Site Management Plan implemented, including deed and use restrictions, RAOs for soil, soil vapor, and groundwater would be met.

6.6.6 Implementability

Construction of a vertical barrier to a depth of 130 feet over a 1,850-foot length across off-site areas and subsurface utilities would be difficult. If driving sheet piling, the frictional resistance encountered, maintaining verticality and interlocking, and grouting the interlocks to such depths would be extremely challenging. Also, utilities would have to be permanently or temporarily disconnected, and re-routed or re-located to allow barrier installation. There could also be significant vibration and noise issues related to this work. An alternative to grouted sheet piling through the entire depth may be jet grouting, augered soil columns, or slurry trench methods. However, given the high permeability of the formation, this could be difficult to control. Construction of the barrier is proposed outside of the Natural Gas Regulator Station and gas lines due to health and safety concerns.

Installation of ozone injection wells and on-site manufacturing of ozone during remediation would not be overly difficult; however, a Site-specific system design would have to be evaluated to determine if, given the Site hydrogeology, an adequate configuration of vertical barriers and treatment area could be developed which would not negatively affect the surrounding groundwater flow system. The primary in situ treatment area would be located on property not owned by KeySpan and would require property acquisition or long-term access agreements.

6.6.7 Cost

Estimated capital and operation, maintenance, and monitoring (OM&M) costs for Alternative 5 are presented on Table 6-1.

6.7 Comparative Analysis of Alternatives

6.7.1 Overall Protection of Public Health and the Environment

All alternatives except Alternative 1 meet RAOs for the Site, either through remediation or Site management controls. Alternative 2, which includes the largest volume of source removal, would result in the smallest residual and meet on-site SCGs to the greatest extent. Alternatives 3 and 4, which include treatment in the saturated and unsaturated zones using ISCO and ISS, respectively, are protective of public health and the environment. Alternative 5, which reduces the mobility of contaminants in soil and groundwater by containment and treatment, and relies on Site use restrictions, is less protective.

6.7.2 Compliance with SCGs

Alternative 2 with source removal would comply with SCGs for soil in the shortest time frame. Alternative 3 with ISCO would comply with SCGs for soil in a longer time period. Alternatives 1 and 5 would not comply with SCGs for soil, as the majority of soil source material would remain on-site. Alternative 4 would meet soil SCGs over portions of the site.

Contaminant concentrations in groundwater within the remediation area would be significantly reduced toward meeting SCGs for Alternatives 2, 3 and 4, which include source removal and treatment, respectively. Alternatives 1 and 5 do not improve groundwater quality within the containment area. Once the source was removed or treated, bioremediation would commence and SCGs would be reached in groundwater downgradient of the source area.

Air emissions from the processes included in Alternatives 2 through 5 would be monitored and controlled, as necessary, to meet SCGs during operations.

6.7.3 Long-term Effectiveness and Permanence

Alternatives 2 through 5 all include removal of soil source material between depths of 0 to 8 ft resulting in no residual contamination to a depth of 8 ft. This permanent source removal is effective on site contaminants and reduces the restrictions and controls necessary for future Site use and management. Alternative 2 results in the least amount of residual at the Site followed by Alternatives 3 and 4. Alternatives 1 and 5 result in the largest residual. Following bioremediation, contaminant concentrations present in the downgradient dissolved phase groundwater plume would be similar for Alternatives 2, 3 and 4. Alternative 5 would rely on off-site groundwater use restrictions. Alternative 1 is not considered effective or permanent.

6.7.4 Reduction of Toxicity, Mobility and Volume with Treatment

Alternative 2, with the largest extent of soil source material removal, would reduce the volume of contaminants from the Site to the greatest extent. Alternative 3 with ISCO would reduce the toxicity of contaminants in soil and groundwater. Alternative 4 would reduce the mobility of contaminants in both soil and groundwater. Bioremediation would reduce the toxicity of contaminants within the dissolved phase plume equally for Alternatives 2, 3, and 4. Alternative 1 would not reduce the toxicity, mobility or volume of contaminants. Alternative 5 would reduce contaminant concentrations in groundwater passing through the treatment gate.

6.7.5 Short-term Effectiveness

Alternative 2, which includes the largest amount of soil excavation, would have the greatest potential impact on human health and the environment. Significant efforts will have to be undertaken in the short-term to minimize impacts to human health and the environment with respect to air emissions, odor control, noise, dust suppression, and transportation/traffic in nearby areas. All alternatives except Alternative 1 include shallow excavation of soil source material during which time a sprung structure would be utilized to minimize impacts to human health and the environment. Air emissions would be monitored and off-gas collection undertaken as necessary for Alternatives 2 through 5. Alternatives 3 and 5 would have greater short-term impacts than Alternative 4, as they require a longer time period to implement.

Remedial action objectives would be met for all alternatives except Alternative 1, by a combination of treatment processes, containment, and/or a Site Management Plan utilizing deed and use restrictions.

6.7.6 Implementability

Alternative 1 would be the easiest to implement. Alternative 2, with substantial excavation, would be the most difficult to implement. Treatment Alternatives 3 and 4 would not be overly difficult to implement, but would all require sampling and analysis, bench/pilot-scale testing, and controls during implementation. It would be difficult to construct the vertical barrier in Alternative 5. Further, construction of Alternative 5 would require a Site-specific system design to determine if, given the Site hydrogeology, an adequate configuration of vertical barriers and treatment area could be developed which would not negatively affect the surrounding groundwater flow system.

6.7.7 Cost

A review of costs for each alternative indicates that Alternative 2 has the highest capital cost followed in descending order by Alternatives 4, 5, 3, and 1. Alternative 5 has the highest annual OM&M cost, followed in descending order by Alternatives 3 and 1, 2 and 4. Alternatives 1 and 5 are anticipated to continue for 30 years as compared to the 10-year period of OM&M for Alternatives 2, 3, and 4.

In ascending order, the lowest total present worth cost is for Alternative 1 followed by Alternatives 3, 4, 5, and 2 which has the highest total present worth cost.

7.0 RECOMMENDED REMEDY AND CONCEPTUAL DESIGN

7.1 Selection of Recommended Alternative

Alternatives 1 and 5 were rejected because they provide limited protection to human health and the environment, do not satisfy RAOs for soil or groundwater except through site management controls and restrictions, and do not satisfy SCGs. Additionally, Alternative 5 would be difficult to implement and requires the longest and most costly OM&M treatment effort.

Alternatives 2, 3, and 4 are protective of human health and the environment and would meet RAOs and SCGs for air and groundwater. Alternative 2 would meet RAOs and SCGs for soil in the shortest time period; Alternative 3 would require a longer time period; Alternative 4 would meet RAOs for soil and soil SCGs over portions of the Site.

Drawbacks of Alternative 2 include implementation issues related to: excavation at depth in the saturated zone, especially in the Medical Office Building parking lot; the potential for air emissions during excavation; the cost for disposal of water collected during dewatering; impacts to nearby residents and businesses during excavation, transportation, and backfill activities; and the time frame required for remediation. Alternative 2 is also the most expensive alternative.

Drawbacks of Alternative 3 include the uncertainty in the effectiveness of ISCO at treating NAPL saturated soils at MGP sites and treatment endpoint and number of injection applications required (i.e., cost escalation risk) due to the large volume of NAPL saturated soils.

Based on the evaluation, Alternative 4 - Excavation of Remaining Shallow Source Soil, In Situ Solidification, and Bioremediation of the Dissolved Phase Groundwater Plume is the recommended remedy for the site. When combined with implementation of the IRM and the vapor intrusion mitigation program, Alternative 4 includes proven technologies that are protective of public health and the environment, requires a shorter implementation time frame for construction as compared to other alternatives, and meets remedial action objectives and SCGs for the Site. It eliminates source material within the top 8 ft of the Site, allowing for a variety of future Site uses in accordance with 6 NYCRR Part 375. NAPL is recovered to the extent practicable during the IRM and soil source material is solidified and encapsulated, restricting future leaching of contaminants to groundwater and volatilization to vadose zone soils.

The Recommended Remedy is comprised of:

1. Excavation and off-site treatment of shallow source material at the Site to a general depth of 8 ft and removal of all MGP remnant structures within the solidification area.

2. Continued regular product removal through monitoring and product recovery wells (as initiated in the IRM) until ISS is implemented.

3. Solidification of soil source material (including remaining NAPL) to a minimum depth of 34 ft with vapor emission controls if necessary.

4. Where feasible as based on mixing equipment capabilities, solidification of intermittent discreet zones of NAPL below 34 ft bgs and up to 60-70 ft bgs will be assessed. It is assumed that an additional 30,000 cy of soil to a depth of 70 feet may be solidified, adding approximately $2,900,000 to the estimated capital cost.

5. All areas of solidification will be restored with 4 to 8 ft of clean backfill to the ground surface to minimize the future risk of direct contact with solidified soils.

6. Land use restrictions related to shallow groundwater use for potable purposes and prevention of direct contact with solidified soils.

7. Installation of groundwater bioremediation wells within the downgradient groundwater plume.

8. Annual sampling and analysis of groundwater for BTEX and PAH compounds, as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity.

9. Soil vapor intrusion mitigation through air monitoring and installation of sub-slab depressurization systems as deemed necessary.

10. An annual report would evaluate OM&M activities.

11. Five-Year Review would evaluate remedial activities (earlier reviews may be performed if supported by the data).

A conceptual model of the implementation of Alternative 4 at the Site is illustrated in Figure 7-1. Alternative 4 meets remedial action objectives including the NYSDEC standards, criteria and guidance for the Site as described below:

Soil RAOs

Eliminate or reduce, to the extent practicable, non-aqueous phase liquid (NAPL) and MGP-related contamination sources that contribute to soil, air, soil vapor and groundwater contamination.

Prevent, to the extent practicable, human exposure to MGP-related chemicals present in surface and subsurface soil at and around the Site at levels exceeding SCGs.

Soil RAO Compliance – IRM product recovery and ISS within the source area would eliminate the DNAPL plume and contain source material to 34 ft bgs. Additionally intermittent discrete areas of deeper NAPL-saturated soils may be treated, where feasible. Containment of the source material would mitigate contaminant contributions to soil, air, soil vapor, and groundwater. Human exposure to MGP-related chemicals would be prevented through the excavation of MGP-related remnant structures and contaminated shallow soil to a depth of 8 ft.

Air and Soil Vapor RAOs

Prevent, to the extent practicable, potential inhalation of MGP-related chemicals exceeding SCGs in ambient and indoor air on and near the Site.

Prevent, to the extent practicable, utility worker exposure to soil vapor off-site.

Air and Soil Vapor RAO Compliance – Excavation of contaminated shallow source material soil and solidification would remove or encapsulate the majority of material that has the potential to impact air and soil vapor. Air monitoring results following solidification will determine the need for installation of vapor sub-slab depressurization systems to mitigate potential inhalation in ambient and indoor air.

Groundwater/NAPL RAOs

Reduce or mitigate NAPL, to the extent practicable, to decrease the source of chemicals that contribute to soil, air, soil vapor and groundwater contamination.

Prevent or mitigate, to the extent practicable, off-site migration of groundwater contamination resulting from site-related contaminants.

To restore, to the extent practicable, groundwater impacted by Site related MGP contaminants of concern to meet ambient water quality standards and guidance values.

Groundwater RAO Compliance – IRM product recovery and subsequent solidification would eliminate the DNAPL plume and encapsulate the mass of contaminants into a low permeability soil-cement monolith. Leaching of contaminants to groundwater, which currently occurs from the NAPL and through advective and dispersive transport via the groundwater, would be restricted to slow diffusive transport based on concentration gradients and not on groundwater flow through contaminated soils. With the source soils contained, groundwater contaminant levels will be significantly reduced. Bioremediation would further reduce the concentration of contaminants in groundwater.

7.2 Conceptual Design

Components of the recommended remedy are proposed in the following sequence:

1. IRM regular product removal from the monitoring and product recovery wells will be based on the degree to which product is present in the wells and will continue until either the individual well(s) no longer produces product, or the solidification remedy is ready for implementation (following design approval and contractor procurement).

2. Soil sample collection for bench-scale testing of solidification mix designs and leachability reduction evaluation.

3. Shallow source material excavation, and delineation of treatment limits for areas at the fringe limits of source material.

4. Solidification activities may run concurrently with excavation prior to backfilling of the open (excavated) areas, or may commence following excavation, as determined during the remedial design considering construction sequencing needs related to work on non-KeySpan-owned properties.

5. The Site will be restored to grade and vegetated. Alternate surface restoration plans will be determined during the design phase and identified in the Site Management Plan based on anticipated Site reuse. Off-site properties will be restored to similar surface conditions/uses as pre-remediation conditions.

6. Depending on the treatment method that is selected, field testing may be conducted to support design of the groundwater bioremediation system.

7. Potential well locations to enhance intrinsic aerobic bioremediation of the dissolved phase groundwater plume are shown on Figure 5-6.

8. Groundwater monitoring will occur with annual sampling and analysis for BTEX and PAH compounds, as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity.

9. Soil vapor intrusion mitigation through air monitoring and installation of sub-slab depressurization systems as deemed necessary will be performed.

10. An annual report will document OM&M activities.

11. A Five-Year Review to evaluate remedial activities.

7.2.1 Regular Product Removal

Approximately 24 new product recovery wells are proposed for the IRM Remedial Action Work Plan proceeding independently of the FS/RAP. These recovery wells, along with existing monitoring wells, will be used to recover NAPL until such time as they no longer produce recoverable product, or they must be removed due to source remediation implementation. It is anticipated that NAPL will be removed regularly by a method found to be acceptable during the IRM, either through pumping or hand bailing. The frequency and method of NAPL collection will be adjusted for individual wells, based on the degree to which product is present in the wells, (i.e., the NAPL recharge rate is determined). Collected NAPL will be drummed and/or collected in a central above-ground storage tank and subsequently transported off-site for treatment/disposal.

7.2.2 Source Material Excavation

Remediation will include the excavation and off-site disposal of shallow (generally to a minimum 8-foot depth) source material soils in areas not previously excavated during the IRM, which concentrated on the north-central portion of the Site. Additionally, in order to prepare the Site for solidification, remnant MGP structures, foundations, piping, utilities, and large debris that can interfere with solidification equipment will be removed for off-site disposal. A temporary enclosure building will be constructed and moved as necessary to completely contain the active areas of excavation. The building will have an air handling system to mitigate the potential impact of the excavation activities on air quality of the surrounding areas. The excavated source materials will be appropriately disposed of off-site for thermal treatment. Excavation areas will be restored to pre-existing grades, or as determined to be necessary for continued site remediation through solidification, with clean backfill, topsoil, and vegetation.

Excavated source materials will be disposed at an approved facility. The following thermal treatment facilities have been identified for this project:

- Environmental Soil Management (ESMI) of New Jersey, LLC
  75 Crows Mill Road
  Keasbey, NJ 08832
  Phone: (732) 738-6000
  NJDEP # 1225001522

- Clean Earth Philadelphia
  3201 South 61st Street
  Philadelphia, PA 19153-3592
  Phone: (215) 724-5520
  Permit # 301220

- Clean Earth of Southeast Pennsylvania
  7 Steel Road East
  Morrisville, PA 19067
  Phone (215) 428-1700
  Permit # 301254

- Clean Earth of New Castle, Inc.
  94 Pyles Lane
  New Castle, DE 19720
  Phone: (302) 427-6633
  Permit # SW 95/07

- Casie Protank
  3209 North Mill Road
  Vineland, NJ 08360
  Phone (856) 696-4401
  Permit # Class B CBG030002 (former # 0614001450)

<u>Excavation Sequencing</u>

The components of excavation will generally be sequenced as follows:

1. Site mobilization activities.

2. Clearing (not grubbing) of any woody vegetation in areas to be excavated. Disposal of cleared material off-site.

3. Installation of a shoring system within the limits of excavation such as areas of deepest excavations, along property lines, or where otherwise deemed necessary

4. Erection, and movement as needed, of a temporary building over all areas to be excavated.

5. Installation of an air handling system to provide a safe working atmosphere within the temporary building and to control the release of odors and gasses to the surrounding area.

6. Excavation of shallow source materials to the limits determined during the Design. Excavation in the area of the Natural Gas Regulator Station will require additional health and safety measures and/or coordination of temporary shut down of utilities.

7. If necessary, collection and laboratory analysis of post-excavation samples for waste characterization required by the waste disposal facility.

8. Stockpiling of excavated source materials, if necessary, within the temporary building or covering stockpiles if the temporary building is moved prior to stockpile removal. Loading of excavated source materials into trucks and transportation to, and disposal at, the pre-selected disposal facility.

9. Backfill and restoration of excavation areas as appropriate for continued site remediation through solidification.

Temporary Building

Because VOCs and odors will be released during excavation, a temporary building of a sprung structure type will be installed over each excavation area prior to start-up of excavation operation in that area. The building will have an air handling system to prevent the discharge of odors and VOCs to the surrounding community. To expedite construction, the building would be moved between excavation areas once an excavation area has been satisfactorily backfilled to completion.

The area in which the building is to be erected will be cleared of woody vegetation. The stumps will not be grubbed. The cleared vegetation will be stockpiled separately on clean soil and disposed of off-site. All excavated source material will be loaded directly onto waste hauling trucks inside the building. After excavation and backfill of an area is completed, the building will be moved to cover the next excavation area.

The temporary building will completely cover any active excavation area. For those proposed areas that are larger than the building, the source material will be excavated and backfilled in stages and moved as needed from stage to stage.

The air handling system of the temporary building will be designed to accomplish the following two objectives:

1. To maintain a safe working atmosphere within building. The volume of air within the building will be turned over approximately 4 to 5 times every hour to ensure that soot, dust, carbon monoxide and other contaminants are removed. The requirements for work-zone air quality specified in the Contractor's Health & Safety Plan (HASP) will be enforced within the building.

2. To clean the exhaust from the air handling system of dust, VOCs and odors. The air handling system will be equipped, at a minimum, with carbon filters and in-line particulate filters which will remove any dust and thereby minimize the potential for "blinding" of the carbon units. The exhaust stack of the system will discharge at least 10 ft above the ground and be directed away from all personnel and/or equipment. The performance of the filters on the air handling system will be monitored as they impact the air quality at the site perimeter.

If the level of noise created by the air handling system is considered to be excessive for the surrounding community and/or potentially creates an unsafe work atmosphere, the contractor will be required to attenuate the noise via temporary foam panels, enclosures, or other means as necessary.

In addition to the air handling system, the contractor may be required to use odor suppressants and foams to mitigate odors and VOC concentrations, vent vehicle exhaust gases directly out of the temporary building with hoses, and put workers in various types of respiratory protection. These measures must be readily available and implemented with no delays in construction. Monitoring of air within the structure, as well as these and other mitigation measures will be required to be addressed in the contractor's HASP.

Excavation, Transportation, Off-Site Disposal

Source material will be excavated within the temporary building from the pre-defined limits of excavation. All excavation equipment will be kept within the building during the work and will be decontaminated (steam-cleaned) before being removed from the building. Excavation sidewalls without shoring systems will be sloped to facilitate visual confirmation of source material limits except along the easternmost and westernmost limits and in shored areas.

Soil source material will be loaded onto haul trucks for transportation and disposal at the off-site thermal treatment facility.

Site Restoration

All areas excavated during Site remediation will be backfilled to grade, or at an elevation deemed necessary for performing ISS. Surface water flow patterns will follow those established during the Remedial Design. Backfill will be clean, compacted granular soil.

7.2.3 Solidification

Technology Description

In situ solidification, as applied to MGP Sites with NAPL, accomplishes the following during treatment:

- ISS achieves source control through encapsulation and soil hydraulic conductivity reduction;
- ISS minimizes long-term impacts to groundwater by markedly reducing the leaching of MGP-related constituents to groundwater;

- ISS eliminates mobile NAPL by homogenizing it with the surrounding soils, reducing its concentration to below its residual saturation point and blending the impacted soils with cementitious reagents, creating a low-hydraulic conductivity solidified monolith.

Solidification is an established technology that has been used for over 20 years to treat a variety of residual wastes at industrial sites. Solidification creates a large monolithic block with a hydraulic conductivity much less than the surrounding soil. Groundwater flows around the monolith, rather than through it, therefore there is no advective transport of contaminants from within the treated soil mass to the surrounding environment. Solidification has been applied to MGP sites since 1990, when this remedial technology was applied at the Southern Company's Columbus, Georgia MGP Site, adjacent to the Chattahoochee River (EPRI, 2000, 2003). Since then several additional MGP sites have utilized ISS including Macon, GA (Oosterhoudt, et al., 2004), Augusta, GA (Portland Cement Association, 2004), Des Moines Iowa, Exeter, NH (Geo-Con, 2003), and Cambridge, MA (Jayaram, et. al., 2002) among others. Additionally, MGP sites in New York have successfully implemented ISS including the former Nyack Gas Plant in Nyack, NY, Plattsburgh, NY, and the Cortland/Homer Former MGP Site in Homer, NY (Remedial Action Plan approved for implementation). Since ISS was first used at an MGP site in 1990, the test methods and approaches have evolved over time as the collective understanding of the mechanisms involved in ISS are better understood by the remediation engineering, remedial construction, and academic communities.

As described previously, ISS is most commonly applied with large mixing augers, using overlapping treatment columns, as shown in Figure 7-2. Implemented in this manner, cementitious grout (typically between 10 and 30% grout to soil ratio on a dry weight basis) is injected into the soil through mixing augers, homogenizing the soil vertically within the mixing column. Typical auger penetration rates are 1 to 4 feet per minute, and typical solidification production rates are on the order of 400 to 1,000 cy treated per day. Other solidification grout application methods used, based on site-specific circumstances, include blender rakes, excavator rotary blender heads, long-reach excavators, and jet grout injection. Site conditions conducive to ISS include:

- Limited overhead restrictions for crane operation;
- Pre-excavation of underground obstructions;

- Readily available water source (125 gpm typical);
- Relatively flat ground surface;
- Locations where open excavations would result in excessive odors; and
- Sufficient laydown area for a grout batch plant near the work area, and a vapor collection and treatment system (if necessary).

A typical layout for ISS implementation was shown on Figure 4-4. Full-scale ISS implementation is the final phase in a three-phase process required to effectively implement ISS. These three phases include:

- **Bench-scale treatability testing** to select the appropriate binders and to determine the ability to meet performance criteria;
- **Pilot-scale field testing** to confirm the results of the treatability testing, optimize the selected mix design(s) for field-scale conditions, and to assess the performance of the selected full-scale equipment. This phase generally includes a more intensive field quality control program than site-wide full-scale implementation; and
- **Full-scale implementation** using the information gained from the bench- and pilot-scale testing to achieve the desired performance criteria.

Typical Performance Criteria

Strength - Unconfined compressive strength (UCS) is the most common parameter used to evaluate the physical performance of solidified soils. The strength of the solidified soils affects the following soil characteristics:

- Load bearing capacity as a subgrade for pavements or environmental covers, for construction equipment access during in situ mixing, or for building foundations;
- Workability or handling ease for excavation and backfill to install utilities or foundations, spreading and subgrade shaping for soil cover construction, or excavation and loading for disposal;
- Serves as a measure of adequate physical/chemical bonding of the solidified soils; and

- Serves as an indicator of long-term durability.

The USEPA has recommended that solidified waste destined for land burial have a UCS of greater than or equal to 50 psi (USEPA, 1986a, 1986b, 1989). URS' experience with other solidification projects indicates that the post-solidification strength criteria determination is site-specific. The minimum strength criteria should be sufficient for construction equipment access over solidified areas during remedial construction, for supporting environmental covers (if required), and for future site uses. A maximum upper limit of UCS of 200 to 500 psi may be desirable to maintain the soil in an excavatable form should the need arise in the future for the construction of underground utilities, footings, or foundations that require penetration of the solidified soils.

Hydraulic Conductivity - The USEPA has recommended that stabilized waste destined for land burial have a hydraulic conductivity of less than $1x10^{-5}$ cm/sec (USEPA, 1986a, 1986b, 1989). While diffusion mechanisms limit the rate of contaminant transport at hydraulic conductivities less than $1x10^{-6}$ cm/sec, analysis has shown that when two adjacent soil materials differ in hydraulic conductivity by two orders of magnitude or greater, water will follow the path of least resistance by flowing mainly around the lower permeability soil and through the higher permeability soil (Environment Canada, 1991). Therefore, determining the hydraulic conductivity performance criteria is best determined during the bench-scale testing phase, where the UCS, permeability, and leaching characteristics can be evaluated collectively before determining the performance parameters to be used in the field.

Durability/Weatherability - Durability is a measure of a solidified soil's ability to withstand repeated cycles of wet/dry conditions and freeze/thaw conditions without significantly impacting the structural integrity of the solidified soil monolith. Tests to assess this parameter for solidified soils were initially utilized to ensure that the solidified waste will remain intact during placement operations in a landfill, until it was covered with soil and protected from exposure to the elements (Environment Canada, 1991). The typical assumption was that erosion of the structural integrity of the solidified matrix could lead to increased long-term contaminant mobility.

Early MGP solidification projects utilized durability/weatherability evaluations as a quality control parameter with a maximum mass loss criterion of 15%. Cement-based solidification mixes applied at MGP sites have typically shown less than 3 % mass loss and it is no longer considered a critical performance parameter, especially for sites where the majority of the solidified soil is well below the ground surface and/or below the water table and where a clean soil cover is placed over the solidified soils. A post-solidification study performed 10 years after solidification at the Columbus, Georgia MGP site demonstrated that the solidified soils continue to meet their original performance criteria and show no sign of structural deterioration (EPRI, 2003).

Leachability Reduction – Containment and encapsulation of source material through solidification has, as a primary objective, the reduction of leaching of soluble contaminants to groundwater. ISS, as applied to MGP sites, typically achieves greater than a 90% reduction in leaching, and often much greater. Leachability of various mix designs is commonly determined using a static leaching test on solidified soil specimens that have cured for at least 28 days. The non-destructive leaching test is based on ANSI/ANS-16.1 (American Nuclear Society, 1986), where the solidified specimens are submerged in deionized water for specified leaching intervals, approximating the in-place conditions that the solidified monolith will encounter. The protocol consists of tank leaching of continuously water- saturated monolithic material with periodic renewal of the leaching solution. The vessel and sample dimensions are chosen so that the sample is fully immersed in the leaching solution, using a liquid-to-surface area ratio of 10 milliliters of deionized water for every square centimeter of exposed solid surface area. The vessel is covered and the headspace is minimized to reduce the loss of volatile organics through volatilization. After specified time intervals of 14 days, 28 days, and 56 days, the leachate is analyzed for contaminants of concern and the specimens are re-submerged in fresh deionized water. Analysis of the results after at least three successive leaching intervals allows for evaluation of the rate and mechanism of leaching.

With the development of the ANS 16.1 leaching protocol for solidified specimens, an index value called the Leachability Index was derived, which is a dimensionless index value related to the leaching characteristics of solidified waste materials. As described by Environment Canada (Environment Canada, 1991), modeling of Fickian Diffusion has allowed the development of predictive curves for using the Leachability Index to predict the cumulative fraction leached over a 100-year time span. This modeling indicates that for large monoliths, the cumulative fraction leached after 100 years would not exceed 10 percent if the Leachability Index is larger than 9. It is not uncommon for solidified MGP soils with a permeability of less than $1x10^{-6}$ cm/sec to achieve a Leachability Index greater than 9. In addition to determining a Leachability Index, a direct comparison of leaching characteristics for unsolidified and solidified soils or a comparison of leaching test concentrations of solidified soil specimens to groundwater concentrations in source soil areas can also provide a reasonably representative correlation of mass flux reduction accomplished through solidification.

Free Liquids – The presence of free liquids is a qualitative evaluation of the thoroughness of mixing/homogenization, and of effectiveness of solidification at eliminating NAPL and restricting groundwater flow through the solidified soil. No free liquid is the performance criteria and is typically assessed through visual observation of solidified soils and split specimens.

Site-Specific Implementation Considerations

Treatment through ISS is viable for the entire mass of soil and NAPL source material (approximately 171,000 cy to 34 ft bgs), which includes areas on the Site, the LIRR ROW, the municipal property near the recharge basin, a portion of Intersection Street, the majority of the Medical Office Building parking lot, and a portion of Wendell Street. These areas are shown on Figure 7-3. A portion of this source material (approximately 27,000 cubic yards) will be excavated from the Site for off-site disposal to remove contaminated soil to 8 feet and remnant abandoned MGP infrastructure prior to solidification. This results in a solidification volume of the primary source material of up to 144,000 cubic yards. While KeySpan intends to negotiate access to all non-owned property to implement solidification, it is important to note that, outside of the Site and the Medical Office Building parking lot, the volume of source materials present represents less than 3% of the overall site-wide source material. Therefore, if access to some of these "fringe" properties (i.e., Wendell Street, the LIRR ROW or the municipal property) cannot be obtained for ISS, other remedial technologies may be evaluated for residual contamination.

With ISS of the source areas, some limited intermittent areas of deeper residual NAPL impacts are present that will also be solidified, where feasible, as shown on Figures 7-1 and 7-3. The additional volume of deeper soils to be solidified if feasible is approximately 30,000 cubic yards. During bench-scale testing, the shear resistance during mixing of the soils with solidification reagents can be evaluated at varying moisture contents, reagent strengths, and reagent types. Admixtures can also be evaluated which lubricate the mixing. These bench-scale measurements can then be correlated to the torque required to overcome shear resistance, which determines the necessary equipment size and power requirements. While this information will not guarantee the ability to mix to a given depth, it will provide valuable data to identify equipment, reagent, and admixture combinations to maximize the achievable mixing depth. Discussions with ISS contractors during the preparation of the FS/RAP indicated that a 60 to 70-foot depth is the practical limit for granular soils. The ability of ISS auger equipment to penetrate 60 to 70 ft. will be evaluated during ISS bench-scale testing to enable reasonable maximum treatment depth expectations for the full-scale design.

The “fringe” properties identified above with minor amounts of source material currently delineated are, in some areas defined by only one investigation location with an estimated impact area illustrated. These areas will require confirmation as part of a delineation investigation to verify the limits and thickness of NAPL-saturated source material. This information will also be useful, in conjunction with utility location information, in assessing the most appropriate solidification application methodology and/or alternate remedial technology.

Overhead and underground utilities must be identified and located while planning ISS implementation. Abandoned utilities may be removed. Some active utilities may be able to be relocated temporarily or permanently. For those underground or overhead utilities that cannot be relocated, alternate solidification methods can be utilized to solidify soils in those areas, typically jet grouting. A detailed utility survey will be performed in all proposed remediation areas prior to final design. KeySpan is currently working with its Site operations personnel to determine the location and status of on-site gas and water utilities and evaluating potential options for temporary or permanent relocation to accommodate remediation. A preliminary plan of utility locations is shown on Figure 7-3. KeySpan is also assessing options for the Natural Gas Regulator Station relative to remediation of source material in that area.

As part of the design phase, optimization of the solidification approach will be performed relative to the depth interval of impacted soils requiring solidification, the thickness of existing clean soil overlying source material, the anticipated volume increase or “swell” (typically 20 to 30%), and the cost to solidify versus the cost to excavate and replace clean overburden soils. For example, in the Medical Office Building parking lot where the majority of impacts are greater than 16 ft bgs, it may be cost-effective to excavate clean overburden soils to 8 to 16 feet bgs. This excavated clean soil could be used to backfill the top 4 to 8 feet in other solidified areas (particularly where the top 8 ft will be excavated source material for off-site disposal), allowing swell material generated through solidification to remain in place, and restore the solidified area to pre-construction grades with stockpiled clean site soil. Consideration will also need to be given to sequencing construction to accommodate temporary lost use of properties during remediation such as the Sold property, the Medical Office Building parking lot, West Intersection Street, and Wendell Street.

The bulk of the remedial excavation work will be performed within the temporary structure that will dampen sound. The Contractor's Construction Operations Plan (COP) will be required to address general noise mitigation. Any pertinent local noise ordinances of the Villages of Garden City and Hempstead will be applicable, as will possible mitigative measures that must be considered by the Contractor if excessive noise levels occur. To ensure minimal noise levels, the Contractor's equipment will be functioning properly to reduce noise levels and idling of trucks will be minimized.

Vapor emissions during solidification can generally be controlled/managed with foaming or other minimal engineering controls when the target impacted material is beneath several feet or more of clean soil that will also be treated. In situations where vapor control is a significant concern and or risk, vapor collection hoods under vacuum can be used with the solidification equipment to collect vapor emissions from the active treatment zone and run through a vapor treatment system as shown on Figure 4-4.

7.2.4 Bioremediation

The downgradient plume has lower level concentrations, in the range of 50-100 µg/L. However, bioremediation is proposed within the dissolved-phase groundwater plume at and/or downgradient of the Site following a review of groundwater conditions after the ISS is completed. Bioremediation would include technologies that promote and sustain aerobic conditions in the saturated zone. Methods would be used that provide oxygen introduction with ambient air or high-purity oxygen gas; or introduction of an oxygen releasing amendment as a solid or slurry (e.g., Oxygen Release Compound [ORC®] or EHC-O™). Solidification above or upgradient of an aerobic bioremediation system may necessitate aquifer-buffering amendments to maintain neutral aquifer conditions. Additional microbial cultures can be introduced to the subsurface if determined necessary based upon evaluation of the naturally occurring microbial community.

As with all in situ applications, subsurface distribution is a key component in the potential success of bioremediation. In general, microbial communities do not necessarily move with groundwater and are fixed to the soil matrix. Introduction of oxygen and amendments, if necessary, can be accomplished via injection wells, in well inserts (i.e., socks) or through open boreholes. Once a hospitable aquifer is established, microbes may 'bloom' or grow randomly in all directions, which can increase subsurface distribution where surface access is limited or unavailable (i.e., below buildings, utilities, etc.).

Delivery wells can be installed within the downgradient groundwater plume for introduction of oxygen to the saturated zone for bioremediation. Potential well location areas are shown on Figure 5-6, the number of treatment wells will be determined in the design phase. After any design phase testing that may be performed, the system would be designed and installed.

7.2.5 Long-Term Monitoring

Soil Vapor Intrusion Sampling and Mitigation

Soil vapor intrusion testing is being completed in parallel to the FS/RAP. The vapor intrusion sampling program will assess the need for exposure point mitigation system installations as a component of the recommended remedy. This includes installation and operation of sub-slab depressurization systems located at selected occupied buildings as part of the vapor intrusion mitigation. The systems can collect soil gas from beneath the buildings and vent them to the atmosphere. By maintaining a slight vacuum below the basement slab, contaminant vapors are prevented from migrating through cracks and other openings in the basement slab and infiltrating into the indoor air. To date the soil vapor intrusion data indicates that there are no MGP-related soil vapor intrusion issues in the buildings that were tested.

Groundwater

Annual sampling and analysis for BTEX and PAH compounds, as well as dissolved oxygen, nitrate, nitrite, sulfate, iron, methane, ethane, alkalinity, oxidation-reduction potential, pH, temperature and conductivity would be performed in monitoring wells. It is assumed that the majority of on-site monitoring wells will be removed during Site remediation. Remaining existing monitoring wells which may be included in the post-remediation groundwater monitoring program are: HIW-03S,I,D; HIMW-05S,I,D; HIMW-08S,I,D; HIMW-12S,I,D; HIMW-13SI,D; HIMW-14I,D; HIMW-15I,D. The number and location of monitoring wells used for groundwater monitoring will be determined during the development of the OM&M Plan following completion of the remedy.

Annual Report and Five-year Review

An annual report will present and evaluate OM&M activities such as Site maintenance, bioremediation efforts, and monitoring results. A Five-Year Review will be performed to evaluate past and on-going remedial activities at the site, and, as appropriate, provide recommendations for either maintaining the current level of effort, reducing, or furthering remedial activities at, or downgradient of, the Site.

7.2.6 Community Air Monitoring Plan

A Community Air Monitoring Program (CAMP) will be developed in accordance with NYSDEC DER-10, and in particular with the NYSDOH Generic Community Air Monitoring Plan as presented in DER-10. The purpose of an air monitoring program is to prevent and/or mitigate potential short-term emissions and off-site migration of Site-related contaminants during remedial construction by early detection in the field. Early detection of emissions and associated contingency measures will mitigate the potential for the community and general public to be exposed to contaminants at levels above accepted regulatory limits and guidelines. Worker protection and community air monitoring will be conducted using a combination of real-time air monitoring for total VOCs (TVOCs) and particulates (i.e., dust) at on-site and perimeter locations.

At this preliminary stage, it is anticipated that the objectives of the CAMP would be as follows:

- Provide an early warning system to alert the Contractor and/or Agencies that concentrations of TVOCs, dust, or odors in ambient air are approaching the agreed-upon Site-specific action levels due to site conditions.
- Provide details for a site contingency plan that are designed to reduce the off-site migration of contaminants/odors if action levels are exceeded.
- Determine whether construction controls are effective in reducing ambient air concentrations to below action levels, and make appropriate adjustments.

- Develop a permanent record that includes a database of perimeter air monitoring results and meteorological conditions, equipment maintenance, calibration records, and other pertinent information.

7.3 Additional Investigations

Surface Soil Delineation

A delineation program to further define the lateral extent of identified surface soil areas with concentrations above the NYSDEC 375 soil cleanup objectives has been submitted to the NYSDEC for review.

Excavation Delineation

A delineation program similar to that conducted prior to the IRM may be performed to delineate the extent of required shallow source material excavation in the remaining soil source material areas shown on Figure 7-3. Details of the program will be similar to that provided in the IRM Remedial Action Work Plan (URS, 2007) using a visual cleanup standard.

Source Material Perimeter ('Fringe Area') Supplemental Delineation

Source material limits delineation may be performed to confirm the limits of NAPL-saturated source material where there is some uncertainty based on lack of a sufficient number of data points on the outer limits. Specific areas to be targeted for additional source material delineation include the LIRR ROW, Wendell Street, and the area west of the Site.

Solidification Bench-Scale Treatability Study

A bench-scale treatability study will be performed on source material soil samples from the site. Typically average and worst case conditions are evaluated in determining solidification mix reagents design as well as the on-site mixing processes, ideally, composite samples are collected and homogenized to reflect in situ mixing conditions, rather than testing mix designs on discrete samples. In order to generate the sample volumes required to perform bench-scale treatability testing (typically 2 to 3 five-gallon buckets), representative samples can be obtained from drill auger flights at the depth interval of interest.

The bench-scale treatability study is typically designed as a tiered approach whereby the mix strength is narrowed down by assessing strength and permeability, then testing the leachability of cured specimens on those that meet strength and permeability performance criteria. The optimum mix design is one that meets the project performance criteria, is cost effective in terms of material costs and availability, is pumpable as a fluid grout, and has sufficient working time to mix, store, inject, blend with soils. Quality control samples of solidified material are collected for curing and testing.

Design-Phase Testing for Bioremediation

Design-phase testing may be performed to evaluate the extent of ongoing biodegradation and determine if amendments required. Additional parameters such as soil buffering capacity, microbial community strength, and nutrient concentrations could be evaluated. The potential for vapor migration and/or gas production would also be considered if field-scale testing is performed. Impacts from ISS within the source area would require an evaluation of contaminant mass removal.

7.4 Preliminary Cost Estimate

A Preliminary Cost Estimate for the recommended remedy includes the cost of Alternative 4 from Table 6-1 of $44,030,200, which includes ISS to a depth of 34 feet, plus an estimated cost of $2,900,000 for possible additional ISS to a depth of approximately 70 feet for a preliminary cost estimate of $46,930,200 or approximately $47 million. The resulting preliminary cost estimate includes the IRM; ISS to a depth of generally 34 feet and 70 feet in selected area; bioremediation, the vapor mitigation program and groundwater monitoring.

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TABLES

TABLE 2-1
NAPL THICKNESS AND RECOVERY MEASUREMENTS

Well #	DNAPL thickness (ft) (12/03)	DNAPL removed (gal) 12/01 – 12/03	DNAPL thickness (ft) (4/07)	DNAPL thickness (ft) 5/07	DNAPL removed (gal) 5/07	DNAPL thickness (ft) 6/07	DNAPL removed (gal) 6/07	DNAPL thickness (ft) 8/07	DNAPL removed (gal) 8/07	DNAPL thickness (ft) 9/07	DNAPL removed (gal) 9/07	DNAPL thickness (ft) 10/07	DNAPL removed (gal) 10/07	DNAPL thickness (ft) 11/07	DNAPL removed (gal) 11/07
01S	3.77*	7.25	0.95*	1.1*	5	0.8*	5	0	0	0.02	0.0034	trace	0	-	0
01I	0	0	7.25	7.3	8	4.65	10	**	**	3.65	0.62	3	0.93	2.96	0.2
06S	3.4	9.5	1.9	4.25	10	1.05	5	1.07	4	0.5	0.09	2.2*	0.63	0.5	2
07S	3*	3.35	1.16	1.85	6	0.93	4	1.38	3	2.35*	0.4	0.54*	0.12	0.67	0.6
10S	0	0.5	0	-	-	-	-	-	-	-	-	-	-	-	0
11S	0*	3.825	0*	0*	1	0*	1	0*	0	*	0	*(0.17'LNAPL)	0	-	0
16S	4.25*	0	2.4	NA	NA	NA	NA	NA	NA	NA	NA	3.5	0.6	2.28	3
16I	5.3	0	4.6	NA	NA	NA	NA	NA	NA	NA	NA	5.6	0.95	3.52	3
17S	5.75*	0	1.06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.05	2
18S	1.15	0	2.62	2.42	3.5	0.4	1	1.48	5	0.25*	0.04	0.06	0.01	0.02	0.6
19S	0.41	0	1.5	1.35	4	0.05	3	0	0	0.15	0.03	trace	0	trace	0
PZ-08	0	0	2.8	1.42	6	0.97	3	1.58	5	1.43	0.24	1.5	0.52	1.35	0.75
Total Gallons Removed		24.425			43		32		17		1.42		3.76		12.15

NA – no access to well

- well not included in current measurement program

* LNAPL sheen present

** pump stuck in well casing

10/07 and subsequent measurements were obtained by a different individual and are the maximum thickness of DNAPL and total recovered product during all rounds of the month

TABLE 2-2
POTENTIALLY APPLICABLE STANDARDS, CRITERIA AND GUIDANCE

Division/ Agency	Title	Standard or Guidance	Requirements
DAR/ NYSDEC	Air Guide 1 – Guidelines for the Control of Toxic Ambient Air Contaminants	G	▪ Control of toxic air contaminants ▪ Screening analysis for ambient air impacts ▪ Toxicity classifications ▪ Ambient standards – short term/annual
DAR/ NYSDEC	6 NYCRR Part 200 (200.6) – General Provisions	S	▪ Prohibits contravention of Ambient Air Quality Standards or causes of air pollution
DAR/ NYSDEC	6 NYCRR Part 201 - Permits & Certificates	S	▪ Prohibits construction/operation without a permit/certificate
DAR/ NYSDEC	6 NYCRR Part 211 (211.1) – General Prohibitions	S	▪ Prohibits emissions which are injurious to human, plant, or animal life, or causes a nuisance
DAR/ NYSDEC	6 NYCRR Part 212 – General Process Emission Sources	S	▪ Establishes control requirements
DAR/ NYSDEC	6 NYCRR Part 257 – Air Quality Standards	S	▪ Applicable air quality standards
DER/ NYSDEC	TAGM HWR-89-4031 Fugitive Dust Suppression and Particulate Monitoring Program at Inactive Hazardous Waste Sites	G	▪ Dust suppression during Interim Remedial Measures/Remedial Actions
DER/ NYSDEC	TAGM HWR-92-4030 Selection of Remedial Actions at Inactive Hazardous Waste Sites	G	▪ Remedy selection criteria/evaluations
DER/ NYSDEC	TAGM HWR-92-4042 Interim Remedial Measures	G	▪ Define and track Interim Remedial Measures (IRMs)
DER/ NYSDEC	TAGM 4061 – Management of Coal Tar Waste and Coal Tar Contaminated Sediment From Former Manufactured Gas Plants (MGPs)	G	▪ Coal tar waste and coal tar contaminated soils and sediment that exhibit the toxicity characteristic for Benzene (D018) may be conditionally exempt from 6 NYCRR Parts 370 – 374 and 376 when they are destined for permanent thermal treatment
DER/ NYSDEC	6 NYCRR Part 375 – Inactive Hazardous Waste Disposal	S	▪ Remedial program requirements ▪ Private party programs; state funded

TABLE 2-2
POTENTIALLY APPLICABLE STANDARDS, CRITERIA AND GUIDANCE

Division/ Agency	Title	Standard or Guidance	Requirements
	Site Remediation Program		programs; state assistance to municipalities
DFW/ NYSDEC	Fish and Wildlife Impact Analysis for Inactive Hazardous Waste Sites (FWIA)	G	▪ Habitat assessments ▪ Contaminant impact assessments ▪ Ecological effects of remedies ▪ Remedial requirements ▪ Monitoring ▪ Checklist
DOW/ NYSDEC	Analytical Services Protocols (ASP)	G	▪ Analytical procedures
DOW/ NYSDEC	TOGS 1.1.2 – Groundwater Effluent Limitations	G	▪ Guidance for developing effluent limitations
DOW/ NYSDEC	TOGS 1.1.1 – Ambient Water Quality Standards and Guidance Values	G	▪ Compilation of ambient water quality standards and guidance values
DOW/ NYSDEC	TOGS 1.2.1 – Industrial SPDES Permit Drafting Strategy for Surface Waters	G	▪ Guidance for developing effluent and monitoring limits for point source releases to surface water
DOW/ NYSDEC	TOGS 1.3.8 – New Discharges to Publicly Owned Treatment Works	G	▪ Limits on new or changed discharges to POTWs; strict requirements regarding bioaccumulative and persistent substances; plus other considerations
DOW/ NYSDEC	6 NYCRR Part 702-15(a), (b), (c), (d) & (e)	S	▪ Empowers NYSDEC to apply and enforce guidance where there is no promulgated standard
DOW/ NYSDEC	6 NYCRR Part 700-705 – NYSDEC Water Quality Regulations for Surface Waters and Groundwater	S	▪ 700 – Definitions, Samples and Tests; ▪ 701 – Classifications for Surface Waters and Groundwaters; ▪ 702 – Derivation and Use of Standards and Guidance Values; ▪ 703 – Surface Water and Groundwater Quality Standards and Groundwater Effluent Standards

TABLE 2-2
POTENTIALLY APPLICABLE STANDARDS, CRITERIA AND GUIDANCE

Division/ Agency	Title	Standard or Guidance	Requirements
DOW/ NYSDEC	6 NYCRR Part 750-757 – Implementation of NPDES Program in NYS	S	▪ Regulations regarding the SPDES program
DSHM/ NYSDEC	6 NYCRR Part 364 – Waste Transporter Permits	S	▪ Regulates collection, transport, and delivery of regulated waste
DSHM/ NYSDEC	6 NYCRR Part 360 – Solid Waste Management Facilities	S	▪ Solid waste management facility requirements; landfill closures; construction & demolition (C&D) landfill requirements; used oil; medical waste; etc.
DSHM/ NYSDEC	6 NYCRR Part 370 – Hazardous Waste Management System: General	S	▪ Definitions and terms and general standards applicable to Parts 370-374 and 376
DSHM/ NYSDEC	6 NYCRR Part 371 – Identification and Listing of Hazardous Wastes	S	▪ Hazardous waste determinations
DSHM/ NYSDEC	6 NYCRR Part 372 – Hazardous Waste Manifest System and Related Standards for Generators, Transporters and Facilities	S	▪ Manifest system and record keeping; certain management standards
DSHM/ NYSDEC	6 NYCRR Part 376 – Land Disposal Restrictions	S	▪ Identifies hazardous waste restricted from land disposal
DSHM/ NYSDEC	6 NYCRR Subpart 373-1 – Hazardous Waste Treatment, Storage and Disposal Facility Permitting Requirements	S	▪ Hazardous waste permitting requirements; includes substantive requirements
DSHM/ NYSDEC	6 NYCRR Subpart 373-2 – Final Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities	S	▪ Hazardous waste management standards such as contingency plans; releases from SWMUs; closure/post closure; container management; tank management; surface impoundments; waste piles; landfills; incinerators; etc.
DSHM/ NYSDEC	6 NYCRR subpart 373-3 – Interim Status Standards for Owners and Operators of Hazardous Waste Facilities	S	▪ Similar to 373-2

TABLE 2-2
POTENTIALLY APPLICABLE STANDARDS, CRITERIA AND GUIDANCE

Division/ Agency	Title	Standard or Guidance	Requirements
OSHA/ PESH	29 CFR Part 1910.120; Hazardous Waste Operations and Emergency Response	S	▪ Health and safety
USEPA	40 CFR Part 261 – Hazardous Waste Management System; Definition of Solid Waste; Toxicity Characteristic; Final Rule; Response to Court Order Vacating Regulatory Provisions	S	▪ TCLP may not be used for determining whether MGP waste is hazardous under RCRA

NOTES:

DAR – Division of Air Resources
DER – Division of Environmental Remediation
DFW – Division of Fish and Wildlife
DOW – Division of Water
DSHM – Division of Solid and Hazardous Materials
HWR – Hazardous Waste Remediation
NPDES – National Pollution Discharge Elimination System
NYSDEC – New York State Department of Environmental Conservation
OSHA – Occupational Safety and Health Administration
POTW – Publicly Owned Treatment Work
PESH – New York State Department of Labor’s Public Employee Safety and Health
RCRA - – Resource Conservation and Recovery Act
SWMUs – Solid Waste Management Units
TCLP – Toxicity Characteristic Leaching Procedure
USEPA – United Sates Environmental Protection Agency

TABLE 3-1
NAPL PROPERTIES

Sample ID	Matrix	Temperature °F	Specific Gravity	Density, g/cc	Viscosity	
					centistokes	centipoise
MW-6S	DNAPL	55	1.0727	1.0721	322	346
		70	1.059	1.057	78.9	83.4
		100	1.058	1.050	28.5	29.9
		130	1.057	1.042	14.0	14.6
MW-7S	DNAPL	55	1.0803	1.0797	375	405
		70	1.068	1.065	116	124
		100	1.065	1.058	39.3	41.6
		130	1.063	1.048	17.9	18.7
MW-17S	DNAPL	55	1.0565	1.0559	150	158
		70	1.043	1.041	56.2	58.5
		100	1.040	1.033	22.6	23.4
		130	1.038	1.024	11.1	11.4
MW-1S	DNAPL	55	1.0394	1.0388	65.5	68.0
		70	1.029	1.027	28.5	29.3
		100	1.025	1.018	13.4	13.6
		130	1.018	1.004	7.51	7.53
MW-1S	LNAPL	70	0.9541	0.9521	14.3	13.6
		100	0.9482	0.9416	7.77	7.32
		130	0.9408	0.9276	4.84	4.49
MW-18S	DNAPL	55	1.0645	1.0639	844	898
		70	1.057	1.054	169	178
		100	1.052	1.045	55.2	57.7
		130	1.047	1.032	23.8	24.6
PZ-08	DNAPL	55	1.0953	1.0946	424	464
		70	1.082	1.079	103	111
		100	1.078	1.071	35.1	37.5
		130	1.075	1.059	17.5	18.5
MW-19S	DNAPL	55	1.0836	1.0830	134	145
		70	1.072	1.070	52.2	55.8
		100	1.063	1.056	18.9	19.9
		130	1.060	1.045	11.1	11.6
MW-16I	DNAPL	55	1.0807	1.0800	346	373
		70	1.073	1.071	96.1	103
		100	1.065	1.058	33.5	35.4
		130	1.062	1.047	16.2	17.0
MW-16S	DNAPL	55	1.0782	1.0776	258	278
		70	1.061	1.059	60.4	64.0
		100	1.057	1.050	23.1	24.2
		130	1.054	1.039	12.1	12.5

TABLE 3-1 (Continued)
NAPL PROPERTIES

Fluid ID	Temp., (°F)	Initial Volume, cc	Volume Water, cc	Volume Sediment, cc	Volume of Water and Sediment, %
MW-6S	73	100	0.00	0.50	0.50
MW-7S	71	100	0.00	0.55	0.55
MW-17S	71	100	2.65	0.20	2.85
MW-1S (DNAPL)	71	100	0.00	0.075	0.08
MW-1S (LNAPL)	71	50	4.375	0.025	8.80
MW-18S	71	100	0.00	1.10	1.10
PZ-08	71	100	0.00	0.00	0.00
MW-19S	71	100	20.75	0.03	20.78
MW-16I	74	100	0.00	0.00	0.00
MW16S	74	100	0.00	0.00	0.00

GC Fingerprint Analysis Results for MW-11S – This sample closely approximates but is not an exact match of Fuel Oil Standard #2. Variations in the sample as compared to the standards may be attributed to weathering, evaporation, contamination and/or degradation.

TABLE 4-1
SUMMARY OF REMEDIAL TECHNOLOGY SCREENING
HEMPSTEAD INTERSECTION STREET FORMER MGP

General Response Actions	Remedial Technologies	Description	Screening Comments
No Action	Monitored Natural Attenuation	Naturally-occurring processes would continue to reduce contaminant levels. Monitoring would be performed.	Applicable, retained.
Exposure Point Mitigation	Vapor Intrusion Mitigation Units	Monitoring and sub-slab depressurization units at individual buildings.	Applicable, retained.
Containment	Capping	Low permeability cover to limit infiltration.	Limits future use. Not retained.
		Asphalt cap	Applicable, retained.
	Vertical Barriers	Vertical barriers installed to the top of impermeable layer.	Relatively high permeability of glacial deposits and deep impermeable unit require a substantial depth to install. Retained.
	Funnel and Gate/ Containment and Gate	Three-sided vertical barrier (funnel) or four-sided vertical barrier (containment) with downgradient ozone injection (gate)	Difficult implementation. Containment and gate retained.
Groundwater Collection	Collection Trench	A trench excavated to the required depth and filled with stone.	Limited additional effectiveness in permeable glacial outwash. Not retained.
	Vertical Extraction Wells	Vertical extraction wells drilled to the appropriate depth.	Applicable and proven technology. Retained.
NAPL Recovery	Passive NAPL recovery	Recoverable quantities of NAPL are extracted through periodic hand bailing.	Continued hand bailing/pumping on a determined schedule. Retained for existing wells.
	Active NAPL recovery	Use of product recovery pumps in newly constructed wells.	Applicable, retained.

TABLE 4-1
SUMMARY OF REMEDIAL TECHNOLOGY SCREENING
HEMPSTEAD INTERSECTION STREET FORMER MGP

General Response Actions	Remedial Technologies	Description	Screening Comments
Groundwater Treatment	Bioremediation	Injection of microorganisms, oxygen, and/or nutrients to enhance natural processes.	Effective for dissolved phase groundwater plume following source remediation.
	Groundwater Treatment On-Site	Collected groundwater is treated on-site in a constructed treatment plant prior to discharge to local water treatment facility.	The construction of a treatment plant would be more cost effective for anticipated large quantities of collected water. Retained.
	Groundwater Treatment Off-Site	Collected groundwater is transported off-site for treatment at a local water treatment facility with no pre-treatment.	Not cost-effective for large quantities of collected water. Not retained.
NAPL Disposal	Off-Site NAPL Disposal	Recovered NAPL is disposed off-site in an appropriate facility.	Retained.
Excavation	Soil Excavation with Off-Site Soil Treatment/Disposal	Excavate contaminated soil and transport off-site to a thermal treatment facility.	Applicable, retained.
In situ Treatment	Chemical Treatment	Chemical Oxidation (ISCO) – oxidants are injected into the subsurface through an infiltration gallery in the vadose zone and through injection wells in the saturated zone to destroy contaminants and convert them to non-toxic compounds. Also has been shown to enhance NAPL recovery during treatment.	Effective and implementable at the Site on BTEX and PAHs. Activated persulfate ISCO retained.
		Surfactant enhanced ISCO – low viscosity surfactant solutions with polymer amendments are added to the ISCO process.	May be more effective than ISCO alone. Retained for use at design level if ISCO is selected.
			Not considered effective for high levels of

TABLE 4-1
SUMMARY OF REMEDIAL TECHNOLOGY SCREENING
HEMPSTEAD INTERSECTION STREET FORMER MGP

General Response Actions	Remedial Technologies	Description	Screening Comments
	Biological Treatment	Microorganisms, oxygen, and/or nutrients added to subsurface to reduce the toxicity of contaminants in soil.	PAHs present. Retained as a secondary step following treatment.
	Solidification Thermal Treatment	ISS - Using large augers or other injection/mixing technology, contaminated soil is mixed in situ with binders isolating and immobilizing contaminants. Thermal desorption (ISTD) – thermal wells apply high-temperature heat to required depth; off-gases are collected and treated. Groundwater control needed to retain heat during treatment.	Applicable in areas where there are no large rocks and/or subsurface obstructions. A volume increase would result. Retained. Large energy requirements needed to create the high heat conditions necessary to destroy PAHs. Reduces contaminant mobility in saturated soils by destroying the more volatile and soluble coal tar components. Retained.

TABLE 6-1

SUMMARY OF REMEDIAL ALTERNATIVE COST ESTIMATES

	Cost Component	Alternative 1 No Action	Alternative 2 Excavation	Alternative 3 ISCO	Alternative 4 ISS	Alternative 5 Containment and Gate
Capital Costs	IRM	$6,276,000	$6,276,000	$6,276,000	$6,276,000	$6,276,000
	Site-Wide Remediation to 34 ft	$0	$64,537,000	$22,544,000	$37,446,000	$29,491,000
Annual OM&M	Alternative Items	$29,900	$29,900	$508,300	$29,900	$1,028,300
	Vapor Mitigation Program	$10,000	$10,000	$10,000	$10,000	$10,000
Present Worth of OM&M	Alternative Items	$460,000	$231,000	$3,925,000	$231,000	$15,805,000
	Vapor Mitigation Program	$153,700	$77,200	$77,200	$77,200	$153,700
Years of OM&M		30	10	10	10	30
Total Present Worth		**$6,889,700**	**$71,121,200**	**$32,822,200**	**$44,030,200**	**$51,725,700**

Additional solidification to 70 ft.: $2,900,000

Total estimate, Alternative 4: $46,930,200

FIGURES

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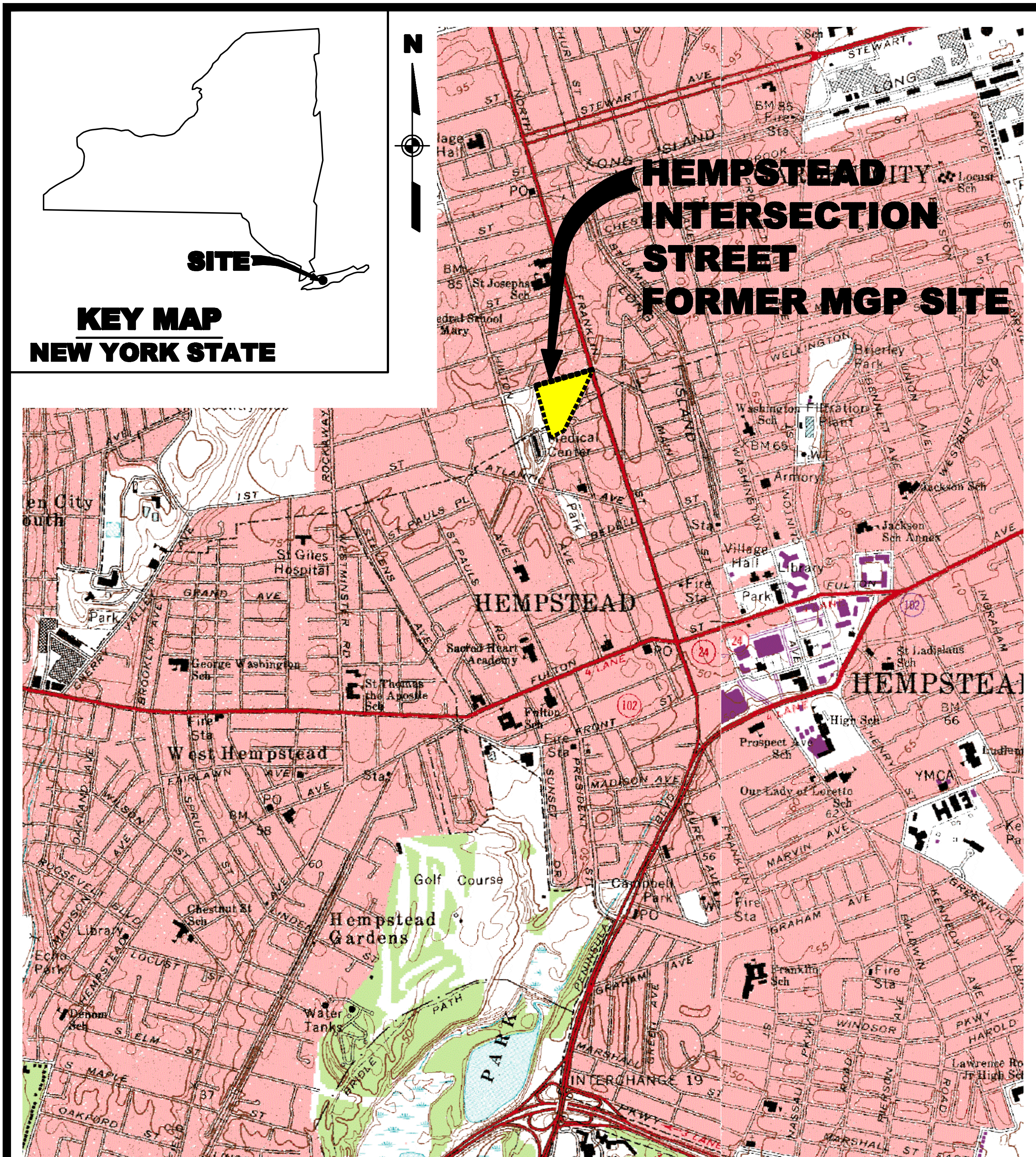


SOURCE:
USGS 7.5 MINUTE SERIES
TOPOGRAPHICAL QUANDRANGLES:
FREEPORT, NY (1969)
LYNBROOK, NY (1969)

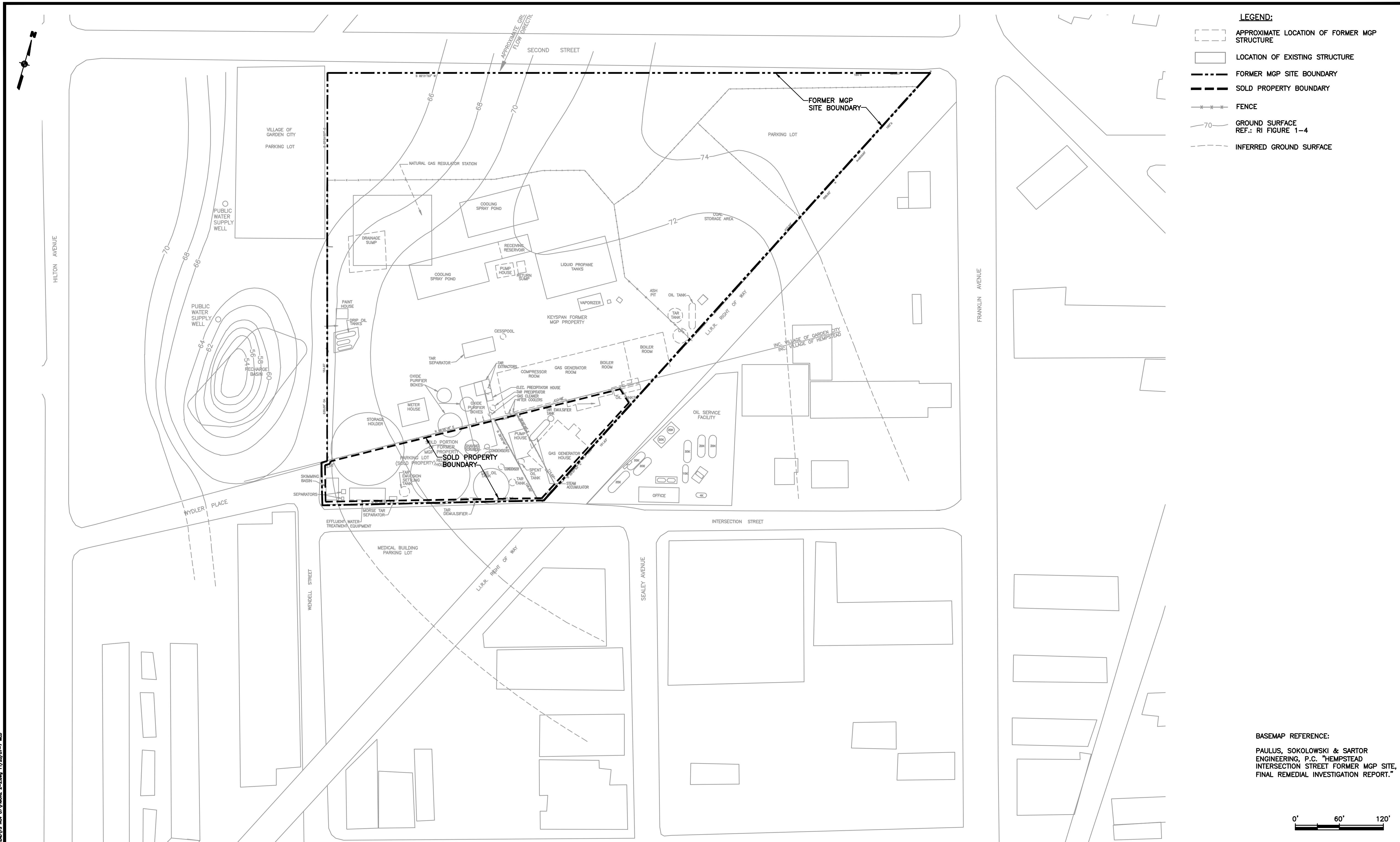
2000' 0 2000'

SCALE IN FEET

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

URS Corporation | **SITE LOCATION MAP** | **FIGURE 2-1**

FIGURE 2-1



URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**SITE MAP AND FORMER SITE STRUCTURES**	**FIGURE 2-2**

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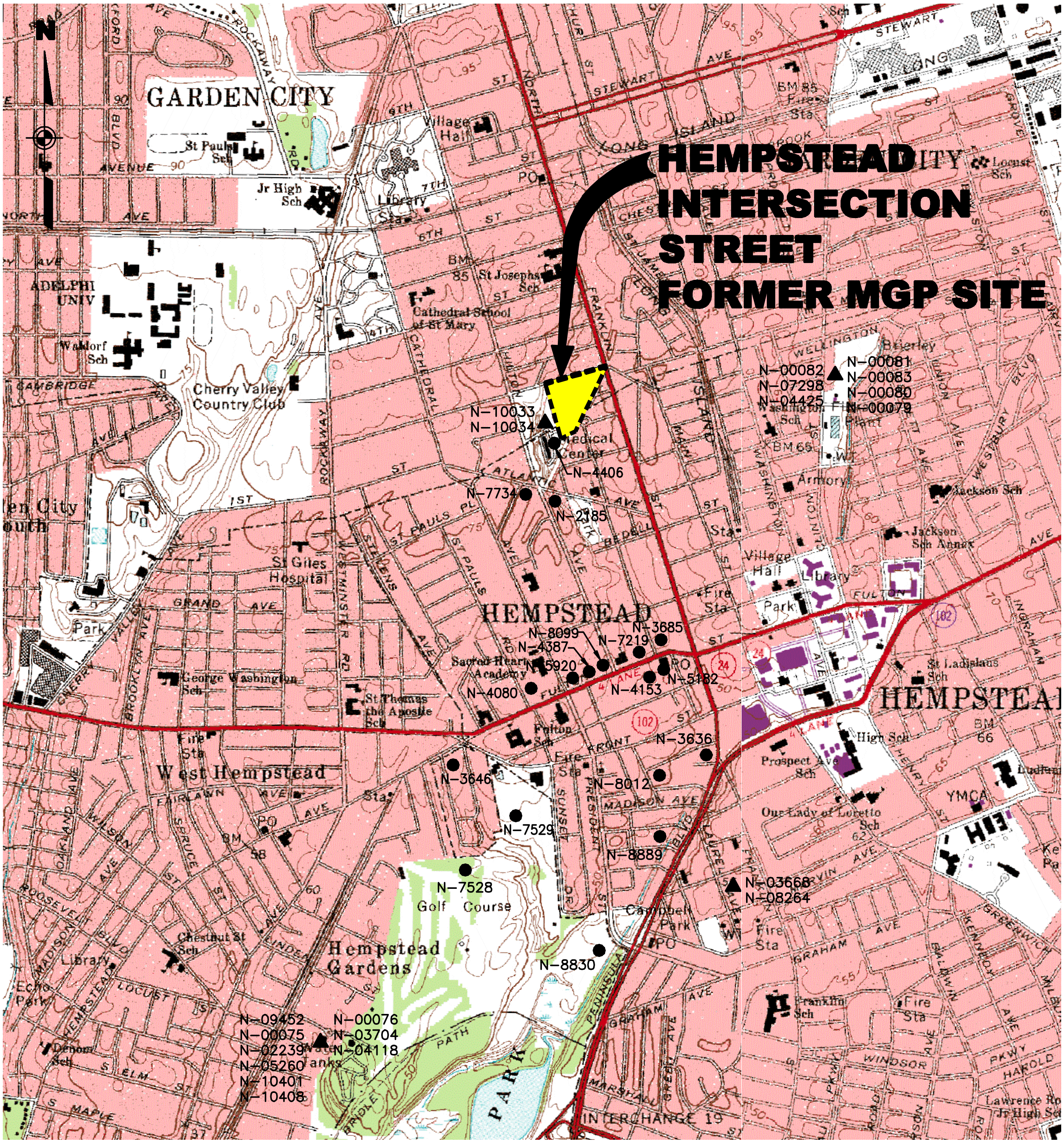


LEGEND:

N-7219 ● APPROXIMATE PRIVATE WELL LOCATION WITH NYSDEC WELL ID

N-10033 ▲ APPROXIMATE PUBLIC WELL/WELL FIELD LOCATION WITH NYSDEC WELL ID

SOURCE:
USGS 7.5 MINUTE SERIES
TOPOGRAPHICAL QUANDRANGLES:
FREEPORT, NY (1969)
LYNBROOK, NY (1969)

2000' 0 2000'

SCALE IN FEET

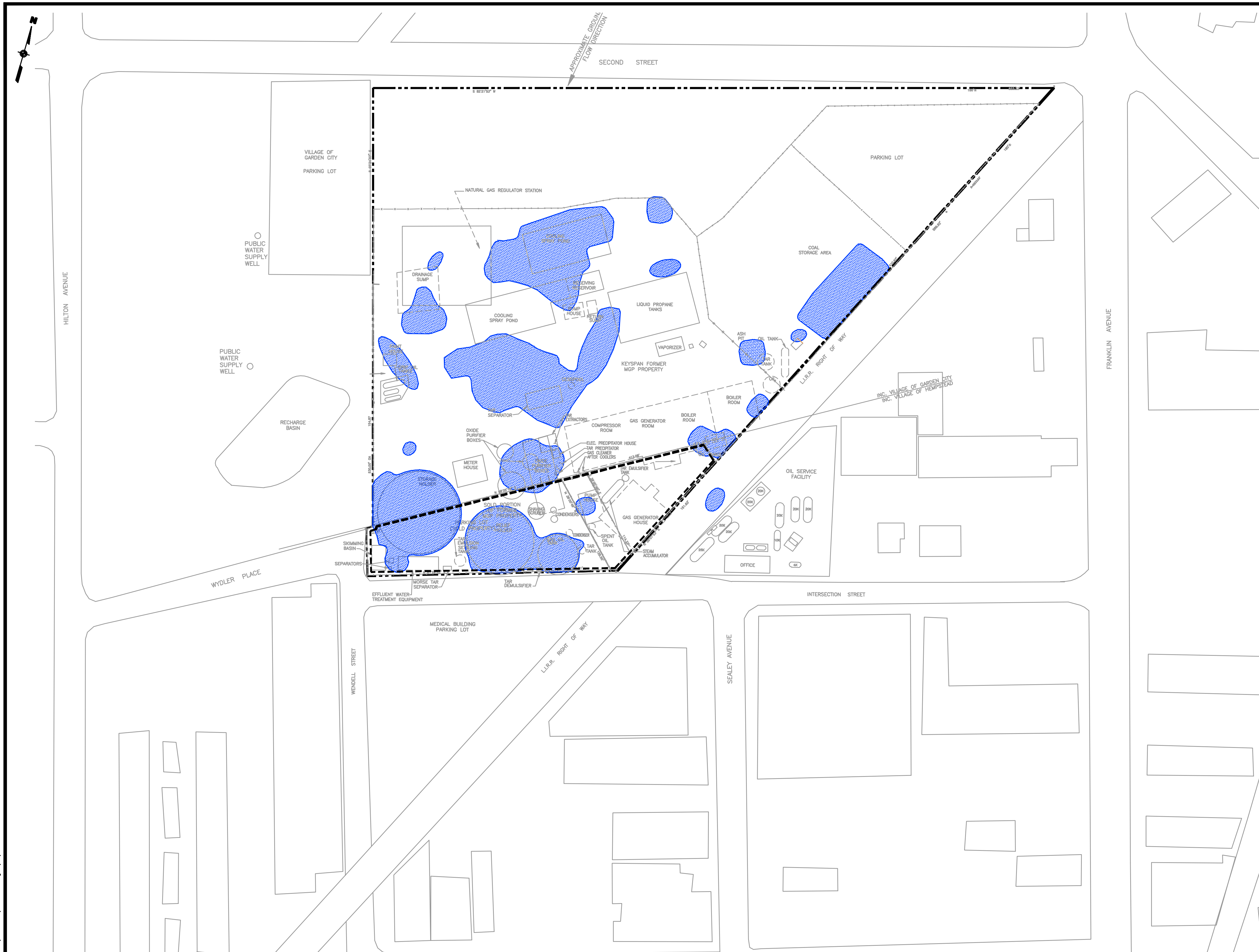
KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

URS Corporation

WATER SUPPLY WELL LOCATIONS

FIGURE 2-3

FIGURE 2-3



LEGEND:

SOIL SOURCE MATERIAL DEFINED AS:

- NAPL SATURATED SOIL, OR
- TOTAL PAHS ≥ 1,000 PPM, OR
- TOTAL BTEX ≥ 50 PPM
- ALL AREAS WITHIN STORAGE HOLDER, RELIEF HOLDER AND GAS OIL TANK

APPROXIMATE LOCATION OF FORMER MGP STRUCTURE

LOCATION OF EXISTING STRUCTURE

FORMER MGP SITE BOUNDARY

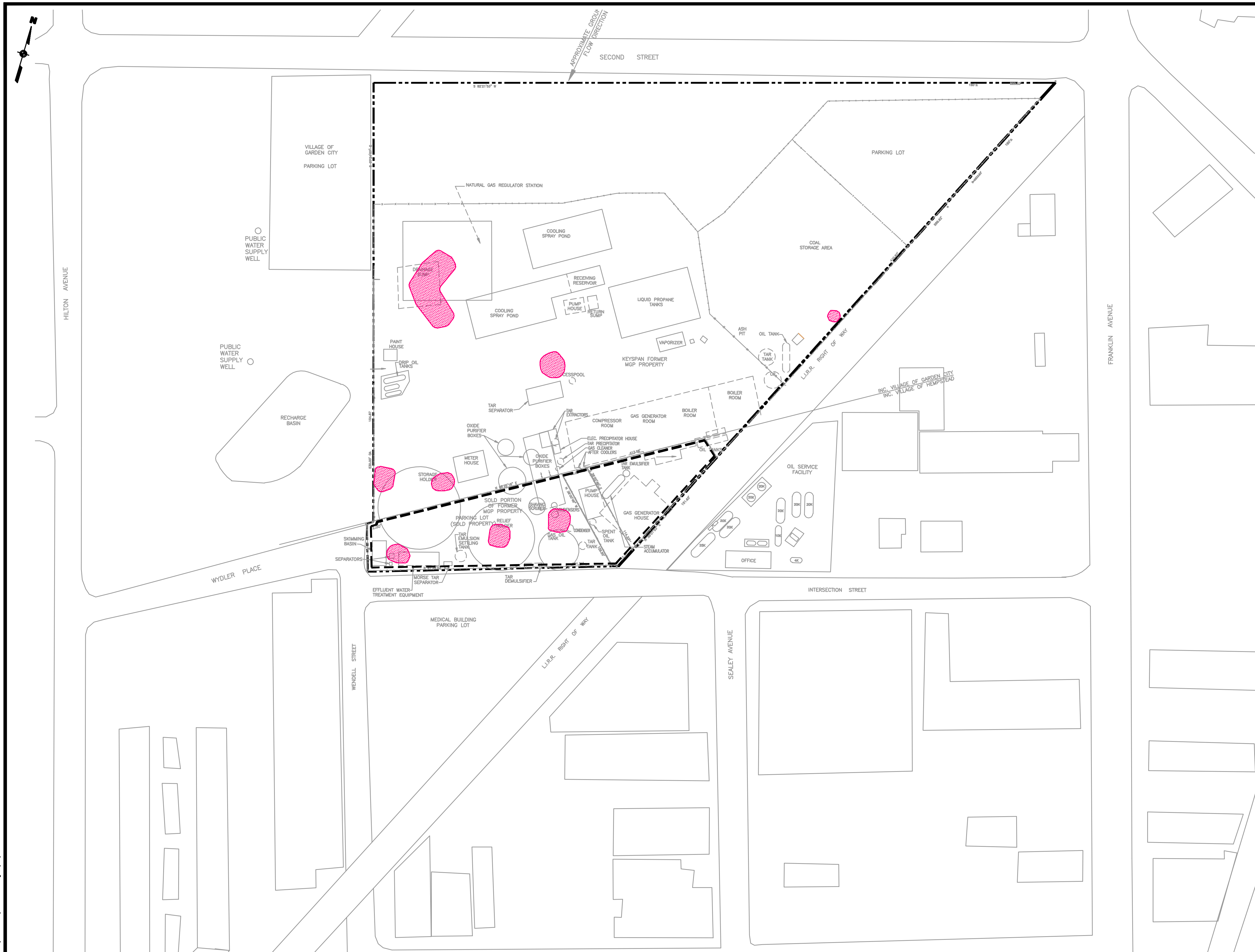
SOLD PROPERTY BOUNDARY

FENCE

NOTE:
DELINEATION BASED ON VISUAL OBSERVATIONS AND CHEMICAL CHARACTERIZATION RESULTS PRESENTED IN THE *RI*.

0' 60' 120'

URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**SOURCE MATERIAL LOCATION MAP** **0-8 FT.**	**FIGURE 2-4**



LEGEND:

SOIL SOURCE MATERIAL DEFINED AS:

- NAPL SATURATED SOIL, OR
- TOTAL PAHS ≥ 1,000 PPM, OR
- TOTAL BTEX ≥ 50 PPM

APPROXIMATE LOCATION OF FORMER MGP STRUCTURE

LOCATION OF EXISTING STRUCTURE

FORMER MGP SITE BOUNDARY

SOLD PROPERTY BOUNDARY

FENCE

NOTE:
DELINEATION BASED ON VISUAL OBSERVATIONS AND CHEMICAL CHARACTERIZATION RESULTS PRESENTED IN THE *RI*.

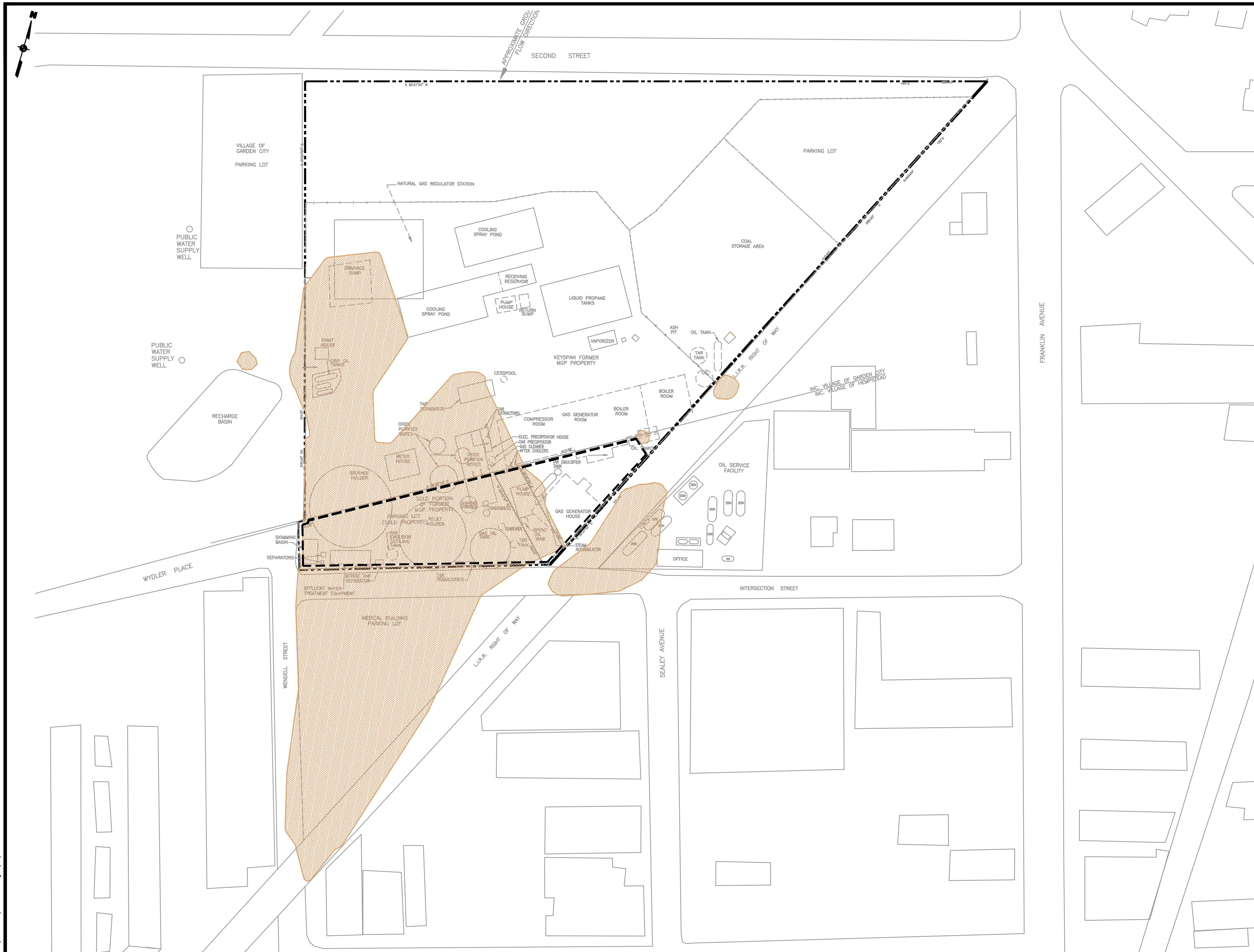
URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**SOURCE MATERIAL LOCATION MAP** **8-16 FT.**	**FIGURE 2-5**

URS Corporation

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

SOURCE MATERIAL LOCATION MAP
16-24 FT.

FIGURE 2-6



LEGEND:

SOIL SOURCE MATERIAL DEFINED AS:

- NAPL SATURATED SOIL, OR
- TOTAL PAHS ≥ 1,000 PPM, OR
- TOTAL BTEX ≥ 50 PPM

APPROXIMATE LOCATION OF FORMER MGP STRUCTURE

LOCATION OF EXISTING STRUCTURE

FORMER MGP SITE BOUNDARY

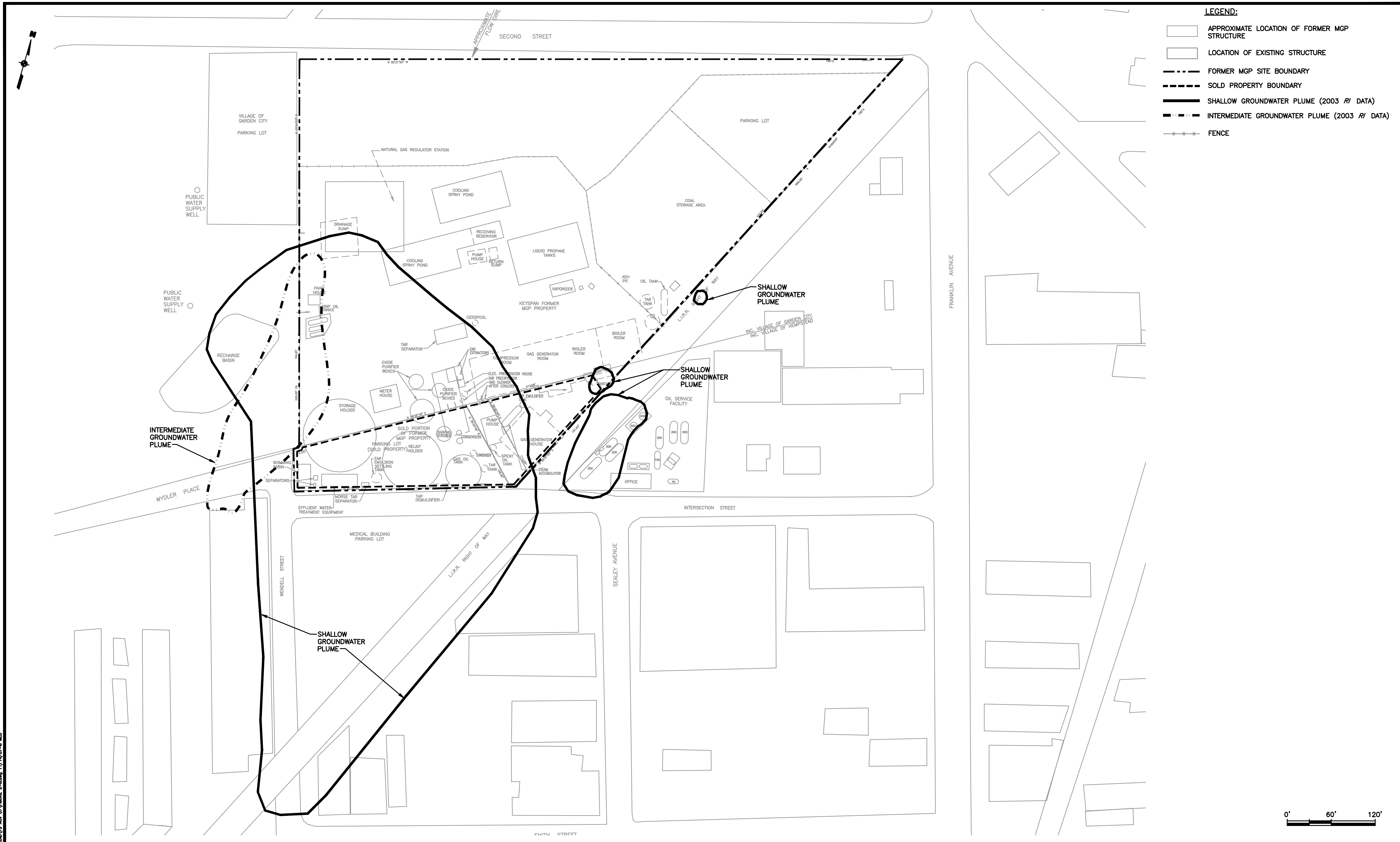
SOLD PROPERTY BOUNDARY

FENCE

NOTE:
DELINEATION BASED ON VISUAL OBSERVATIONS AND CHEMICAL CHARACTERIZATION RESULTS PRESENTED IN THE *RI.*

0' 60' 120'

URS Corporation	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET FORMER MGP SITE GARDEN CITY/HEMPSTEAD, NY	SOURCE MATERIAL LOCATION MAP 24-34 FT.	FIGURE 2-7

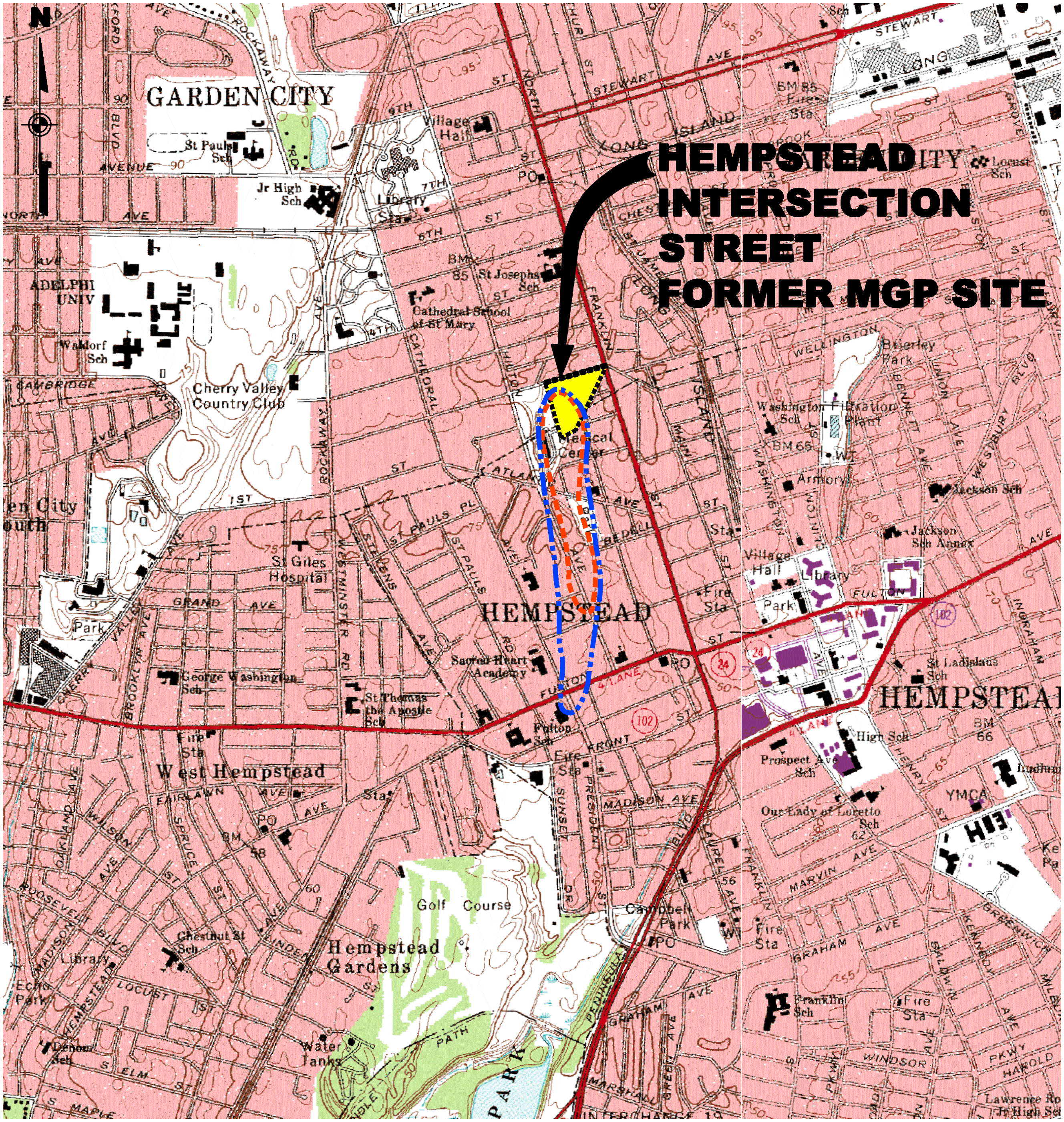


URS Corporation

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

SHALLOW AND INTERMEDIATE GROUNDWATER PLUMES

FIGURE 2-8



SOURCE:
USGS 7.5 MINUTE SERIES
TOPOGRAPHICAL QUANDRANGLES:
FREEPORT, NY (1969)
LYNBROOK, NY (1969)

2000' 0 2000'

SCALE IN FEET

LEGEND:

DISSOLVED PHASE GROUNDWATER PLUME (2003 DATA)

DISSOLVED PHASE GROUNDWATER PLUME (2007 DATA)

NOTE:

PLUME DEFINED AS AN AREA WHERE DISSOLVED CONCENTRATION OF EITHER BTEX OR PAH IS GREATER THAN 100 ppb.

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

URS Corporation

DISSOLVED PHASE GROUNDWATER PLUME PLAN VIEW

FIGURE 2-9

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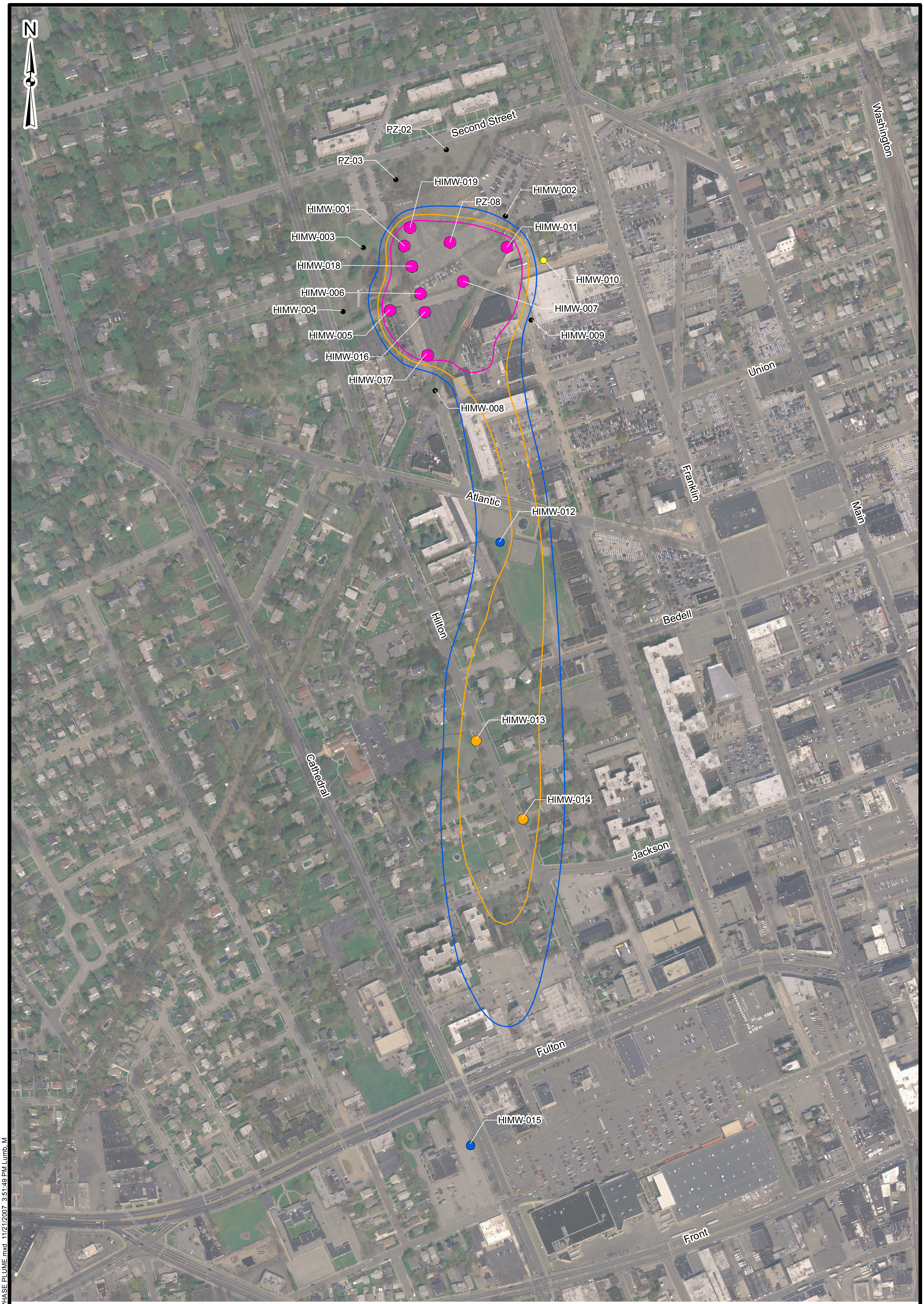
FIGURE 2-9



Legend

Monitoring Well Cluster - Highest BTEX/ PAH Concentrations (ug/L):

- Not Detected
- 1 - 10
- 10 - 100
- 100 - 1,000
- > 1,000; or Product Detected

Isoconcentration Line (ppb):

- 50
- 100
- 1,000

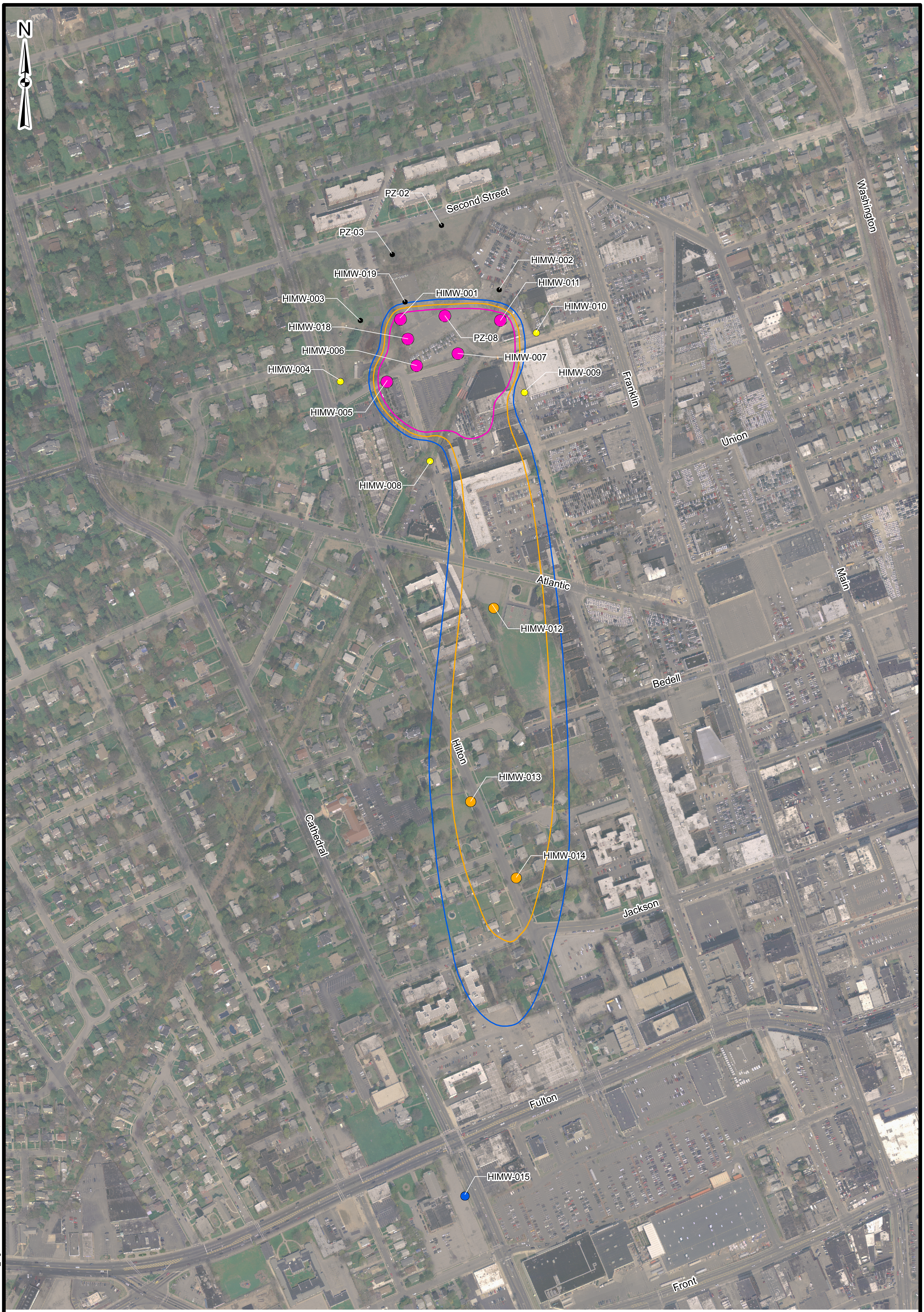
400 0 400 Feet

URS

GARDEN CITY/HEMPSTEAD, NY
EXTENT OF DISSOLVED-PHASE PLUME
APRIL 4-17, 2007

FIGURE 2-10

J:\11175065.00000\DB\GIS\ARCMAP\0407 DISSOLVE PHASE PLUME.mxd 11/21/2007 3:51:49 PM Lumb, M



Legend

Monitoring Well Cluster - Highest BTEX/ PAH Concentrations (ug/L):

- Not Detected
- 1 - 10
- 10 - 100
- 100 - 1,000
- > 1,000; or Product Detected

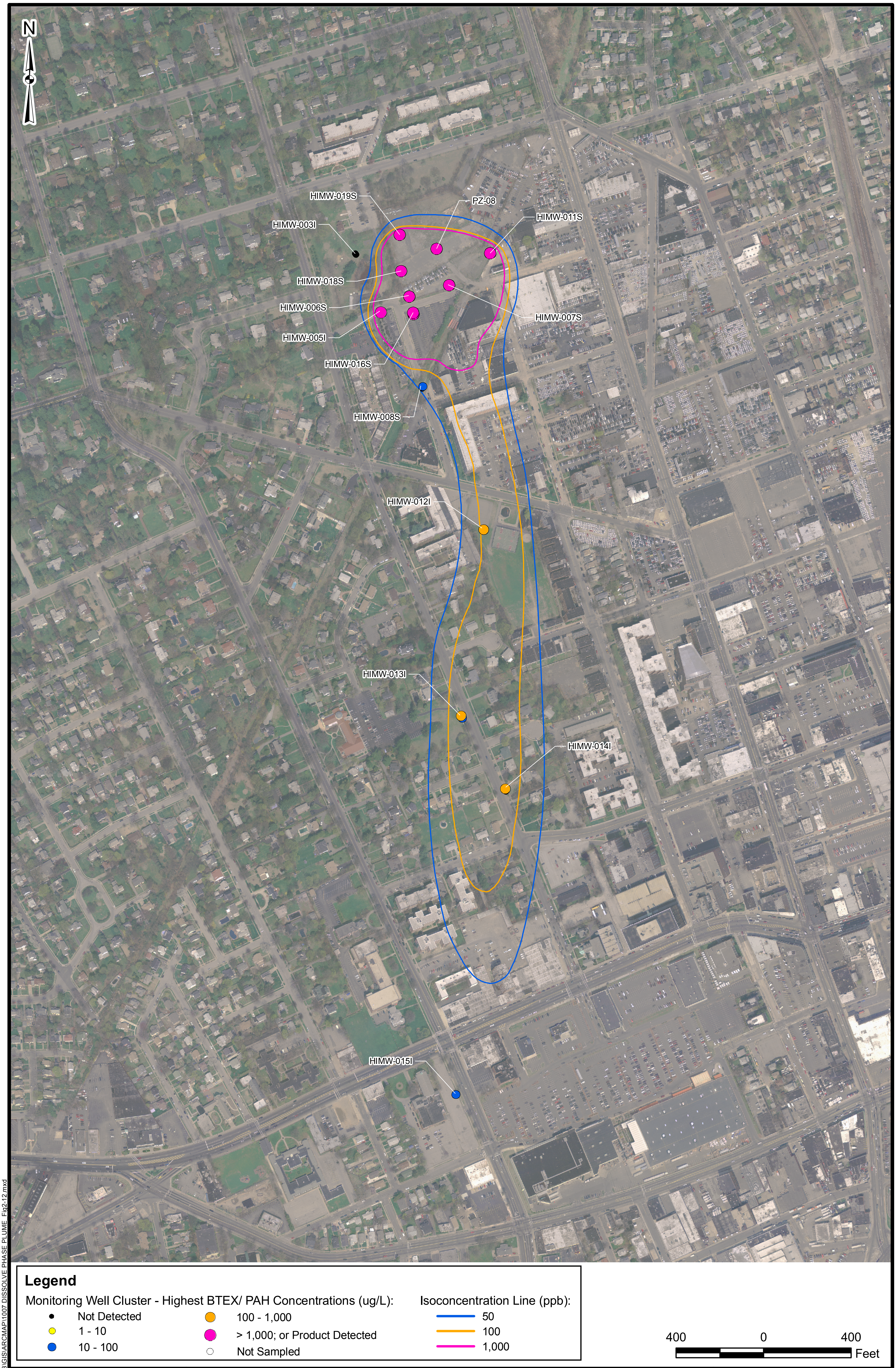
Isoconcentration Line (ppb):

- 50
- 100
- 1,000

400 0 400 Feet

URS	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET - FORMER MGP SITE DISSOLVED PHASE GROUNDWATER PLUME - JULY / AUGUST 2007	FIGURE 2-11

J:\11175065.00000\DB\GISARCMAP\0707 DISSOLVE PHASE PLUME_Fig2-11.mxd 11/21/2007 3:51:49 PM Lumb, M

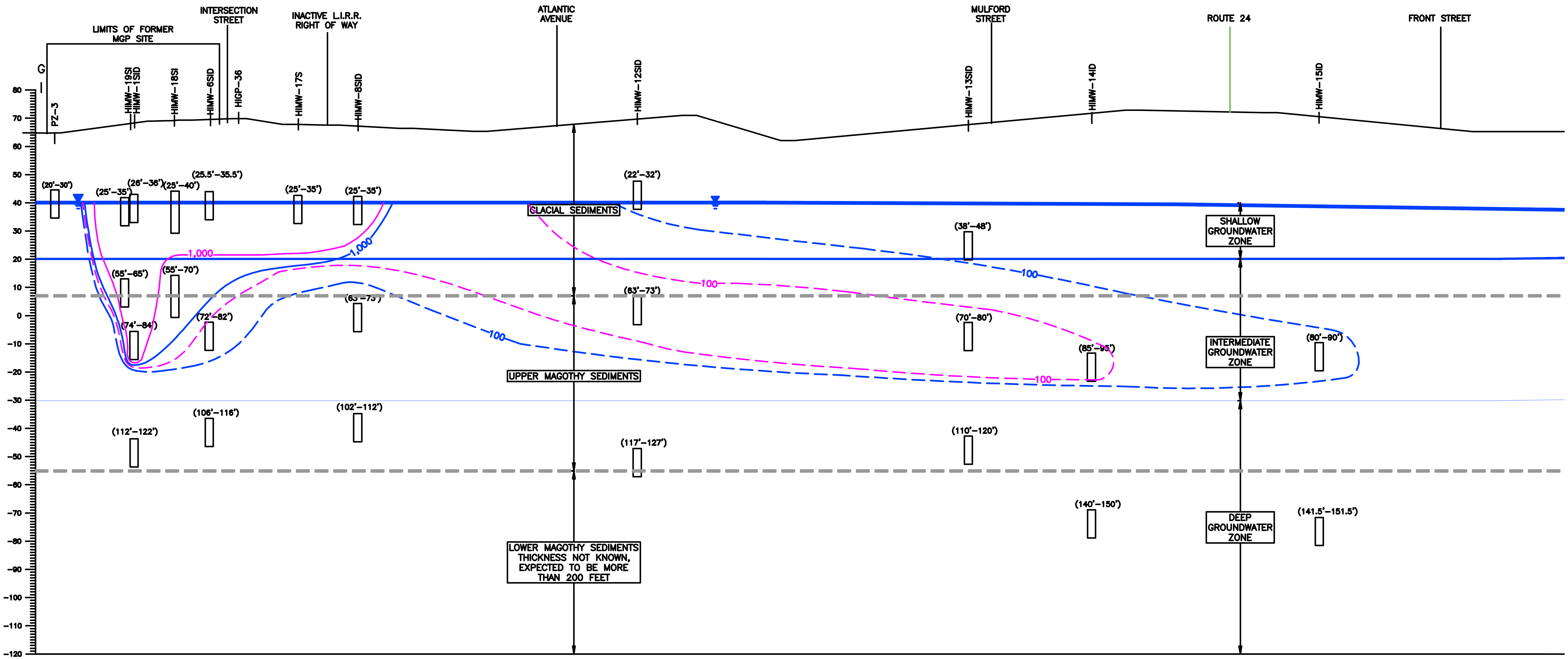


J:\11175065.00000\DB\GIS\ARCMAP\1007 DISSOLVE PHASE PLUME_Fig2-12.mxd

URS

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET - FORMER MGP SITE
DISSOLVED PHASE GROUNDWATER PLUME - OCTOBER 2007

FIGURE 2-12



LEGEND:

—HIMW–01 MONITORING WELL

(50'–60') WELL SCREEN INTERVAL

2003 PLUME

100 — PLUME PERIPHERY: DISSOLVED PHASE CONCENTRATION OF BTEX OR DISSOLVED PHASE CONCENTRATION OF PAH EQUAL TO 100 ppb.

1,000 — PLUME CORE: NAPL PRESENT; OR DISSOLVED PHASE CONCENTRATION OF BTEX OR PAH EQUAL TO 1,000 ppb.

2007 PLUME

100 — PLUME PERIPHERY: DISSOLVED PHASE CONCENTRATION OF BTEX OR DISSOLVED PHASE CONCENTRATION OF PAH EQUAL TO 100 ppb.

1,000 — PLUME CORE: NAPL PRESENT; OR DISSOLVED PHASE CONCENTRATION OF BTEX OR PAH EQUAL TO 1,000 ppb.

SCALE: VERT. 1"=50'
HORZ. 1"=500'

20' 0 20'
SCALE IN FEET

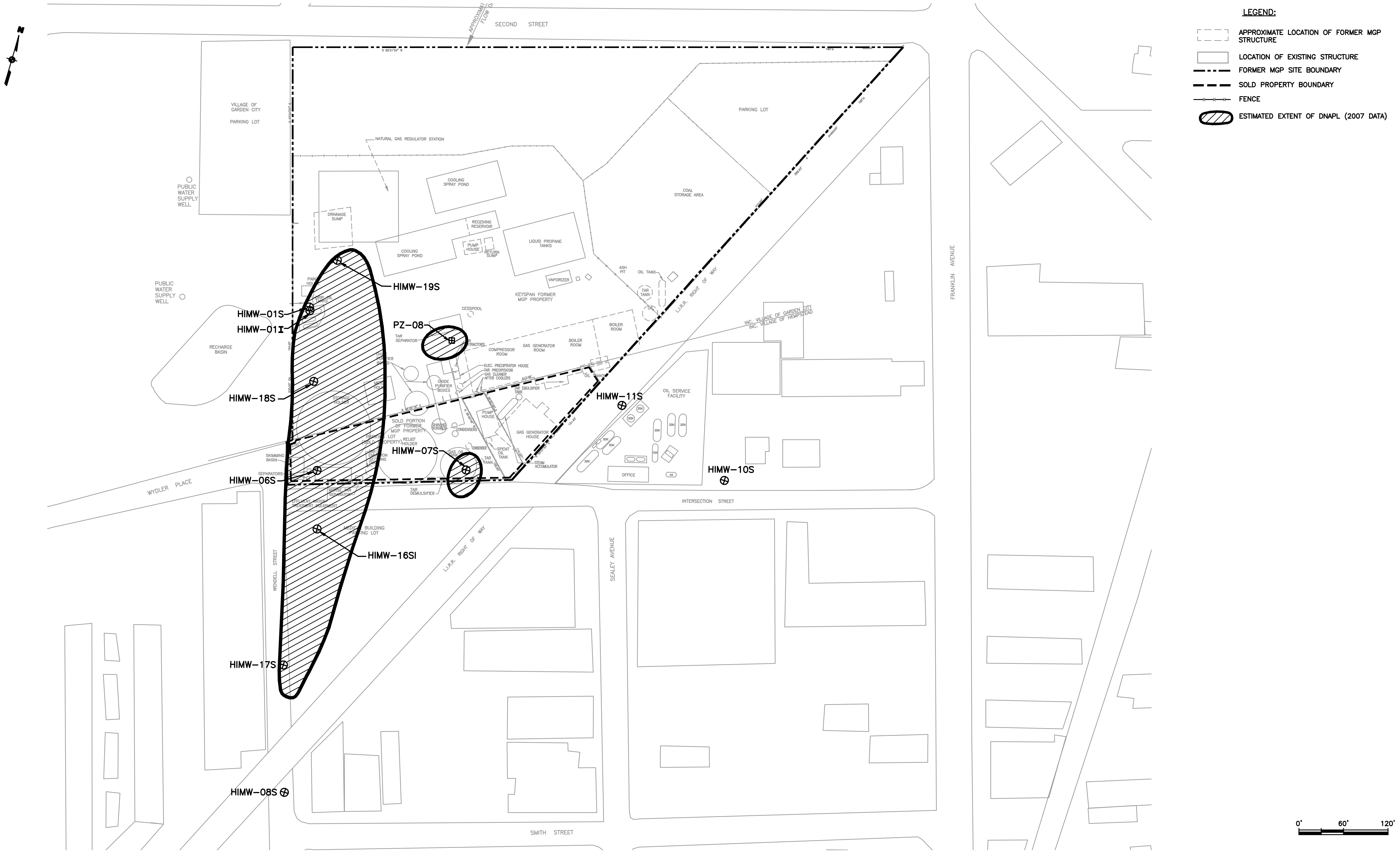
KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

URS Corporation

DISSOLVED PHASE GROUNDWATER PLUME
SECTION VIEW

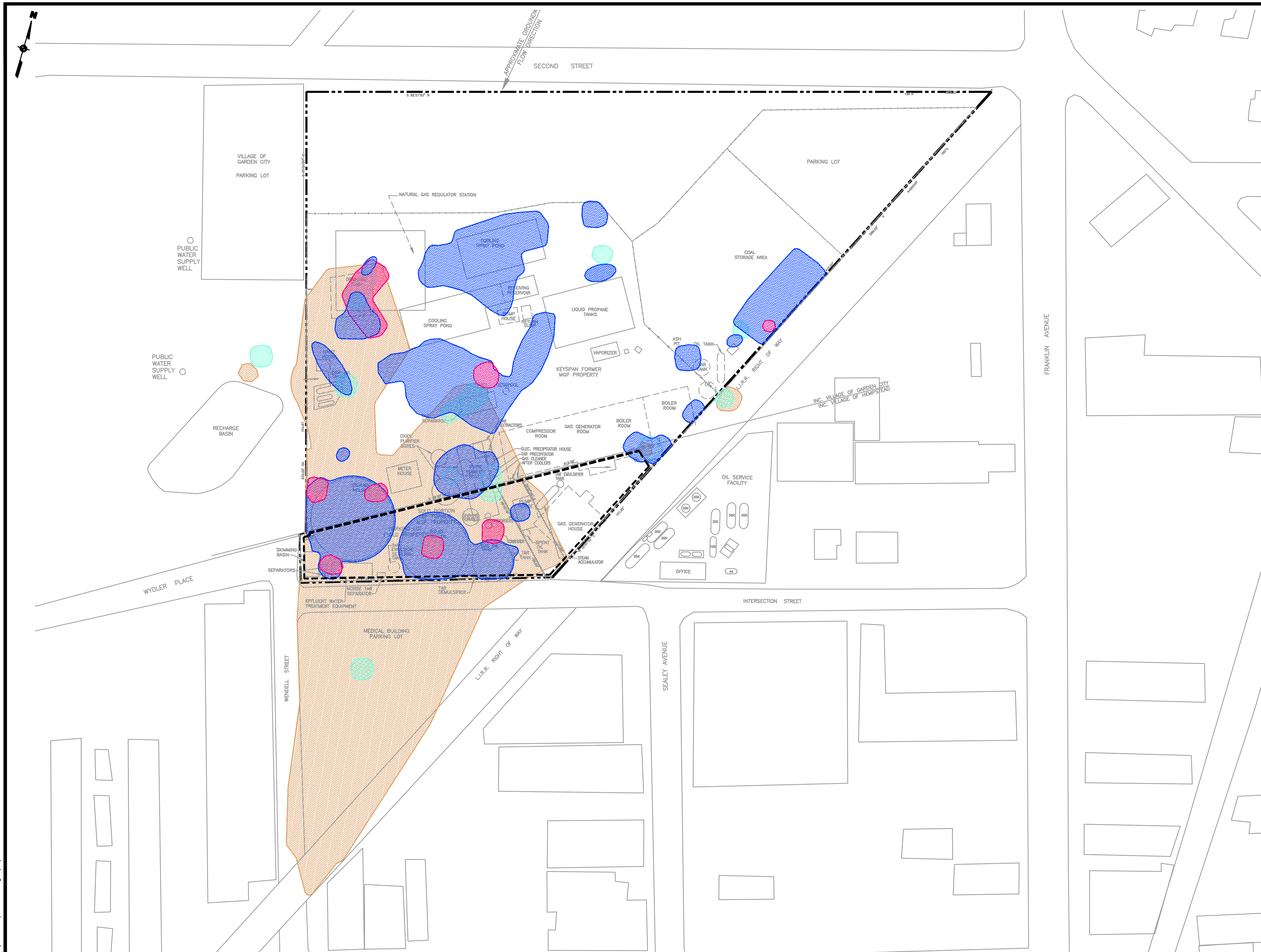
FIGURE 2-13

J:\11175065.00000\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 2-13.dwg, 2/4/08-5 RAL



J:\11175065.00000\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 2-14.dwg 2/4/08 - 3 RAL

URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**DNAPL PLUME**	**FIGURE 2-14**



LEGEND:

0–8 FT.	TOTAL AREA = 61520 sq. ft.	VOLUME = 18250 cu. yards
8–16 FT.	TOTAL AREA = 6990 sq. ft	VOLUME = 2050 cu. yards
16–24 FT.	TOTAL AREA = 8480 sq. ft.	VOLUME = 2500 cu. yards
24–34 FT.	TOTAL AREA = 130200 sq. ft.	VOLUME = 48200 cu. yards

SOIL SOURCE MATERIAL DEFINED AS:

- NAPL SATURATED SOIL, OR
- TOTAL PAHS > 1,000 PPM, OR
- TOTAL BTEX > 50 PPM
- ALL AREAS WITHIN STORAGE HOLDER, RELIEF HOLDER AND GAS OIL TANK

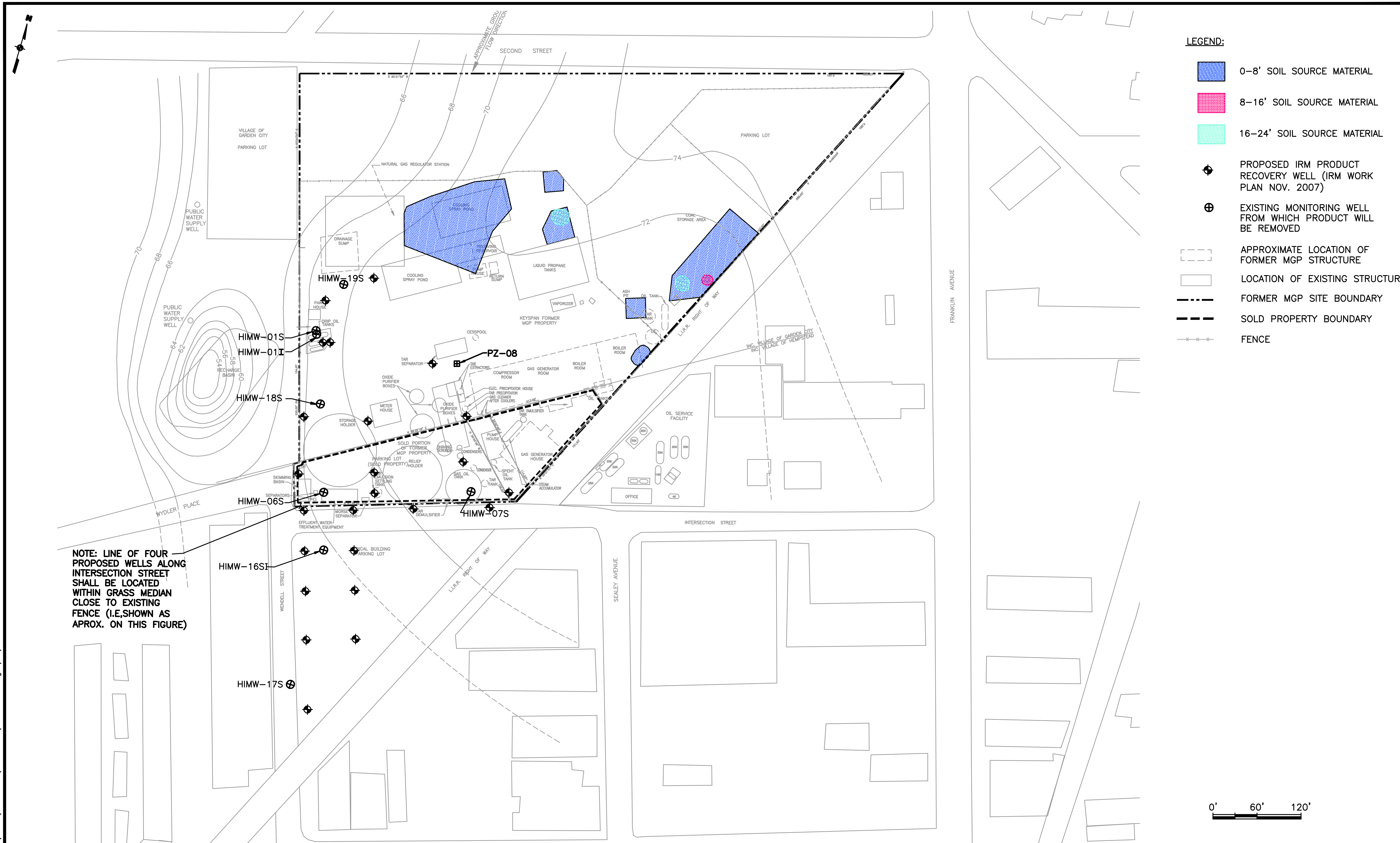
0' 60' 120'

URS Corporation

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

SOURCE MATERIAL LOCATION MAP
0-34 FT.

FIGURE 3-1



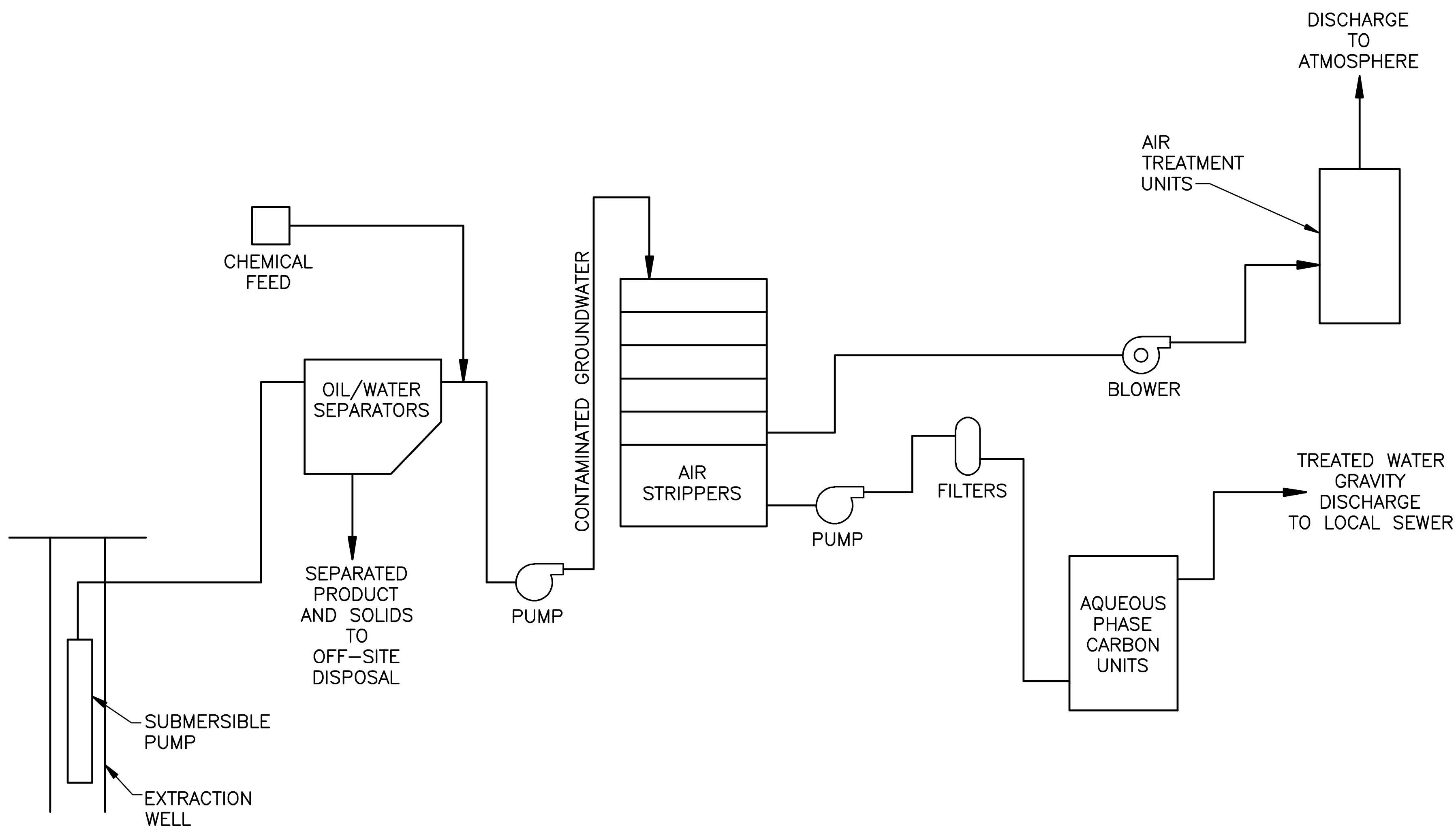
J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 3-2.dwg 1/23/08-4 RAL

URS Corporation

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

PROPOSED
IRM LOCATION MAP

FIGURE 3-2



KEYSPAN CORPORATION
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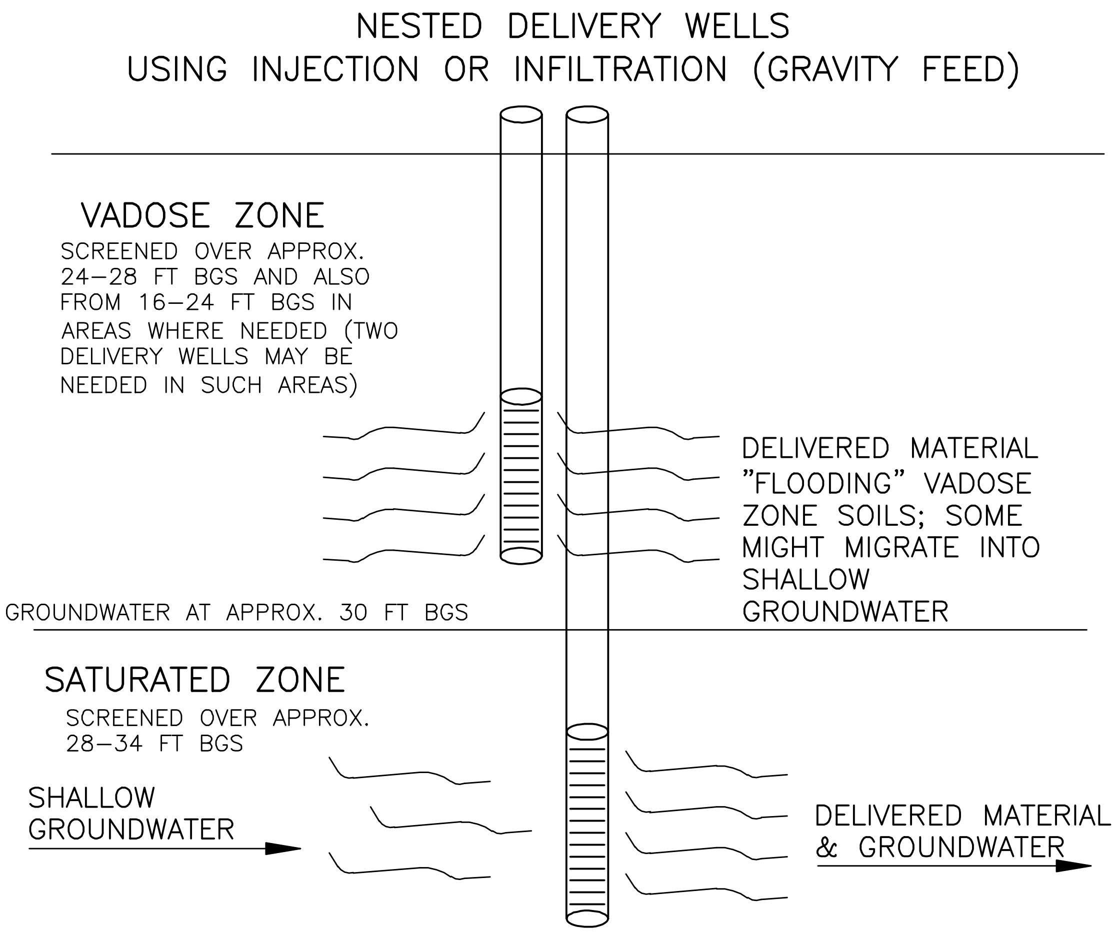
GARDEN CITY/HEMPSTEAD, NY

URS Corporation

CONCEPTUAL GROUNDWATER TREATMENT PROCESS

FIGURE 4-1



FOR THE FS, IT IS ASSUMED THAT A RADIUS OF INFLUENCE OF APPROXIMATELY 15 FEET WILL BE ACHIEVED IN BOTH THE VADOSE AND SATURATED ZONES; THIS CAN BE EVALUATED FURTHER USING FIELD–SCALE PILOT TESTING.

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

NOT TO SCALE

URS Corporation

CONCEPTUAL IN SITU CHEMICAL OXIDATION PROCESS

FIGURE 4-2

J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\ 11/15/07-4 MLU

FIGURE 4–2

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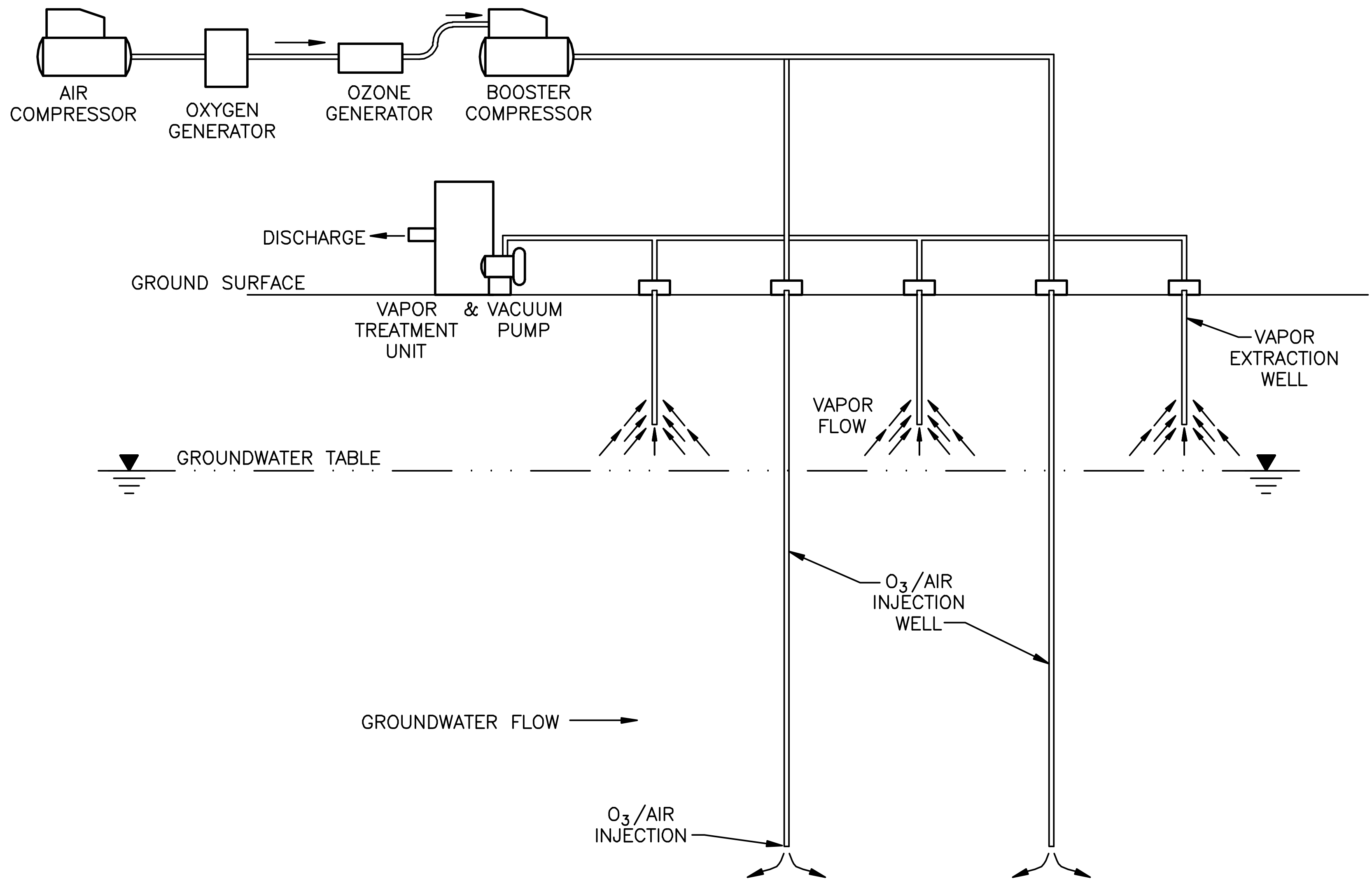

NOT TO SCALE

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

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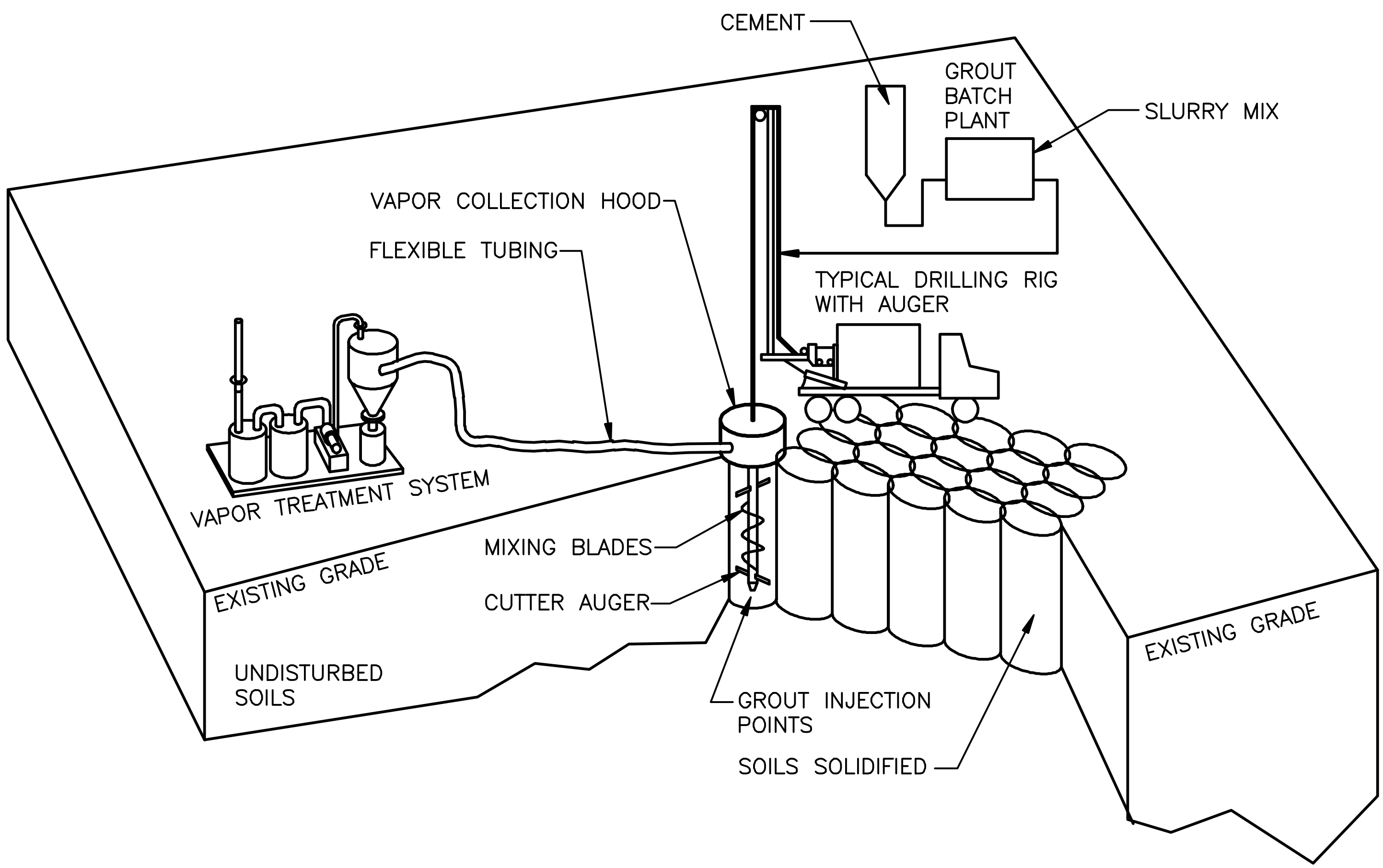
CONCEPTUAL OZONE INJECTION PROCESS

FIGURE 4-3

J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\ 11/15/07-2 MLU



NOT TO SCALE

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

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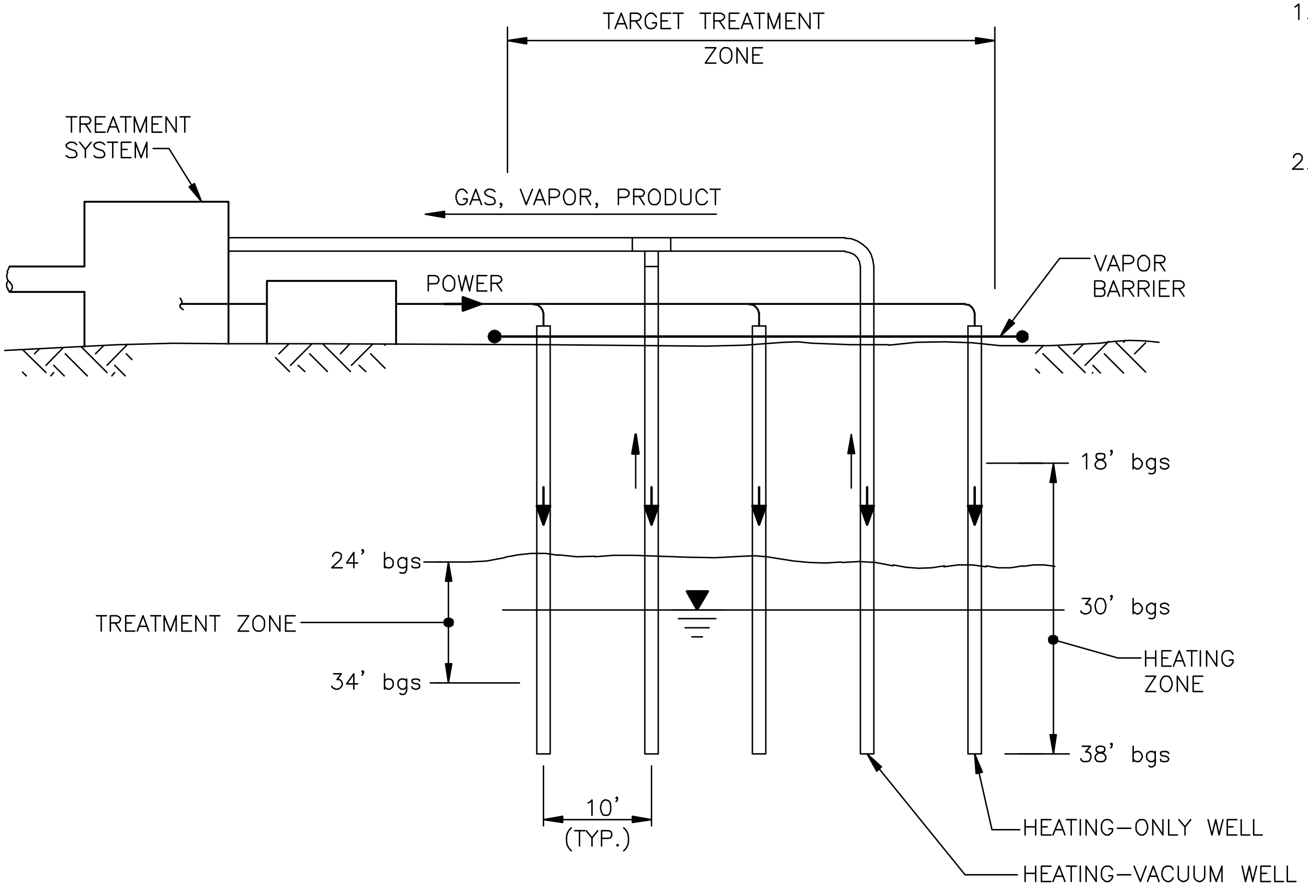
CONCEPTUAL IN SITU SOLIDIFICATION PROCESS

FIGURE 4-4

J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\ 11/15/07-2 MLU



NOTES:

1. CONFIGURATION SHOWN IS FOR TREATMENT OF 24' TO 34' SOIL SOURCE MATERIAL. HEATING ZONE WILL BE SLIGHTLY DIFFERENT FOR THE HIGHER TREATMENT ZONES.
2. DURING THE INITIAL STEP IN EACH SUB AREA OF THE REMEDIATION, THE HEATER-VACUUM WELLS WILL CONTAIN A MULTI-PHASE EXTRACTION PUMP AND WILL NOT BE HEATED.

NOT TO SCALE

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

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CONCEPTUAL IN SITU THERMAL DESORPTION PROCESS

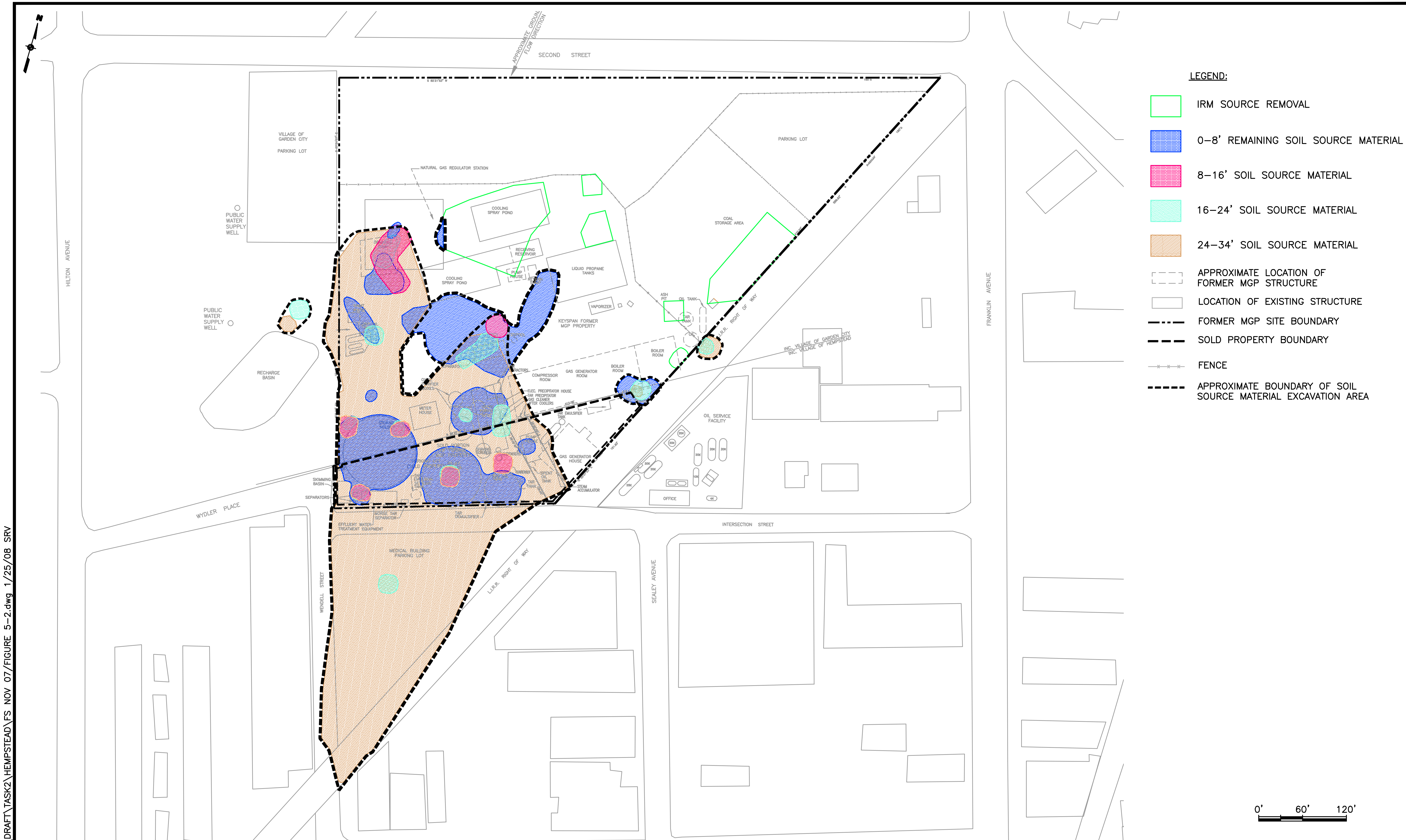
FIGURE 4-5

URS

KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET - FORMER MGP SITE
MONITORING WELL LOCATIONS FOR MNA

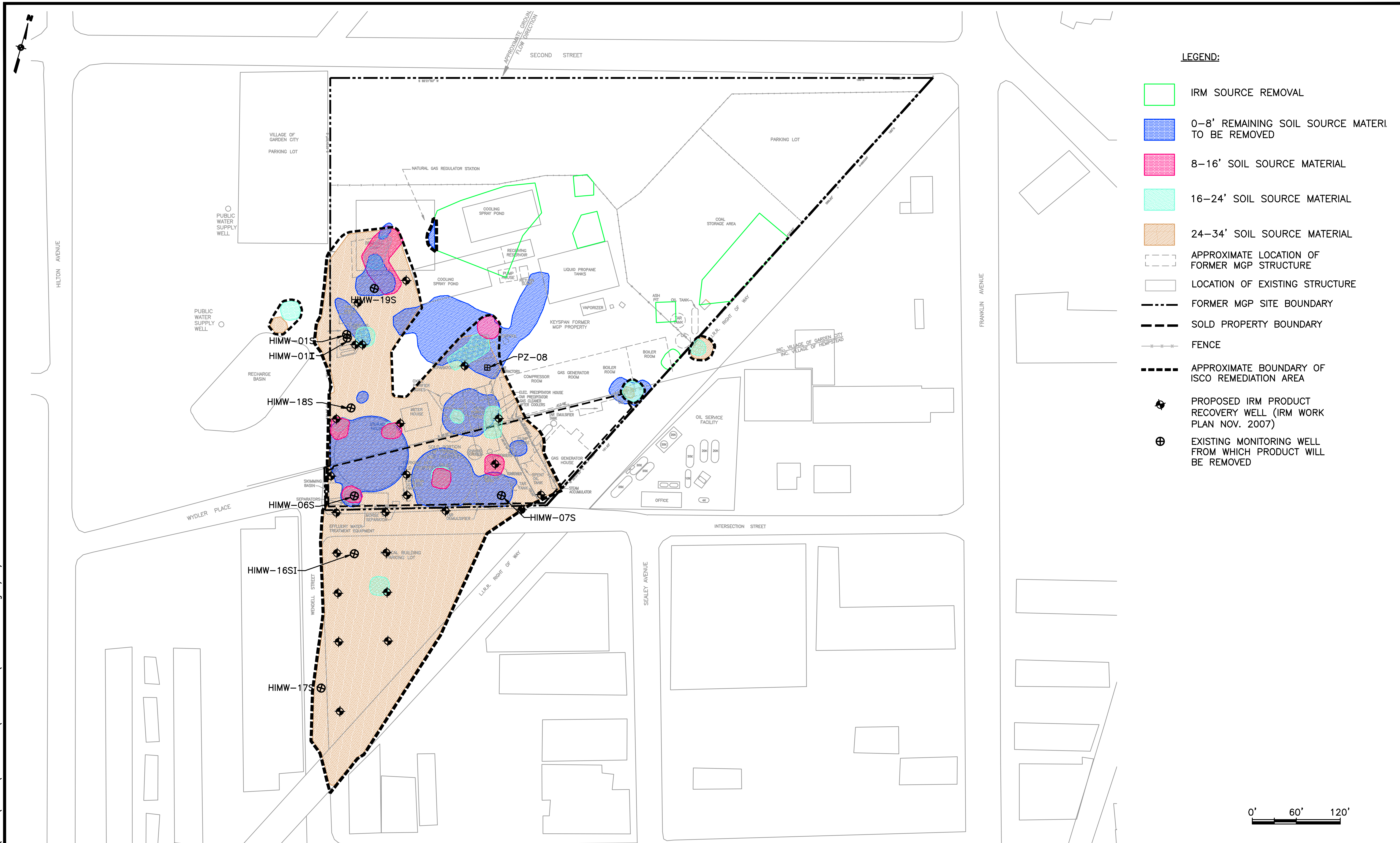
FIGURE 5-1

J:\11175065.00000\DB\GIS\ARCMAP\MW_LOCATIONS_MNA.mxd 1/28/2008

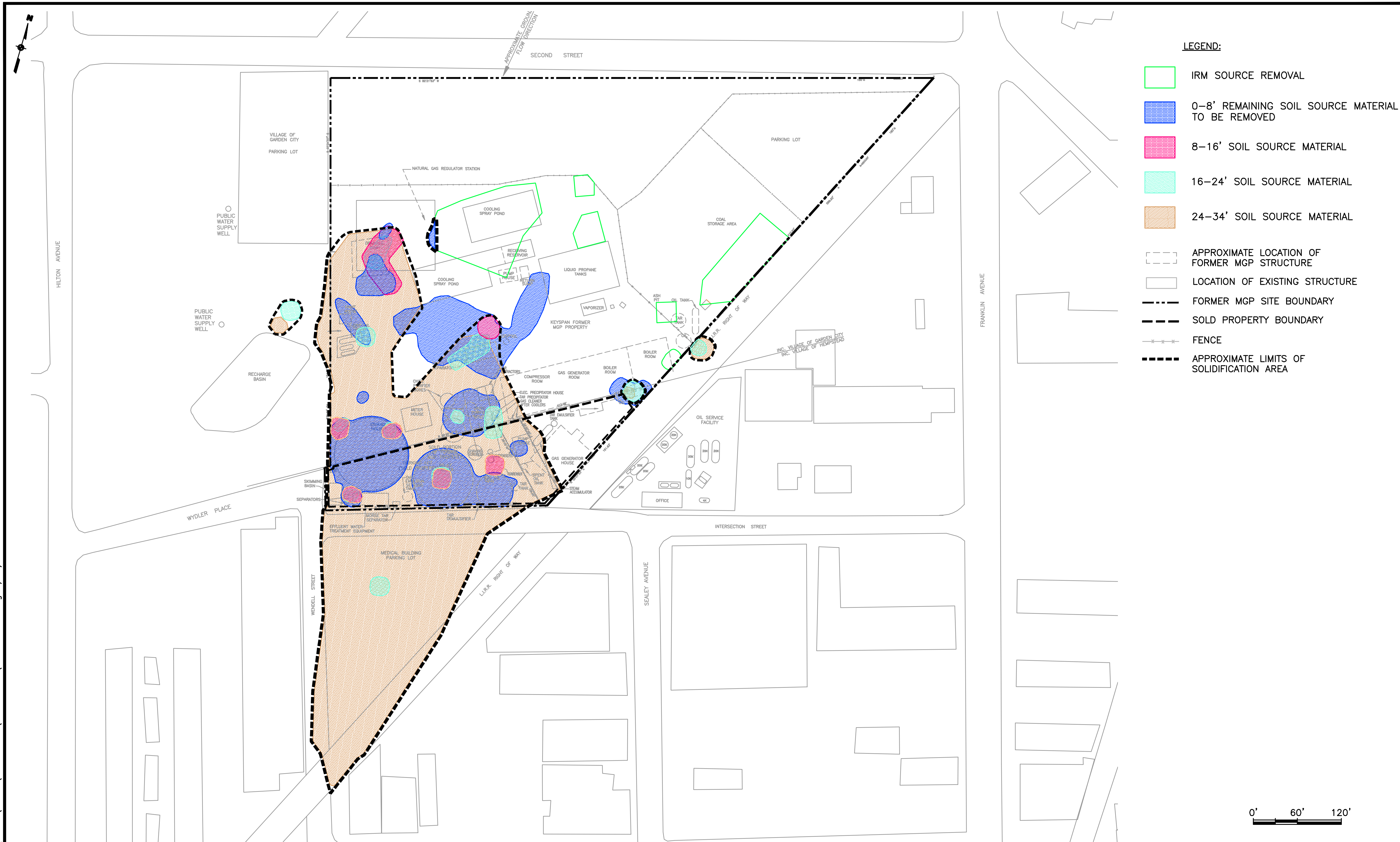


J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 5-2.dwg 1/25/08 SRV

URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**CONCEPTUAL LAYOUT FOR ALTERNATIVE 2 - SOURCE EXCAVATION**	**FIGURE 5-2**

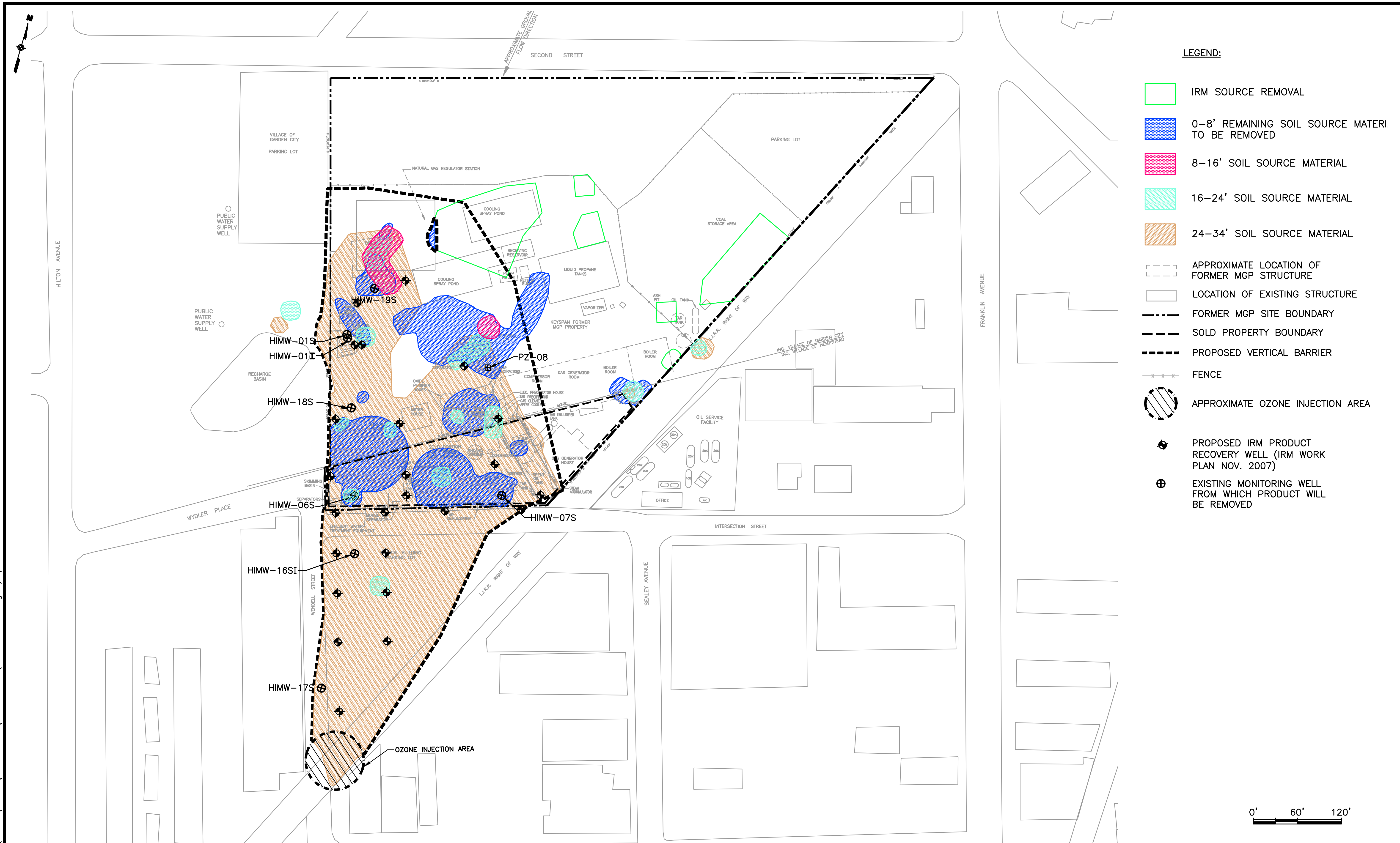


URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**CONCEPTUAL LAYOUT FOR ALTERNATIVE 3 - ISCO**	**FIGURE 5-3**



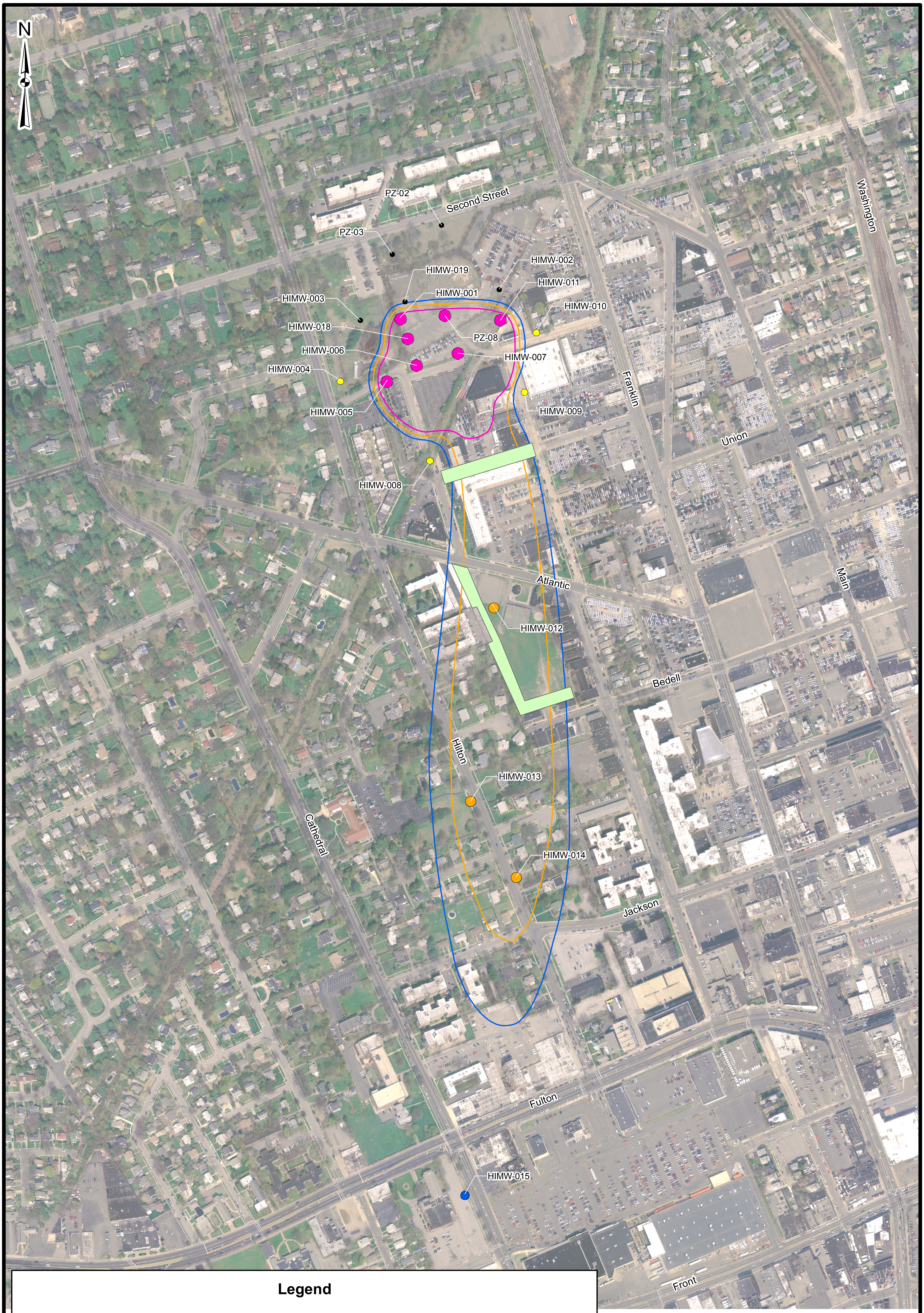
J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 5-4.dwg 1/25/08-3 SRV

URS Corporation	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET FORMER MGP SITE GARDEN CITY/HEMPSTEAD, NY	CONCEPTUAL LAYOUT FOR ALTERNATIVE 4 - IN SITU SOLIDIFICATION	FIGURE 5-4



URS Corporation	**KEYSPAN CORPORATION** **HEMPSTEAD INTERSECTION STREET** **FORMER MGP SITE** **GARDEN CITY/HEMPSTEAD, NY**	**CONCEPTUAL LAYOUT FOR ALTERNATIVE 5 - CONTAINMENT AND GATE**	**FIGURE 5-5**

J:\11175065\CAD\DRAFT\TASK2\HEMPSTEAD\FS NOV 07\FIGURE 5-5.dwg 2/4/08-6 RAL



Legend

Potential Location for Bioremediation Wells

Monitoring Well Cluster - Highest BTEX/ PAH Concentrations (ug/L):
- Not Detected
- 1 - 10
- 10 - 100
- 100 - 1,000
- > 1,000; or Product Detected

Isoconcentration Line (ppb):
- 50
- 100
- 1,000

400 0 400 Feet

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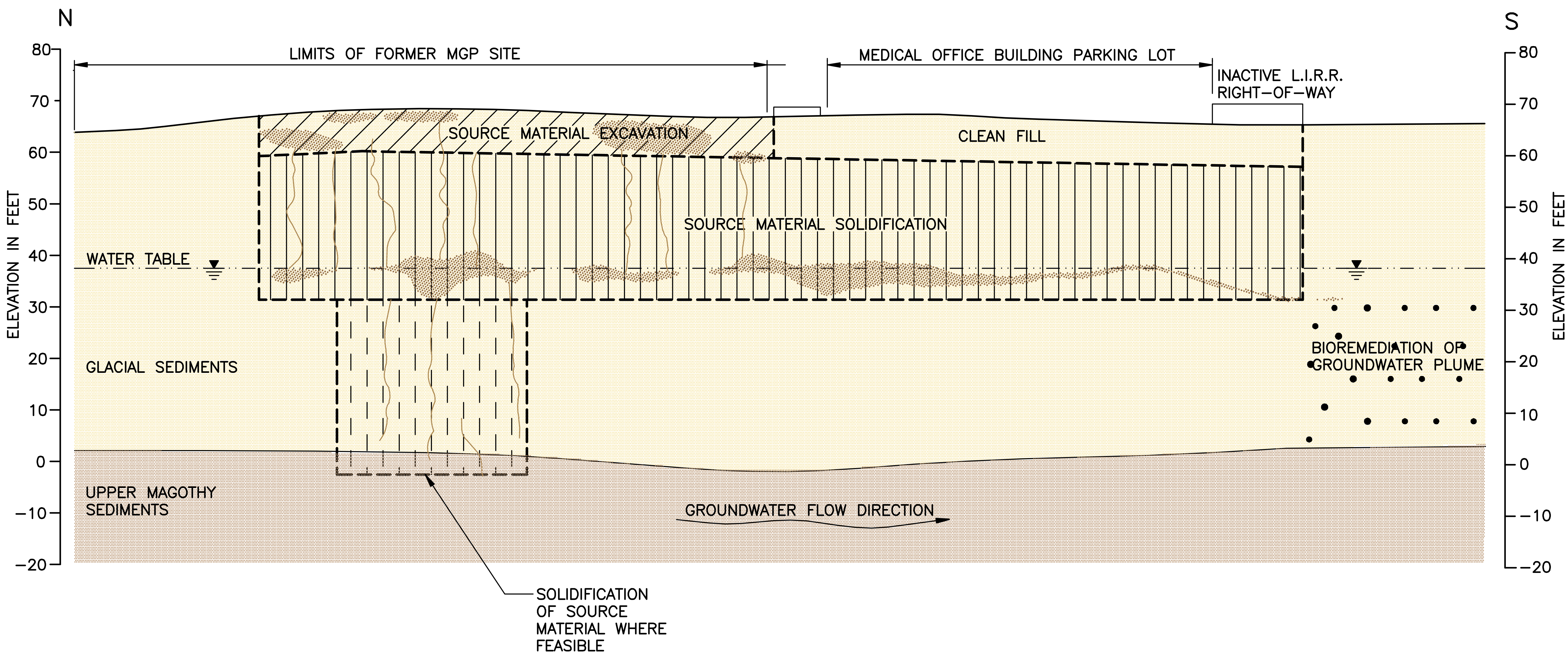
URS	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET - FORMER MGP SITE POTENTIAL LOCATIONS FOR BIOREMEDIATION WELLS	FIGURE 5-6



LEGEND:

WATER TABLE

AREAS CONTAINING TAR/NAPL SATURATED SOILS

AREAS CONTAINING NAPL STRINGERS

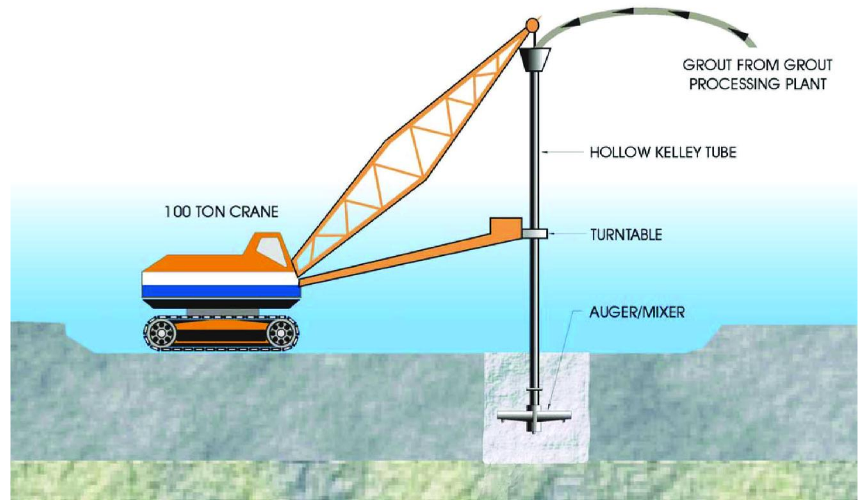
40' 0 40'
HORIZ. SCALE IN FEET

10' 0 10'
VERT. SCALE IN FEET

TYPICAL CROSS–SECTION SOURCE:

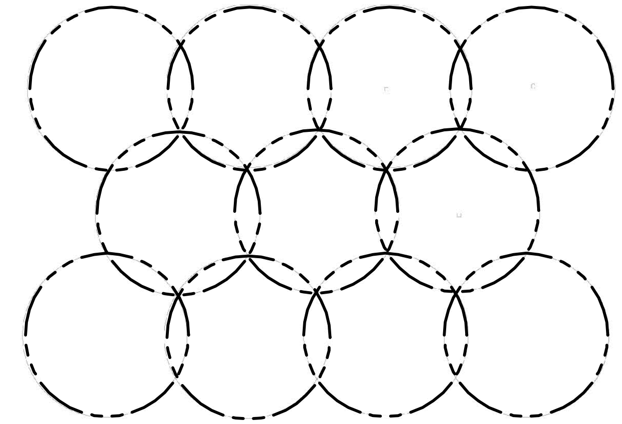
RI FIGURE 6B BY PAULUS, SOKOLOWSKI AND SARTOR ENGINEERING, PC.

URS Corporation	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET FORMER MGP SITE GARDEN CITY/HEMPSTEAD, NY	CONCEPTUAL MODEL OF RECOMMENDED ALTERNATIVE	FIGURE 7-1



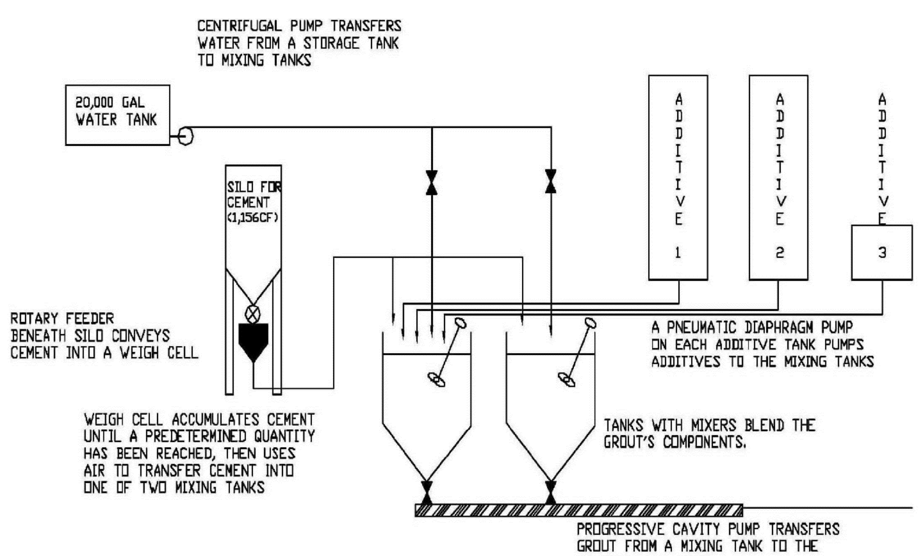
TYPICAL IN SITU AUGER MIXING RIG SCHEMATIC

NOT TO SCALE



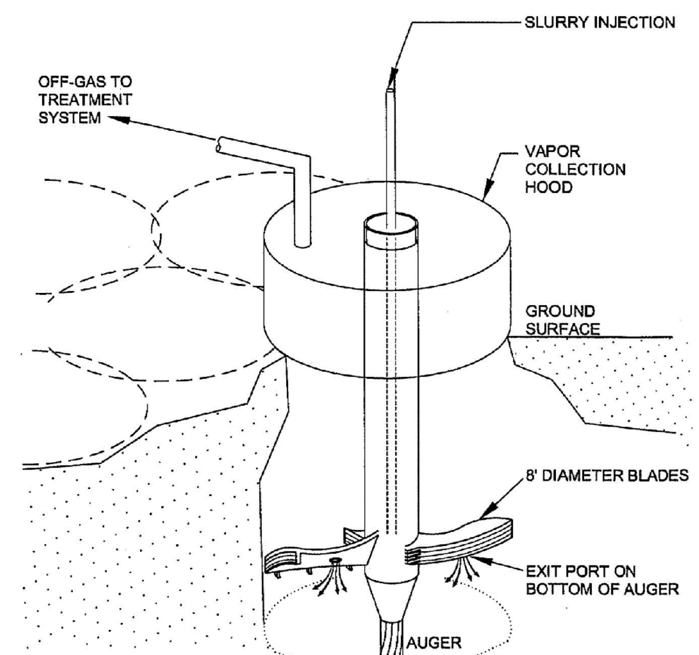
TYPICAL IN SITU SOIL MIXING COLUMN LAYOUT SCHEMATIC

NOT TO SCALE



TYPICAL GROUT BATCH PLANT

NOT TO SCALE



INJECTION/MIXING AUGER

NOT TO SCALE

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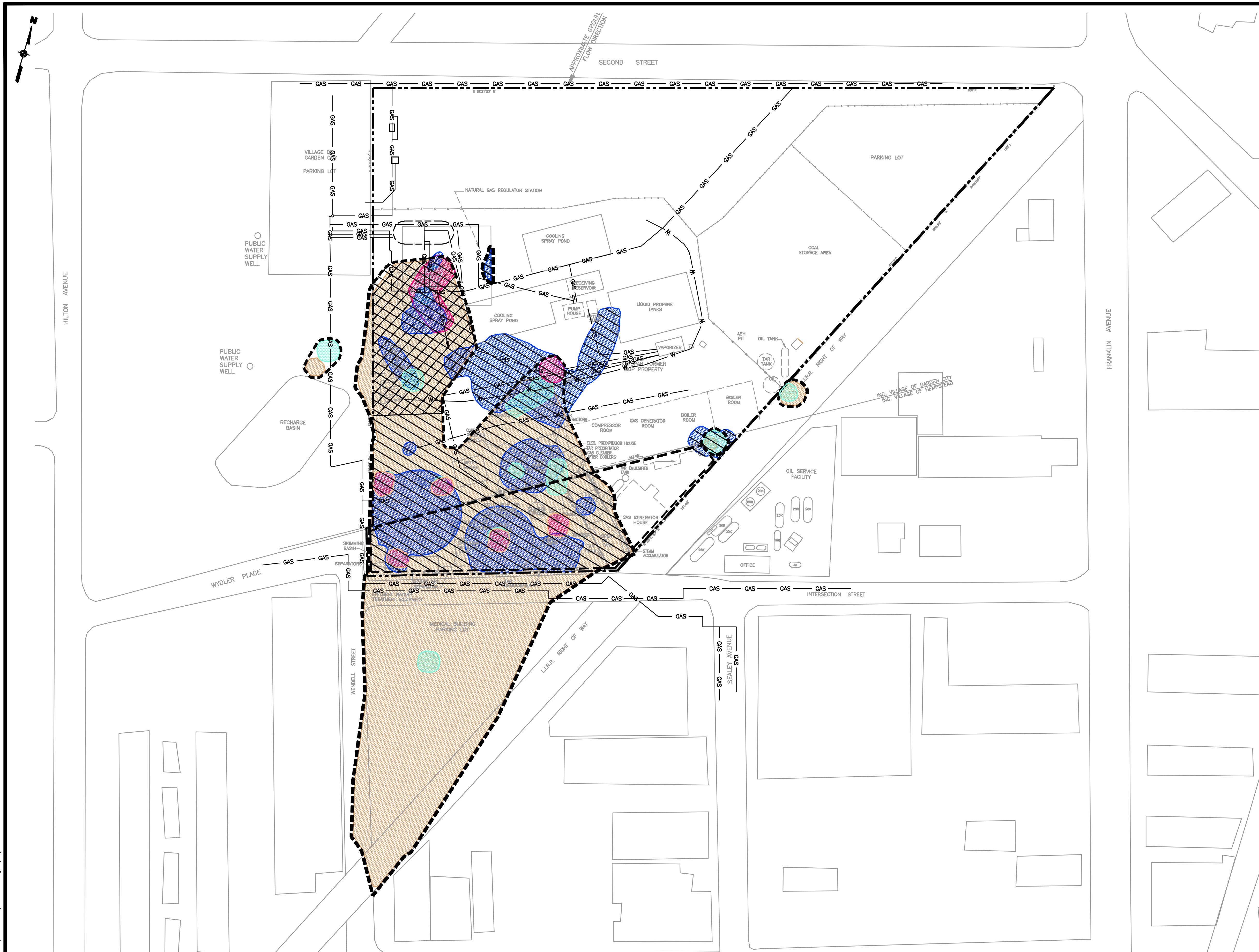
URS Corporation	**KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET FORMER MGP SITE GARDEN CITY/HEMPSTEAD, NY**	**IN SITU SOLIDIFICATION ILLUSTRATION**	**FIGURE 7-2**



LEGEND:

- 0–8' REMAINING SOIL SOURCE MATERIAL TO BE REMOVED
- 8–16' SOIL SOURCE MATERIAL
- 16–24' SOIL SOURCE MATERIAL
- 24–34' SOIL SOURCE MATERIAL
- SHALLOW PRE–ISS EXCAVATION AREAS
- ISS TO 70 FT BGS MAX.
- APPROXIMATE LOCATION OF FORMER MGP STRUCTURE
- LOCATION OF EXISTING STRUCTURE
- FORMER MGP SITE BOUNDARY
- SOLD PROPERTY BOUNDARY
- FENCE
- APPROXIMATE LIMITS OF SOLIDIFICATION AREA TO 34 FEET
- GAS — EXISTING GAS LINE
- W — EXISTING WATER LINE

0' 60' 120'

URS Corporation	KEYSPAN CORPORATION HEMPSTEAD INTERSECTION STREET FORMER MGP SITE GARDEN CITY/HEMPSTEAD, NY	ISS IMPLEMENTATION PLAN VIEW	FIGURE 7-3

APPENDICES

APPENDIX A

GROUNDWATER FLOW CALCULATIONS

URS
77 Goodell Street
Buffalo, New York 14203
(716) 856-5636

CALCULATION COVER SHEET

Client: *Keyspan Corp.* Project Name: *Hempstead Intersection St*

Project / Calculation Number: *111 75 065*

Title: *Hydraulic Containment System*

Total number of pages (including cover sheet): *36 (35 + cover)*

Total number of computer runs: *0*

Prepared by: Marek Ostrowski Date: May 1, 07

Checked by: Amy Monti Date: 5/1/07

Description and Purpose: ** Preliminary design of the hydraulic containment system for the area where concentrations of BTEX or PAH compounds exceed 1,000 ppb.*

** Specify the number, locations, depth and diameter of extraction wells, as well as the expected range of extraction rates.*

Design bases / references / assumptions: *An approximation of wells placed in a uniform flow of water is used. Containment is developed within the Upper Glacial aquifer and the upper unit of the Magothy aquifer. Other ground water extraction features operating in the area are not taken into account.*

Remarks / conclusions:

- *Two extraction wells are recommended (as shown on page 16).*
- *Both wells are 8-inch diamter.*
- *Well depths are: 70 ft for the Upper Glacial aquifer well, 120 ft for the Magothy well.*
- *The expected range of total flow rates required to create the containment is 150 to 500 gpm.*

Calculation Approved by: [signature] 5/1/07
Project Manager / Date

Revision No:	Description of Revisions	Approved by:

Project Manager / Date

MADE BY: M.O. DATE: May 1, 07
CHECKED BY: AMM DATE: 5/1/07

PROJECT: Keyspan Hempstead Intersection Street
SUBJECT: Hydraulic Containment System

1. PURPOSE

The purpose of this calculation is to perform the preliminary design of the hydraulic containment system for the Keyspan's Hempstead Intersection Street site. The following elements of the system will be specified:

- Number and locations of the extraction wells
- Well depth and diameter
- Range of the expected extraction rates

2. SITE DESCRIPTION

2.1 Hydrogeology

Information about the site has been obtained from the March 2006 RI report (reference 1). Site plan is shown on Figure 1-2 of reference 1.

A conceptual cross section is presented on page 15 of this calculation. It is based on DWG 6C of reference 1 (oversized, not included in this calculation) and Sections 3.3, 3.4 and 3.5 of reference 1. Three distinct layers can be distinguished at the site.

The top 60 to 70 feet are composed of glacial outwash sediments of the unconfined Upper Glacial aquifer. These deposits consist mostly of sand and gravel. Some silt lenses are also present; however, they occur mostly above the water table. Ground water table is located within the Upper Glacial aquifer, at the depth of approximately 30 feet below ground surface. The Upper Glacial aquifer is highly permeable.

Below the Upper Glacial aquifer lies the Magothy formation. At the site, the Magothy unit can be divided into the upper and lower subunits.

The upper subunit of the Magothy formation consists of interbedded sands, silts and clays. This layer is between approximately 50 and 110 feet thick. The horizontal conductivity of the upper unit is moderate to high: however, the vertical conductivity is much lower.

The lower unit of the Magothy formation consists of deposits ranging from silty sand to clay. The actual thickness of this unit at the site is not known; however, it is expected to be at least 200 feet. The vertical hydraulic conductivity of this unit is very low.
The regional flow in the Upper Glacial aquifer is to the south-to-southwest (Figure 1-6 of reference 1). The local flow direction is the same (DWG 3G of reference 1, oversized, not included in this calculation). Based on DWG 3H of reference 1(oversized, not included in this calculation), flow within the Magothy unit is to southwest.

2.2 Contamination

The main ground water contaminants at the site are BTEX and PAH compounds. Reference 1 presents ground water contamination based on the division of the aquifers into three zones: shallow ground water (upper layer of the Upper Glacial, DWGS 4K1 and 4K2), intermediate ground water (combined lower layer of Upper Glacial and upper layer of upper subunit of Magothy, DWGS 4L1 and 4L2) and deep ground water (lower layer of the upper subunit of Magothy, DWGS 4M1 and 4M2). This division is shown on a conceptual cross section on page 15. The drawings are oversized and are not presented in this calculation. For the purpose of this estimate, the extent of contamination within the Upper Glacial aquifer is defined as the sum of areal extents of contamination in the shallow and intermediate ground water. The extent of contamination in the upper subunit of Magothy is defined by the extents of contamination in the intermediate ground water. The lower subunit of Magothy is assumed not to be contaminated.

The area targeted for containment is defined as an area where concentrations of either BTEX or PAH compounds exceed 1,000 μg/L. For the Upper Glacial aquifer, and the upper subunit of the Magothy, this information is summarized on page 16.

MADE BY: MO DATE: May 1, 07
CHECKED BY: AMM DATE: 5/1/07

PROJECT: Keyspan Hempstead Intersection Street
SUBJECT: Hydraulic Containment System

3. CALCULATIONS

3.1 Method

The lower subunit of the Magothy formation is characterized by very low vertical hydraulic conductivity. Values on the order of 10^{-7} cm/s were obtained from three undisturbed soil samples collected at the site (Section 3.4 of reference 1). The subunit is expected to be over 200 feet thick. The rate of vertical flow of ground water across this unit is probably negligible. Considering that, it is assumed that the top of the lower subunit of the Magothy formation can be approximated as an impervious bottom for the upper subunit.

Contamination is generally limited to the upper subunit of the Magothy formation and the Upper Glacial aquifer (DWGS 6C and 6D of reference 1, oversized, not included in this calculation). Therefore, water from these two layers is included in the hydraulic containment alternative. Extraction wells are proposed to be screened in the Upper Glacial and upper subunit of Magothy. The interaction between these two units is investigated below.

Assume a well pumping from the upper Magothy. A fraction of the water extracted by the well will originate as vertical leakage from the Upper Glacial aquifer at the site, the remainder will be the water reaching the well as horizontal flow from upgradient. By analyzing the relative contribution of these two flows, the degree to which the flow exchange between the aquifers at the site will occur can be assessed. A large fraction of the extraction rate originating from vertical leakage within the site would indicate that the two aquifers are well connected. However, if only a small fraction of the extracted ground water reaches the well as a vertical leakage originating within the site, the aquifers can be considered to be largely separate.

Based on equations 8-38 and 8-43 of reference 2, the proportion of water derived from the horizontal flow within the Magothy to the total extraction rate, as a function of distance from the well, is:

$$Q(r)/Q_w = (r/\lambda)\ K_1(r/\lambda)$$

$$\lambda = (B'BK/K')^{1/2}$$

Where:

r -	distance from the well, [L]
Q(r) -	horizontal flow towards the well at the distance "r" from the well, $[L^3/T]$
Q_w -	well's extraction rate, $[L^3/T]$
K -	hydraulic conductivity of the aquifer, [L/T]
K' -	vertical hydraulic conductivity of the semi-impervious layer separating the water-bearing zones, [L/T]
B -	thickness of the aquifer, [L]
B' -	thickness of the semi-impervious layer, [L]
K_1 -	modified Bessel function of second kind and zero order, [-]
λ -	leakage factor, [L]

This is based on two-dimensional approximation, in which there is horizontal flow within the screened aquifer and vertical flow between the two aquifers. Conceptualize the vertical flow as having to pass through the upper half of the thickness of the screened aquifer. In this case, the thickness of the semi-impervious unit is B' = B/2, and the conductivity of the semi-impervious layer is equal to the vertical conductivity of the screened aquifer $K' = K_v$.

$$B' = (1/2)B$$

$$\lambda = (B'BK/K')^{1/2} = \{[(1/2)B]BK/K_v\}^{1/2} =$$

$$= 0.71B(K/K_v)^{1/2}$$

The upper subunit of Magothy is approximately 50 to 110 ft thick. Use the average value of B = 80 ft. Based on Table 1 of reference 3, the horizontal to vertical anisotropy within the Magothy is $K/K_v = 100/1$. From that:

$$\lambda = 0.71*80*(100/1)^{1/2} = 570 \text{ ft}$$

The dimension of the site is approximately 500 ft (reference 1, Figure 1-2). From that, r = 250 ft; and:

$$Q(r)/Q_w = (r/\lambda)\ K_1(r/\lambda) = (250/570)\ K_1(250/570) =$$

$$= 0.44\ K_1(0.44)\ 0.44*2.0 = 0.88$$

Horizontal flow from outside of the site = 88% Q_w

Vertical flow within the site = 12% Q_w

Most of the water will reach the well as horizontal flow from outside of the site. The interaction between the extraction wells placed in the Upper Glacial and Magothy will be low. For the purpose of this preliminary design, both water-bearing zones will be considered to be separate aquifers.

The preliminary design of the containment system will be performed using the approximation of wells placed in the uniform horizontal flow of ground water. The extraction rate required to create a given lateral extent of the capture at the line passing through the wells can be estimated as (Reference 4, Figure 12):

$$W = Q / 2\ T\ i$$

$$Q = 2\ W\ T\ i$$

$$T = H_0\ K$$

The Upper Glacial aquifer is unconfined, the Magothy is confined/unconfined. In this calculation, a formula for the well extraction rate in a confined aquifer will be used for both water-bearing zones. This is because the unconfined case can be approximated as a confined case, provided that drawdowns are a small fraction of the saturated thickness. In this case, all drawdowns will be low.

The extraction rate of the well can be related to the drawdown in the well as (Reference 2, Equations 8-4 and 8-12):

$$Q_w = s_w\ 2\ \pi\ K\ H_0\ /\ \ln(R/r_w)$$

$$R = 575 s_w (H_0 K)^{1/2}$$

$$Q_w = s_w\ 2\ \pi\ K\ H_0 /\ \ln[575 s_w (H_0 K)^{1/2}/r_w]$$

Where:

H_0 - Undisturbed saturated thickness, [m]
i - Hydraulic gradient, [-]
K - Hydraulic conductivity, [m/s]
Q - Required total extraction rate, [m^3/s]
Q_w - Extraction rate of a single well, [m^3/s]
R - Well's radius of influence, [m]
r_w - Radius of the well, [m]
s_w - Drawdown an the extraction well, [m]
T - Aquifer's transmissivity, [m^2/s]
W - Width of the capture zone in the direction perpendicular to the flow, at the line passing through the well, [m]

The number of wells needed to extract the required extraction rate is:

$$N = Q\ /\ Q_w$$

$$N = 2\ W\ K\ H_0\ i\ /\ \{(s_w\ 2\ \pi\ K\ H_0)\ /\ \ln[575 s_w (H_0 K)^{1/2}/r_w]\}$$

$$N = (W\ i\ /\ s_w\ \pi)\ \ln[575 s_w (H_0 K)^{1/2}/r_w]\}$$

Note that the required number of wells is only a very weak function of the hydraulic conductivity (a natural logarithm of a square root of conductivity). Therefore, the hydraulic conductivity is relatively unimportant in determining the number of wells. Using the maximum reasonable value of hydraulic conductivity will provide a slightly conservative (i.e. high) estimate of the number of wells.

The required number of wells is mostly determined by the drawdown that can be developed inside the extraction well.

$$N \approx (W\ i\ /\ s_w\ \pi)\ \ln[575 s_w (H_0 K_{max})^{1/2}/r_w]$$

$$N = CONST_1\ /\ s_w$$

$$CONST_1 = (W\ i\ /\ \pi)\ \ln[575 s_w (H_0 K_{max})^{1/2}/r_w]$$

$$CONST_1 = (W\ i\ /\ \pi)\ \ln[575 s_w T_{max}^{1/2}/r_w]$$

Once the required number of wells is determined, the downgradient extent of the capture zone of a system consisting of "N" wells is calculated from Table 5 of reference 4:

$$X_d = f\ (Q_w\ /\ 2\ \pi\ K\ H_0\ i) \qquad f(N=1) = 1 \quad f(N=2) = 1 \quad f(N=3) = 3/2$$

$$X_d = f\ \{(s_w\ 2\ \pi\ K\ H_0)/\ \ln[575 s_w (H_0 K)^{1/2}/r_w]\}\ /\ (2\ \pi\ K\ H_0\ i)$$

$$X_d = f\ (s_w\ /\ i)\ /\ \ln[575 s_w (H_0 K)^{1/2}/r_w]$$

Using the minimum reasonable value of hydraulic conductivity will provide a slightly conservative (i.e. low) estimate of the downgradient extent of the capture zone.

$$X_d = f\ (s_w\ /\ H_0\ i)\ /\ \ln[575 s_w T_{min}^{1/2}/r_w] = f\ s_w\ CONST_2$$

$$CONST_2 = (1\ /\ i)\ /\ \ln[575 s_w T_{min}^{1/2}/r_w]$$

3.2 Containment System - Upper Glacial Aquifer

Following parameters are used:

- Saturated thickness - H_0
  From Section 3.3 of reference 1, the thickness of the Upper Glacial deposits in the study area is 60 to 70 feet (say, 65 ft). Based on Section 3.5 of reference 1, water table occurs at depth of 30 feet. From that, the saturated thickness is:
  $H_0 = 65 - 30 = 35$ ft $= 10.7$ m

- Hydraulic gradient - i
  In Section 3.5 of reference 1, local gradient was estimated as 0.00144. From Figure 1-6 of reference 1, the regional gradient can be estimated as i = 20 ft / 2.25 mile = 0.0017. Use:
  $i = 0.002$

- Hydraulic conductivity - K
  Based on Table 1 of reference 3, the hydraulic conductivity of the Upper Glacial aquifer is between 200 and 300 ft/d (outwash deposits, such as those identified at the site - Section 3.3 of reference 1).
  $K_{min} = 200 \text{ ft/d} = 7*10^{-2} \text{ cm/s} = 7*10^{-4} \text{ m/s}$
  $K_{max} = 300 \text{ ft/d} = 1*10^{-1} \text{ cm/s} = 1*10^{-3} \text{ m/s}$

- Well radius - r_w
  Use 6-inch wells:
  $r_w = 3 \text{ in} = 0.076 \text{ m}$

- Width of capture zone - W
  The selection of containment area is explained in Section 2.2. The width of the area to be contained, in the direction perpendicular to the flow, is approximately 500 ft (page 16). Use factor of safety of 1.5:
  $W = 500*1.5 = 750 \text{ ft} = 230 \text{ m}$

Calculate flow rate, number of wells, well drawdown and downgradient extent of capture zone.

Summary of parameters

$H_0 = 10.7$ m
$i = 0.002$
$K_{min} = 7*10^{-4}$ m/s
$K_{max} = 1*10^{-3}$ m/s
$r_w = 0.076$ m
$W = 230$ m

Transmissivity, range for K_{min} to K_{max}

$$T = K H_0 = (7*10^{-4})*10.7 \text{ to } (1*10^{-3})*10.7 =$$
$$= 0.0075 \text{ to } 0.011 \text{ m}^2/\text{s}$$

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SUBJECT: Hydraulic Containment System

Required total extraction rate, range for K_{min} to K_{max}

$$Q = 2\ W\ T\ i$$

$$\begin{aligned} Q &= 2*230*(0.0075 \text{ to } 0.011)*0.002 = \\ &= 0.92*(0.0075 \text{ to } 0.011) = \\ &= 0.007 \text{ to } 0.01\ m^3/s\ (110 \text{ to } 160 \text{ gpm}) \end{aligned}$$

Required number of wells

$$N = CONST_1 / s_w$$

Use well drawdown of 3 ft (approx. 1.0 m).

$$\begin{aligned} CONST_1 &= (W\ i\ /\ \pi)\ \ln[575 s_w T_{max}{}^{1/2}/r_w] = \\ &= (230*0.002/\pi)\ \ln[575*1*0.011^{1/2}/0.076] = \\ &= 0.15*\ln(794) = 0.15*6.7 = 1.0 \text{ m} \end{aligned}$$

$N = 1.0 / 1.0 = 1$ => use 1 well

Note that the drawdown of 1 m is a small fraction (less than 10%) of the entire saturated thickness of 11 m. Therefore, approximating the unconfined aquifer as a confined aquifer for the purpose of calculating the extraction rate of a well is valid here.

Downgradient extent of capture zone

$$X_d = f\ s_w\ CONST_2$$

For N = 1 well, f = 1. Well drawdown is 1 m.

$$\begin{aligned} CONST_2 &= (1\ /\ i)\ /\ \ln[575 s_w T_{min}{}^{1/2}/r_w] = \\ &= (1/0.002)\ /\ \ln[575*1*0.0075^{1/2}/0.076] = \\ &= 500\ /\ \ln(655) = 500\ /\ 6.5 = 77 \end{aligned}$$

$$X_d = 1 * 77 = 77 \text{ m} = 250 \text{ ft}$$

Summary of results

Within the Upper Glacial aquifer, a single well, with a drawdown of approximately 3 ft and extraction rate of 110 to 160 gpm is sufficient to create a capture zone that would encompass the entire area to be contained. In order to create containment, the well must be placed less than 250 feet upgradient from the downgradient limits of the containment area.

3.3 Containment System - Upper Unit of Magothy Aquifer

Following parameters are used:

- Saturated thickness - H_0
  From Section 3.4 of reference 1, the thickness of the upper Magothy subunit in the study area is 50 to 110 feet (say, 80 ft).
  H_0 = 80 ft = 24.3 m

- Hydraulic gradient - i
  Hydraulic gradient in the Magothy formation can be calculated from the potentiometric surface maps presented on DWGS 3H, 3J and 3K of reference 1 (oversized, not included in this calculation package).
  i = 3.5 ft / 1,300 ft = 0.0027 DWG 3H
  i = 4 ft / 400 ft = 0.01 DWG 3J
  i = 1 ft / 500 ft = 0.002 DWG 3K
  Considering prevailing gradients in the area, the value of 0.01 is likely a small-scale property. Value of 0.003 will be used in this calculation.
  i = 0.003

- Hydraulic conductivity - K
  Based on Table 1 of reference 3, the hydraulic conductivity of the Upper Glacial aquifer is between 30 and 180 ft/d.
  K_{min} = 30 ft/d = $1*10^{-2}$ cm/s = $1*10^{-4}$ m/s
  K_{max} = 180 ft/d = $6*10^{-2}$ cm/s = $6*10^{-4}$ m/s

- Well radius - r_w
  Use 6-inch wells:
  r_w = 3 in = 0.076 m

MADE BY: MO DATE: May 1, 07
CHECKED BY: AMM DATE: 5/1/07

PROJECT: Keyspan Hempstead Intersection Street
SUBJECT: Hydraulic Containment System

- Width of capture zone - W
  Based on information compiled on page 16, the width of capture zone in the upper Magothy is approximately 200 feet. However, at this stage, it is assumed that the extraction wells can be installed only on the east side of the Wendell Street. Since the almost the entire area of containment is located on the west side of Wendell Street, the width of the capture zone will have to be twice the width of the containment area - approximately 400 feet. Use factor of safety of 1.5 for design.

  $W = 400*1.5 = 600 \text{ ft} = 180 \text{ m}$

Calculate flow rate, number of wells, well drawdown and downgradient extent of capture zone.

Summary of parameters

$H_0 = 24.3$ m
$i = 0.003$
$K_{min} = 1*10^{-4}$ m/s
$K_{max} = 6*10^{-4}$ m/s
$r_w = 0.076$ m
$W = 180$ m

Transmissivity, range for K_{min} to K_{max}

$$T = K\ H_0 = (1*10^{-4})*24.3 \text{ to } (6*10^{-3})*24.3 =$$
$$= 0.0024 \text{ to } 0.015 \text{ m}^2/\text{s}$$

Required total extraction rate, range for K_{min} to K_{max}

$$Q = 2\ W\ T\ i$$

$$Q = 2*180*(0.0024 \text{ to } 0.015)*0.003 =$$
$$= 1.1*(0.0024 \text{ to } 0.015) =$$
$$= 0.003 \text{ to } 0.02 \text{ m}^3/\text{s } (50 \text{ to } 320 \text{ gpm})$$

Required number of wells

$$N = CONST_1 / s_w$$

Use well drawdown of 5 ft (1.5 m).

$$CONST_1 = (W\ i / \pi) \ln[575 s_w T_{max}^{1/2}/r_w] =$$
$$= (200*0.003/\pi) \ln[575*1.5*0.015^{1/2}/0.076] =$$
$$= 0.19*\ln(1{,}390) = 0.19*7.2 = 1.4\ m^2$$

$$N = 1.4 / 1.5 = 1 \text{ well}$$

Note that the drawdown of 1.5 m is a very small percentage (less than 10%) of the entire saturated thickness of 24 m. Therefore, approximating the unconfined aquifer as a confined aquifer for the purpose of calculating the extraction rate of a well is valid here.

Downgradient extent of capture zone

$$X_d = f\ s_w\ CONST_2$$

For N = 1 well, f = 1. Well drawdown is 1.5 m.

$$CONST_2 = (1 / i) / \ln[575 s_w T_{min}^{1/2}/r_w] =$$
$$= (1/0.003) / \ln[575*1.5*0.0024^{1/2}/0.076] =$$
$$= 333 / \ln(555) = 333 / 6.3 = 53$$

$$X_d = 1.5 * 53 = 80\ m = 260\ ft$$

Summary of results

Within the upper unit of the Magothy aquifer, a single well, with a drawdown of approximately 5 ft and extraction rate of 50 to 320 gpm is sufficient to create a capture zone that would encompass the entire area to be contained. In order to create containment, the well must be placed less than 260 feet upgradient from the downgradient limits of the containment area.

3.4 Containment System

In both Upper Glacial and Magothy aquifers, a single well placed less than 260 ft upgradient of the downgradient limit of containment area would be sufficient to achieve hydraulic control of the source. However, the southern limits of the containment areas are different in both aquifers. In order to locate wells closer to the contaminated areas, two separate wells are recommended.

The maximum expected extraction rate is 160 gpm from the Upper Glacial and 320 gpm from the Magothy, for the total rate of 480 gpm. The minimum expected rates are 110 gpm from the Upper Glacial and 50 gpm from the Magothy, for the total rate of 160 gpm.

4. SUMMARY AND RECOMMENDATIONS

Results of this calculation indicate that a single well is sufficient to develop hydraulic containment in the Upper Glacial aquifer. Likewise, for the containment in the Magothy, a single well is also sufficient. Proposed well locations for the Upper Glacial and the Magothy are shown on pages 16 . The well in the Upper Glacial would penetrate to the depth of approximately 70 feet. The depth of the Magothy well would be approximately 120 feet.

Extraction rates required to affect capture are not known, as site-specific aquifer tests were not performed, and local values of hydraulic conductivity are not available. Using hydraulic conductivities based on literature sources, the total expected extraction rates are between approximately 150 gpm and 500 gpm. Expected extraction rates per well are in the range of 50 to 300 gpm. The rate of 300 gpm is relatively high; therefore, 8-inch diameter wells are recommended in this preliminary design.

The estimates contained in this calculation are preliminary. They do not take into account influences of other extraction wells that might operate in the study area. Use of a numerical model might be necessary to evaluate such effects.

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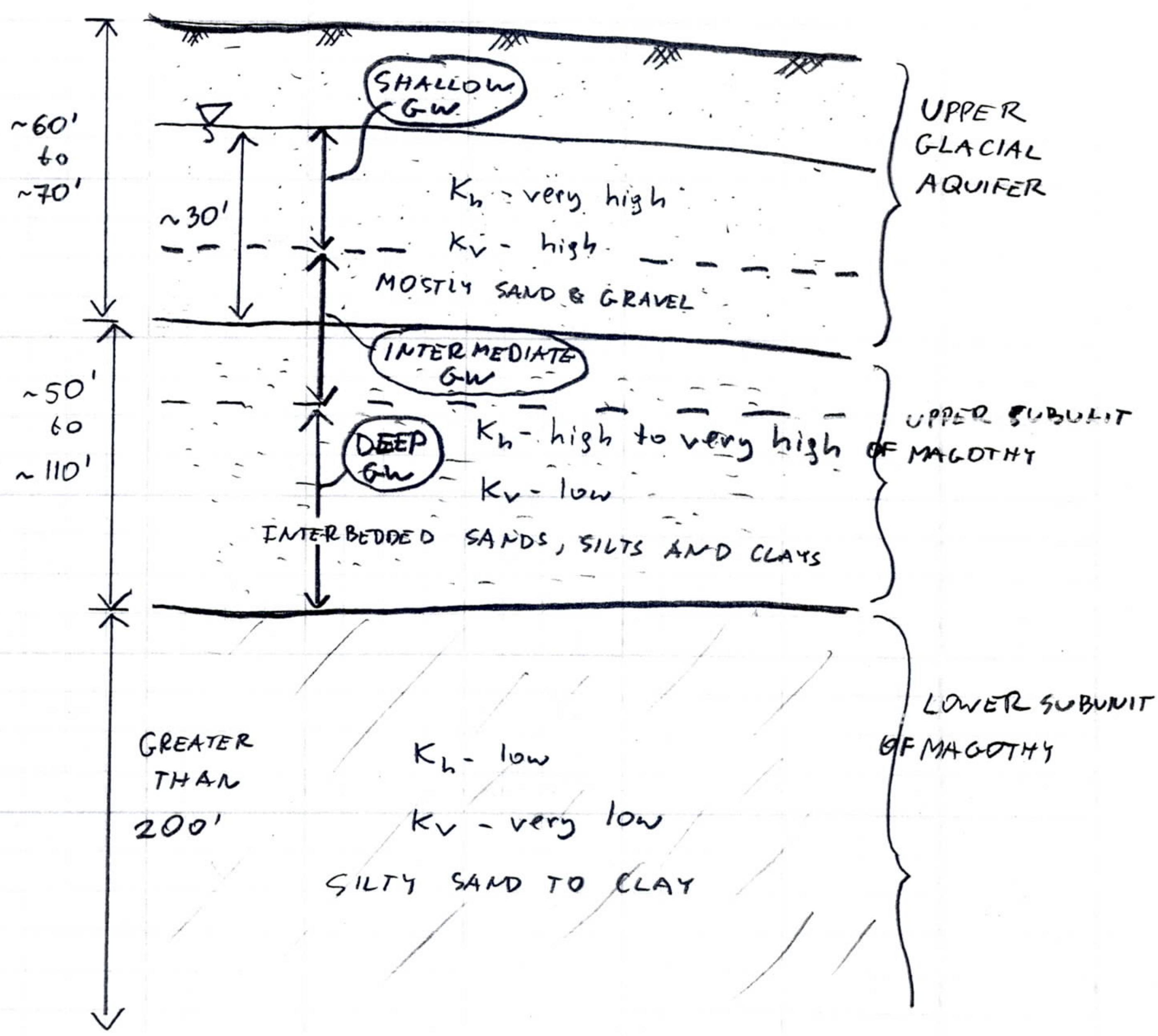
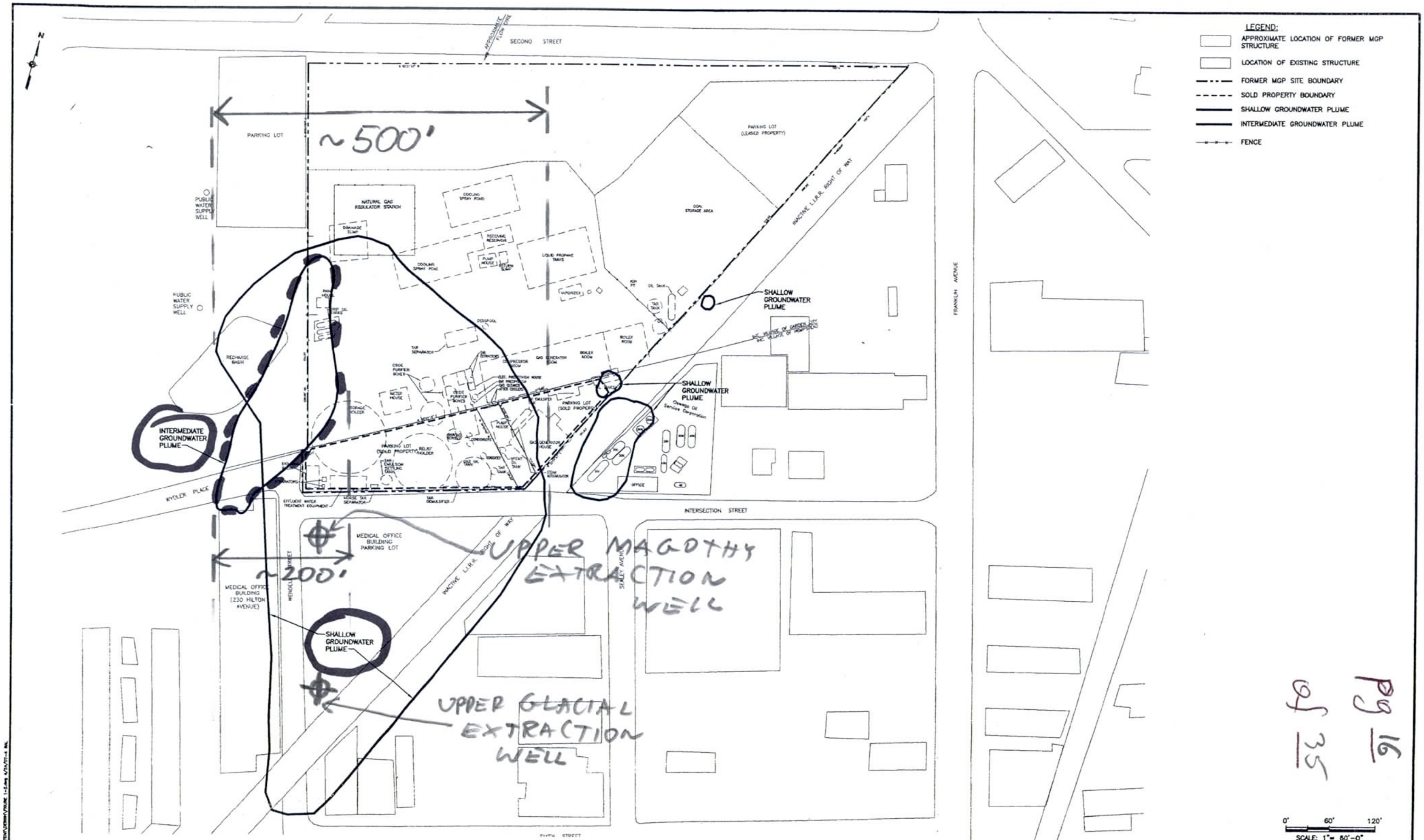
   Lewis Publishers, 1993

URS

Job Hempstead Intersection St | Project No. 111 75 065 | Sheet ___ of ___
Description Hydraulic Containment System | Computed by M.O. | Date Apr 5, 2007
Checked by AMM | Date 5/1/07
Reference

CONCEPTUAL CROSS SECTION





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HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

SHALLOW AND INTERMEDIATE GROUNDWATER PLUMES

FIGURE 2-8

HEMPSTEAD INTERSECTION STREET
FORMER MANUFACTURED GAS PLANT SITE

Reference 1

FINAL REMEDIAL INVESTIGATION REPORT

Prepared for:

KEYSPAN CORPORATION
One MetroTech Center
Brooklyn, New York

MARCH 2006

Prepared by:

PS&S engineering

Paulus, Sokolowski and Sartor Engineering, PC
67A Mountain Boulevard Extension
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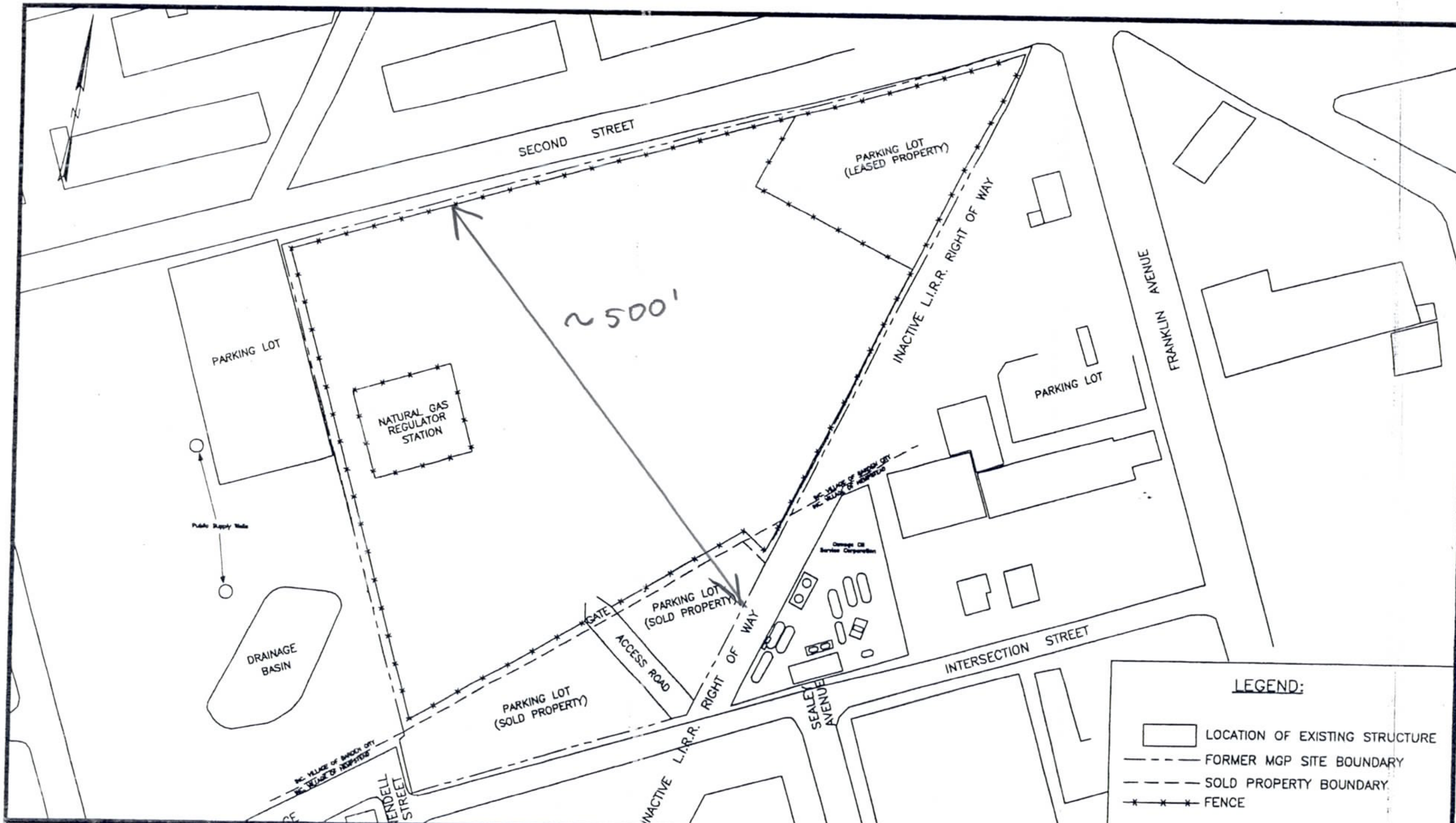

SOURCE:

DVIRKA AND BARTILUCCI CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

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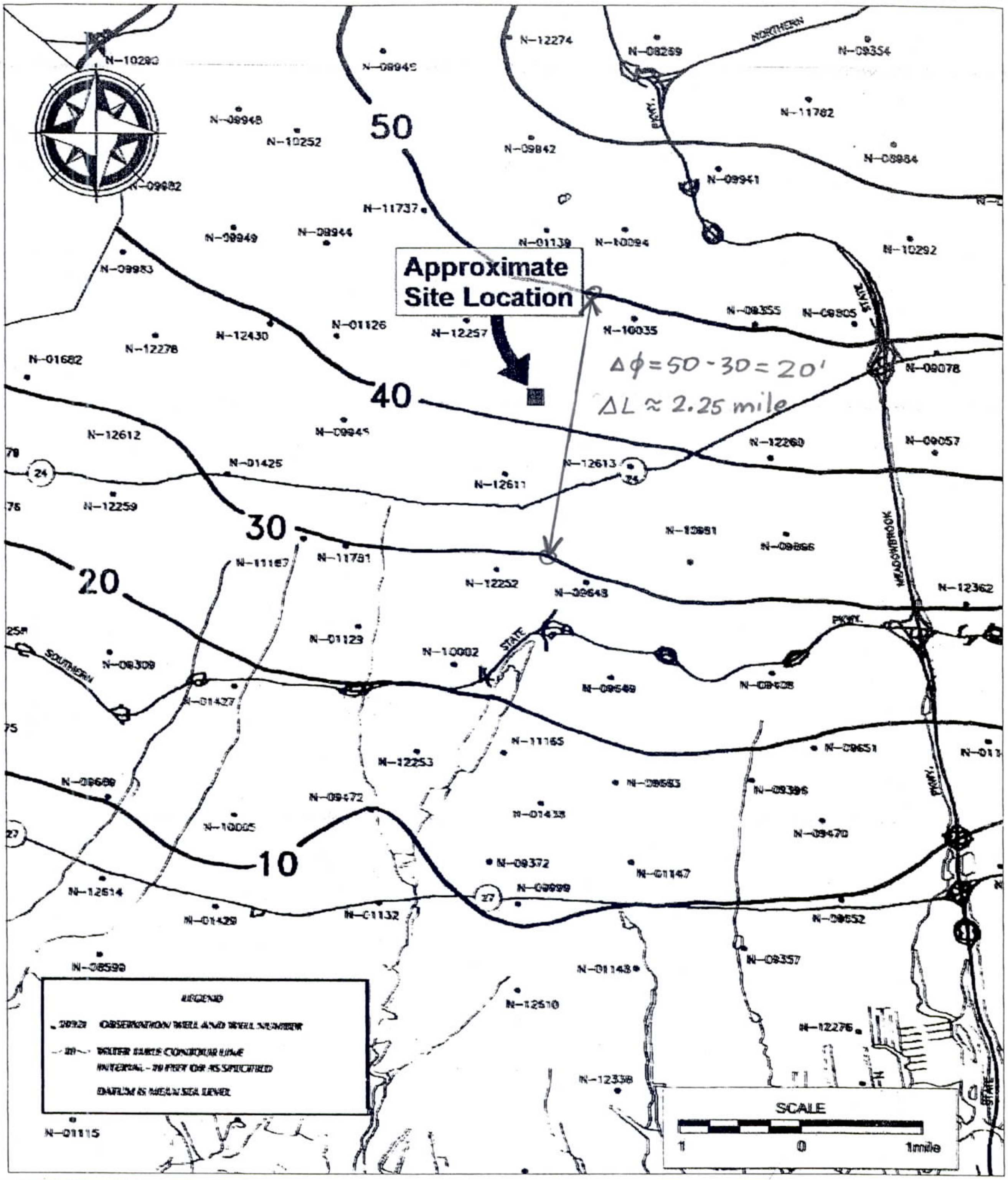
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE REMEDIAL INVESTIGATION
GARDEN CITY/HEMPSTEAD, NEW YORK

SITE MAP

Drn. By: JJ	Scale: 1" = 150'	Proj. No.: 02522.013.024
Ck'd By: JMP	Date: FEBRUARY 2005	Fig. No.: 1-2



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GARDEN CITY/HEMPSTEAD, NEW YORK
WATER TABLE CONTOUR MAP
FOR CENTRAL NASSAU COUNTY

Source: Source: DVIRKA AND BARTILUCCI CONSULTING ENGINEERS A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

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Drn. By: JJ	Scale: AS SHOWN	Proj. No.: 02522.013.024
Ck'd By: JMP	Date: FEBRUARY 2005	Fig. No.: 1-6

concrete, brick, coal, bluestone, clinker, vesicular slag and wood. The unit is not continuous throughout the site and varies in thickness from approximately 1/2-foot up to 16 feet. However, as indicated by **Drawing 3A**, the unit is fairly continuous along the southern and eastern boundaries of the site where it extends up to 4 feet in thickness at soil boring HISB-35. The unit appears to be thickest in the central-western portion of the site as illustrated on **Drawing 3C**. The unit is up to 16 feet thick at soil boring HISB-14, which is located within the area of the former drip oil tanks, and up to 8 feet thick at soil boring HISB-15, which is located at the former tar separator. It is possible that, after removal of these former MGP structures, the excavations were backfilled with fill material. The north-south cross-sections, illustrated on **Drawings 3E** and **3F**, demonstrate that the fill unit decreases in thickness toward the north end of the site. As mentioned above, the existence and thickness of this unit appears to correlate well with the location and number of former MGP structures, and therefore, could possibly be related to demolition methods that occurred at a particular boring location. With the exception of a thin layer of topsoil, the fill unit does not appear to extend a significant distance south of the site as indicated by **Drawing 3B**. A thin layer of fill does appear to be present at several soil borings located west of the site within the Village of Garden City property, including BBSB-19, 20, 21, 22, 26 and 46.

3.3 Glacial Sediments

Consistent with regional geology, relatively porous glacial outwash deposits consisting of yellow to light brown fine to coarse sand with varying amounts of gravel underlie the site as well as surrounding areas. However, zones or lenses of silty sand and silt were identified within the glacial unit at a number of boring locations. The majority of the silt-sand lenses were encountered from ground surface to a depth of approximately 20 feet. As shown on **Drawing 3B**, one exception to this general observation was at monitoring well HIMW-08D where up to 32 feet of silt and silty sand was observed. The silty sand lenses may limit the vertical movement of groundwater where present at or near the water table, such as in the southern portion of the site (refer to **Drawing 3F**). Additionally, a number of gravel-rich sand lenses were identified in the glacial unit. The majority of these gravel-rich lenses were found from approximately 30 to 50 feet below ground surface. Although encountered throughout the area of investigation, the gravel-rich lenses appear to be more prevalent and continuous in the western half of the site (refer to **Drawings 3A, 3C** and **3E**) and off-site to the west and south (refer to **Drawing 3B**). Where present below the water table, these gravelly zones may act as preferred flow paths for groundwater.

The glacial outwash sediments comprise the entire unconfined Upper Glacial aquifer in the site area. Within the site, the glacial sediments are approximately 60 to 70 feet thick. South of the site, the total thickness of the glacial sediments increases to at least 95 feet as observed at monitoring well HIMW-13D (refer to **Drawing 3B**). The glacial sediments are underlain by the Magothy formation within the site as well as at downgradient areas, at least as far south as Hempstead Lake State Park, approximately 1.3 miles from the site. The interface between the glacial and Magothy formation is characterized by a transition from the glacial sand to a brown to gray layer of silty fine sand, silt and/or silty clay. A review of United States Geologic Service (USGS) reports confirms that this transition has also been recognized as the contact between the two major stratigraphic units in this area of Nassau County.

As discussed in **Section 1.5.8**, the glacial sediments within this area of Long Island exhibit excellent water transmitting properties with horizontal and vertical hydraulic conductivities averaging approximately 250 feet per day (McClymonds and Franke, 1972). Six samples of the glacial sediments were selected for geotechnical analysis (which included grain size analysis by sieving and hydrometer testing, specific gravity and water content) and total organic carbon (TOC). The results of these analyses are summarized on **Table 3-1**. Five of the six samples consist of fine to very coarse sand, typical of the majority of glacial sediments encountered at the site. The effective grain size (d_{10}), which is the grain size at which 90 percent of the sample is larger and 10 percent is finer, for these five samples ranged from 0.17 to 0.38 mm and the amount of the samples finer than 0.073 mm (i.e., grains that may be considered silt or clay) averaged 8 percent. This data indicates that the majority of the glacial sediments consists of fine to coarse sand and has good to excellent water transmitting properties. The remaining glacial sediment sample (HIMW-06 [28 to 30 ft]) consisted of a silty fine sand characteristic of the silty-sand lenses described above. The geotechnical data for this sample indicates a d_{10} of only 0.052 mm with 22 percent of the sample comprised of silt and clay. This would indicate that the silt-sand lenses present in the glacial sediment have poor water transmitting properties. As a result, where present, the silt-sand lenses may act as partial confining units, limiting the vertical migration of water and/or NAPL. Based on the TOC data presented in **Table 3-1**, the outwash deposits are relatively poor in organic matter having an average TOC content of approximately 0.5 percent. The fraction of organic content in soil is the dominant characteristic affecting the adsorption capacity of non-ionic organic compounds such as BTEX and PAHs onto the soil matrix (S.S. Suthersan, 1997). Soil with a very low fraction of organic content will have a limited ability to adsorb and therefore immobilize such organic compounds.

3.4 Magothy Formation Sediments

Prior to the deposition of glacial sediments described above, the underlying Magothy formation was subjected to erosional processes. As a result, the upper surface of this formation is not a flat plain but includes erosional valleys generally trending in a southerly direction towards the Atlantic Ocean. Based on the review of USGS reports, there are no mapped erosional valleys within the site or within two miles downgradient of the site. However, due to the erosional processes and variation in ground surface elevation, the depth at which the upper surface of the Magothy formation may be encountered varies throughout the site area. This variation in the topography of the Magothy formation's upper surface is clearly illustrated by the geologic cross-sections provided in **Drawings 3A** through **3F**. These drawings show that the depth to the Magothy formation generally increases with increasing distance downgradient of the site.

For the purpose of this investigation, the Magothy formation has been further divided into two subunits, with the upper subunit being characterized by a relatively complex sequence of sand, silt and clay, and the lower subunit being characterized by a low permeable gray to black silty fine sand to a gray to black stiff clay. More detailed descriptions of each of these subunits are presented below.

Upper Magothy Subunit

The Upper Magothy formation directly underlies the glacial sediments. The total thickness of the subunit is estimated to range between 49 feet, as determined at monitoring well HIMW-06D, and 110 feet, as determined at monitoring well HIMW-05D. As discussed above, this subunit consists of a relatively complex sequence of sand, silt and clay, and with widely variable sediment color ranging from brown, orange, red, yellow, gray to black. The sediment was also found to be moderately to highly micaceous (i.e., containing mica particles). In addition, lignite, which is a mineralized form of plant matter and considered an intermediary mineral in the formation of coal, was sporadically encountered along with pyrite nodules in soil samples recovered from this unit. While predominantly composed of fine to very fine sand with varying amounts of silt, a number of more permeable lenses of fine to coarse sand were encountered throughout the Upper Magothy subunit. In addition, it is common to encounter lenses of fine to coarse sand interbedded with thin clay layers or laminae of less than 1/8-inch in thickness. The majority of the sand-rich lenses do not appear to be continuous through the site, but rather more lenticular in nature. The majority of the intermediate and deep groundwater monitoring wells installed as part of the RI were screened in the more sand-rich lenses encountered in the Upper Magothy subunit. Because of its diverse stratigraphy and heterogeneous distribution of sediment types and zones, the Upper Magothy sediments are highly anisotropic with the vertical hydraulic conductivity several orders of magnitude less than the horizontal hydraulic conductivity (Franke and Cohen, 1972). As a result, groundwater has a much greater propensity to flow horizontally than vertically within this unit.

Table 3-2 summarizes the geotechnical and Total Organic Carbon (TOC) data obtained from the six samples collected from the Upper Magothy subunit. Note that the majority of these samples were collected from the screen zones of the deep and intermediate wells, and therefore, generally represent the more sand-rich lenses of the subunit described above. As shown in **Table 3-2**, the d_{10} for these samples ranged from 0.0024 mm (clay sized particles) to 0.17 mm (fine sand) and the amount of clay/silt particles in each sample ranged from five to 35 percent. Based on this data, it is concluded that the sand-rich lenses present in the Upper Magothy formation exhibit fairly poor water transmitting properties. However, it should be noted that the grain size analyses are based on composited samples, and therefore, do not reflect the actual in-situ stratigraphy and anisotropic nature of the sediment as described above. The average TOC of the Upper Magothy formation was found to be 3.5 percent. This relatively high TOC may be attributable in part to the presence of lignite in selected samples. As discussed above, lignite was sporadically encountered in samples recovered from this subunit.

Lower Magothy Subunit

As discussed above, the Lower Magothy subunit is comprised of a black silty fine sand to a gray to black stiff clay. Due to its high clay content, the subunit acts as an effective confining layer limiting the vertical migration of groundwater. The majority of the deep groundwater monitoring wells installed as part of this investigation were screened immediately above this subunit. Based on the completed borings, the Lower Magothy subunit is found from 118 ft-bgs, as identified at monitoring well HIMW-06D, to 270 ft-bgs, as identified at temporary well location HITW-02. The actual thickness of this subunit was not determined as part of this investigation; however, based on the review of well logs for the water supply wells located in the vicinity of the site, it is assumed that this subunit is a minimum of 200 feet thick. **Table 3-3** summarizes the geotechnical data obtained through the analysis of the five samples selected from this subunit. As indicated in this table, the average d_{10} for these samples is 0.012 mm and an average of 67 percent of each sample is comprised of silt and/or clay sized particles. Vertical permeability analysis of three undisturbed soil samples collected using a Shelby Tube sampler from the subunit, summarized in **Table 3-4**, confirmed the low permeability of the Lower Magothy subunit with an average vertical hydraulic conductivity of only 2.0×10^{-7} cm/second or 5.8×10^{-4} feet/day.

3.5 Groundwater Flow and Hydraulic Gradients

Depths to water measured on January 2, 2002 (refer to **Table 2-5**), shows that groundwater at the Hempstead Intersection Street former MGP site is approximately 28 to 32 feet below grade. Based on the water level measurements recorded at the on-site and off-site groundwater monitoring wells on January 2, 2002, two water table/potentiometric surface maps were developed for the Upper Glacial and Magothy aquifers. **Drawing 3G** presents a water table contour map and **Drawing 3H** presents a potentiometric surface map of the Magothy aquifer using water levels measured at all deep wells based on information collected during the initial RI. Both drawings are presented in map pockets at the end of this section. The water level data collected during the Supplemental Remedial Investigation Field Program depict flow directions consistent with those in the initial RI Investigation. **Drawings 3I, 3J** and **3K** present groundwater contour maps for the shallow, intermediate and deep groundwater zones based on information collected during the Supplemental Remedial Investigation Field Program.

As shown on **Drawing 3G**, groundwater within the Upper Glacial aquifer generally flows in a southerly to south-southwesterly direction, which is consistent with groundwater flow for the Hempstead area based on a review of regional groundwater contour maps produced by the USGS and the Nassau County Department of Public Works (NCDPW). Groundwater in the Upper Glacial aquifer south of Fulton Street likely flows in a more southerly direction in response to the influence from Hempstead Lake and its headwaters, which serve as an area of groundwater discharge. NYSDEC well records indicate that a number of water supply wells have been installed in the Upper Glacial aquifer downgradient of the site. Based on information regarding screen settings and pumping capacities, a number of these wells, if still in service, have the potential of influencing groundwater flow within the Upper Glacial aquifer.

Drawing 3H is a potentiometric surface map of the Lower Magothy formation developed using water level measurements obtained at all deep wells on January 2, 2002. Based on measured water levels, groundwater flow within this unit is in a southwesterly direction. This is generally consistent with regional flow directions, based on previously developed potentiometric surface maps produced for the Magothy aquifer. Note that the Magothy aquifer is between 500 and 650 feet thick within the site area and all nearby public supply wells are screened in the coarser basal sediments of this aquifer, between 450 and 625 feet below ground surface. As a result, groundwater flow direction in the deeper portion of the Magothy aquifer may be different from the direction determined by the deep monitoring wells screened between 120 and 170 feet below ground surface.

Using calculated hydraulic gradients based on the water table contour map, an average horizontal hydraulic conductivity for the glacial sediments of 250 feet/day (refer to **Section 1.5.8**) and a modified form of Darcy's Law for groundwater flow velocity, an estimated value for horizontal groundwater velocity or vector within the Upper Glacial aquifer can be calculated for the study area where:

$$Va = \frac{KI}{N}$$

where:

Va	=	Groundwater velocity or Darcian velocity (ft/day)
I	=	Hydraulic Gradient (ft/ft)
K	=	Hydraulic Conductivity (ft/day)
N	=	Porosity of aquifer sediments (percent)

A calculated hydraulic gradient between monitoring wells HIMW-07S and HIMW-12S is approximately 0.00144 foot per foot, which is generally consistent with published hydraulic gradients for the Upper Glacial aquifer within south-central Nassau County. An average porosity of 30 percent for sand and gravels (USGS Prof. Paper 800-C, 1972) was used in the calculation. Using this method, horizontal groundwater velocity within the Upper Glacial aquifer at and downgradient of the site has been calculated as approximately 1.2 feet per day. This is in the range of published groundwater velocities established for the Upper Glacial aquifer in south-central Nassau County (USGS Water Resources Investigation Report 86-4333).

The differences in hydraulic head elevations (water level elevations) in the vertical direction as monitored by well clusters having both a deep and shallow monitoring well (see **Table 2-5**), indicates no significant vertical head difference to a subtle downward vertical head gradient at most well clusters. Based on the January 2, 2002 water level measurements, the shallow wells at well clusters HIMW-01, HIMW-03, HIMW-04, HIMW-05, HIMW-06, HIMW-08, HIMW-09 and HIMW-13 appear to exhibit a greater static head when compared to each corresponding deep well with a difference ranging from 0.03 to 0.64 foot. Exceptions include HIMW-11 which indicates an upward vertical head distribution with a difference of 0.15 foot between the shallow and deep well. However, downgradient wells HIMW-12, HIMW-14 and HIMW-15, show relatively strong downward vertical gradients with head differences of 1.57, 2.17 and 1.69 feet, respectively. Previous rounds of water level measurements (see **Table 2-5)** are in general agreement with these results. Based on a review of the available head data, groundwater flow appears to be predominantly horizontal with little to no vertical gradient within and immediately downgradient of the site. However, farther downgradient, there appears to be a greater downward vertical gradient between the Upper Glacial and Magothy aquifers.

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Reference 2

JACOB BEAR

Department of Civil Engineering
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Haifa
Israel

Hydraulics of Groundwater

pg 27 of 35

By integrating (8-1) from r_w to R, we obtain

$$s_w = H - h_w = \phi(R) - \phi(r_w) = (Q_w/2\pi T)\ln(R/r_w) \tag{8-4}$$

Between any two distances r_1 and $r_2(>r_1)$, we obtain

$$\phi(r_2) - \phi(r_1) = s(r_1) - s(r_2) = (Q_w/2\pi T)\ln(r_2/r_1) \tag{8-5}$$

Equation (8-5) is called the Thiem equation (Thiem, 1906).

Between any two distances r and R, we obtain

$$s(r) = \phi(R) - \phi(r) = (Q_w/2\pi T)\ln(R/r) \tag{8-6}$$

By dividing (8-3) by (8-4), we obtain

$$\phi(r) - h_w = (H - h_w)\frac{\ln(r/r_w)}{\ln(R/r_w)} \tag{8-7}$$

showing that the shape of the curve $\phi = \phi(r)$, given h_w and H at r_w and R, respectively, is independent of Q_w and T.

The distance R in (8-4), (8-6), and (8-7), where the drawdown is zero, is called the *radius of influence of the well*. Since we have established above that steady flow cannot prevail in an infinite aquifer, the distance R should be interpreted as a parameter which indicates the distance beyond which the drawdown is negligible, or unobservable. In general, this parameter has to be estimated from past experience. Fortunately, R appears in (8-6) in the form of $\ln R$ so that even a large error in estimating R does not appreciably affect the drawdown determined by (8-6). The same observation is true also for another parameter—the radius of the well r_w (Sec. 8-1).

Various attempts have been made to relate the radius of influence, R, to well, aquifer, and flow parameters in both steady and unsteady flow in confined and phreatic aquifers. Some relationships are purely empirical, others are semi-empirical. For example (Bear, Zaslavsky, and Irmay, 1968).

Semi-empirical formulas are

Lembke (1886, 1887):	$R = H(K/2N)^{1/2}$,	(8-8)
Weber (Schultze, 1924):	$R = 2.45\,(HKt/n_e)^{1/2}$,	(8-9)
Kusakin (Aravin and Numerov, 1953):	$R = 1.9\,(HKt/n_e)^{1/2}$	(8-10)

Empirical formulas are

Siechardt (Chertousov, 1962):	$R = 3000 s_w K^{1/2}$,	(8-11)
Kusakin (Chertousov, 1949):	$R = 575 s_w (HK)^{1/2}$	(8-12)

where R, s_w (= drawdown in pumping well), and H are in meters and K in meters per second.

In phreatic aquifers (Sec. 8-3) N, H, and n_e represent accretion from precipitation, the initial thickness of the saturated layer, and the specific yield (or effective porosity) of the aquifer, respectively. In confined aquifers, H and n_e have to be

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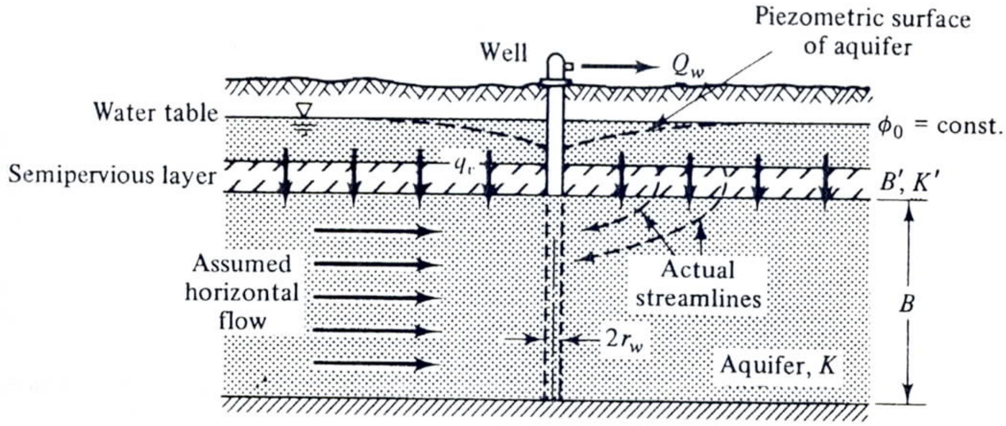
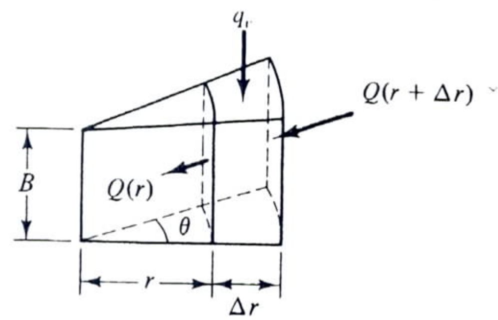


(a)



(b)

Figure 8-9 Schematic representation of approximate flow to a well in a confined leaky aquifer with ponded water on top of semipervious bed.

Continuity considerations for the portion of aquifer between two cylinders of radii r and $(r + \Delta r)$ lead to

$$Q(r + \Delta r) - Q(r) + (2\pi r \Delta r)\, q_v = 0 \tag{8-36}$$

where q_v is shown in Fig. 8-9. In the limit, as $\Delta r \to 0$, this yields

$$\partial Q/\partial r + 2\pi r q_v = 0; \qquad q_v = K' \frac{\phi_0 - \phi}{B'} = \frac{\phi_0 - \phi}{\sigma'} \tag{8-37}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{\partial \phi}{\partial r}\right) + \frac{\phi_0 - \phi}{\lambda^2} = 0; \qquad \lambda^2 = \sigma' T = \frac{B'BK}{K'} \tag{8-38}$$

where λ is a characteristic length of the leaky aquifer called *leakage factor*. Equation (8-38) could be obtained from (5-70) with $\lambda^{(2)} = \infty$, $\phi_1 = \phi_0$, and $\partial\phi/\partial t = 0$.

Equation (8-38) is a Modified Bessel equation of order zero. Its general solution is

$$\phi_0 - \phi(r) = \alpha \mathrm{I}_0(r/\lambda) + \beta \mathrm{K}_0(r/\lambda) \tag{8-39}$$

where K_1 is the Modified Bessel function of the second kind and first order (Table 8-1).

In the practice $r_w/\lambda \ll 1$. Since for $x \ll 1$, $xK_1(x) \approx 1$ with an error of less than one percent for $x < 0.02$, we may approximate (8-40) by

$$s(r) = \frac{Q_w}{2\pi T} K_0(r/\lambda) \tag{8-41}$$

Under the conditions leading to (8-41), $s(r)$ is independent of r_w.

In the vicinity of the pumping well, $r/\lambda \ll 1$. For $x \ll 1$, $K_0(x) \approx \ln(1.123/x)$. Equation (8-41) then becomes

$$s(r) = \frac{Q_w}{2\pi T} \ln \frac{1.123\lambda}{r} \tag{8-42}$$

with an error of less than five percent for $r/\lambda < 0.35$, and less than one percent for $r/\lambda < 0.18$.

Comparison of (8-29) and (8-42) shows that λ (or 1.123λ) expresses the *radius of influence of a leaky aquifer*. This can also be shown by deriving the ratio $Q(r)/Q_w$ which for every distance r indicates the portion of the well's discharge flowing through the aquifer; the remaining part $Q_w - Q(r)$ enters the aquifer through the semipervious cover. We obtain

$$Q(r)/Q_w = (r/\lambda)\, K_1(r/\lambda) \tag{8-43}$$

Figure 8-10 gives a schematic representation of (8-43). For example, for $r = 4\lambda$, $Q(r)/Q_w = 0.05$, which means that 95% of Q_w enters the cylinder of radius $r = 4\lambda$ through the semipervious layer.

In a similar manner, we may also treat cases where the potential on top of the semipervious layer, ϕ_0, or $\phi(r, B + B')$, varies, say as a result of pumping in the upper phreatic aquifer. We then have to introduce another equation which describes the variations of this potential.

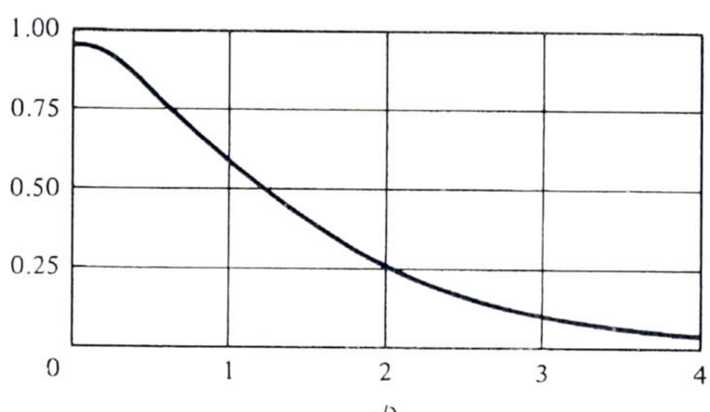


Figure 8-10 Graphical representation of (8-43).

Simulation of Ground-Water Flow and Pumpage in Kings and Queens Counties, Long Island, New York

By Paul E. Misut and Jack Monti, Jr.

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98-4071

Reference 3

Prepared in cooperation with
NEW YORK CITY DEPARTMENT OF
ENVIRONMENTAL PROTECTION

USGS
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Coram, New York
1999

Table 1. Hydrologic units underlying Kings and Queens Counties, N.Y., and their water-bearing properties as represented by the Long Island regional model

[gal/min, gallons per minute; ft, feet; ft/d, feet per day. Modified from Doriski and Wilde-Katz, 1983. Modeled hydraulic properties from Buxton and Smolensky, in press]

System	Series	Age	Stratigraphic unit (hydrologic unit names are in parentheses)	Approximate range in thickness (feet)	Character	Water-bearing properties, modeled hydraulic conductivity, and anisotropy
QUATERNARY	Holocene	Post glacial	Holocene (recent) deposits (upper glacial aquifer)	0-40	Beach sand and gravel and dune sand, tan to white; black, brown, and gray bay-bottom deposits of clay and silt; artificial fill. Beach and dune deposits are mostly stratified and well sorted. Fill includes earth and rocks, concrete fragments, ashes, rubbish, and hydraulic fill.	Sandy beds of moderate to high permeability beneath barrier beaches, locally yield fresh or salty water from shallow depths. Clayey and silty beds beneath bays retard saltwater encroachment and confine underlying aquifers.
	Pleistocene	Wisconsinan	Upper Pleistocene deposits (upper glacial aquifer)	0-300	Till composed of clay, sand, gravel, and boulders, forms Harbor Hill and Ronkonkoma terminal moraines. Outwash consisting mainly of brown fine to coarse sand and gravel, stratified. Interbedded with clays.	Till is poorly permeable. Sand and gravel part of outwash highly permeable; yields of individual wells are as much as 1,700 gal/min. Specific capacities of wells as much as 109 gal/min per foot of drawdown. Water fresh except near shorelines. Horizontal hydraulic conductivity: 20-80 ft/d (moraine), 200-300 ft/d (outwash). Horizontal to vertical anisotropy is 10:1. Specific yield is 0.25 (moraine), 0.3 (outwash).
				0-40	Clay and silt, gray and grayish green; some lenses of sand and gravel. Contains shells, foraminifera, and peat. Altitude of top of unit about 20 ft below sea level. Interbedded with outwash in southern part of area.	Relatively impermeable confining unit. Retards saltwater encroachment in shallow depths. Confines water in underlying outwash deposits when present.
			unconformity			
		Sangamon interglaciation	Gardiners Clay	0-150	Clay and silt, grayish-green; some lenses of sand and gravel. Contains lignitic material, shells, glauconite, foraminifera, and diatoms. Interglacial deposit. Altitude of surface 50 ft or more below sea level.	Relatively impermeable confining layer above Jameco aquifer. Locally contains moderately to highly permeable sand and gravel lenses. Confines water in underlying Magothy aquifer. Vertical hydraulic conductivity is 0.001 - 0.0029 ft/d.
			unconformity			
		Illinoisan(?)	Jameco Gravel (Jameco aquifer)	0-200	Sand, coarse, granule to cobble gravel, generally dark brown and dark gray. A stream deposit in a valley cut in Matawan Group-Magothy Formation undifferentiated deposits. Buried valley of ancestral Hudson River.	Highly permeable. Yields as much as 1,500 gal/min to individual wells. Specific capacities as high as 135 gal/min per foot of drawdown. Contains water under artesian pressure. Water commonly has high iron content and is salty near shoreline. Horizontal hydraulic conductivity is 200-300 ft/d. Horizontal to vertical anisotropy is 10:1. Specific storage is 1×10^{-6} per ft.

Table 1. Hydrologic units underlying Kings and Queens Counties, N.Y., and their water-bearing properties as represented by the Long Island regional model—continued

System	Series	Age	Stratigraphic unit (hydrologic unit names are in parentheses)		Approximate range in thickness (feet)	Character	Water-bearing properties, modeled hydraulic conductivity, and anisotropy
QUATERNARY?	Pleistocene?	Illinoisan(?)	Reworked Matawan-Magothy channel deposits (upper glacial or Magothy aquifer)		0-260	Sand, fine to coarse, dark-gray and brown; gravel. Contains some thin beds of silt and clay.	Moderate to highly permeable. Provides an interconnection between Magothy aquifer and upper glacial aquifer where Gardiners Clay is absent.
			unconformity				
CRETACEOUS	Upper Cretaceous		Matawan Group-Magothy Formation, undifferentiated (Magothy aquifer)		0-500	Sand, fine to medium gray; interfingered with lenses of coarse sand, sandy clay, silt, and solid clay. Generally contains gravel in bottom 50 to 100 ft. Lignite and pyrite abundant.	Slightly to highly permeable. Individual wells yield as much as 2,200 gal/min. Specific capacities as high as 80 gal/min per foot of drawdown. Water mainly under artesian pressure; some wells in southern part of area flow. Water generally is of excellent quality except where contaminated by salty water, high iron concentrations, or by dissolved constituents associated with human activities. Horizontal hydraulic conductivity is 30-180 ft/d. Horizontal to vertical anisotropy is 100:1. Specific yield is 0.15. Specific storage is 1 x 10^{-6} per ft.
			unconformity				
			Raritan Formation	Unnamed Clay Member (Raritan confining unit)	0-200	Clay, gray, white, and some red and purple; contains interbedded layers of sand and gravel. Lignite and pyrite occur widely throughout.	Relatively impermeable confining unit. Local lenses and layers of sand and gravel, moderate to high permeability. Vertical hydraulic conductivity is 0.001 ft/d.
				Lloyd Sand Member (Lloyd aquifer)	0-300	Sand, fine to coarse, gray and white, and gravel; some lenses of solid sandy clay, and clayey sand. Thin beds of lignite locally.	Yields as much as 2,000 gal/min to individual wells. Specific capacities as high as 44 gal/min per foot of drawdown. Water under artesian pressure; some wells flow. Water of good quality except for high iron content. Horizontal hydraulic conductivity is 35-75 ft/d. Horizontal to vertical anisotropy is 10:1. Specific storage is 1 x 10^{-6} per ft.
			unconformity				
	Paleozoic (or) Precambrian		Undifferentiated gneiss, schist, pegmatite (Bedrock)		--	Crystalline metamorphic and igneous rocks. Soft, clayey weathered zone at top, as thick as 100 ft.	Relatively impermeable. Contains water along joints and fault zones.

Groundwater Contamination

Optimal Capture and Containment

Reference 4

Steven M. Gorelick
R. Allan Freeze
David Donohue
Joseph F. Keely

LEWIS PUBLISHERS
Boca Raton Ann Arbor London Tokyo

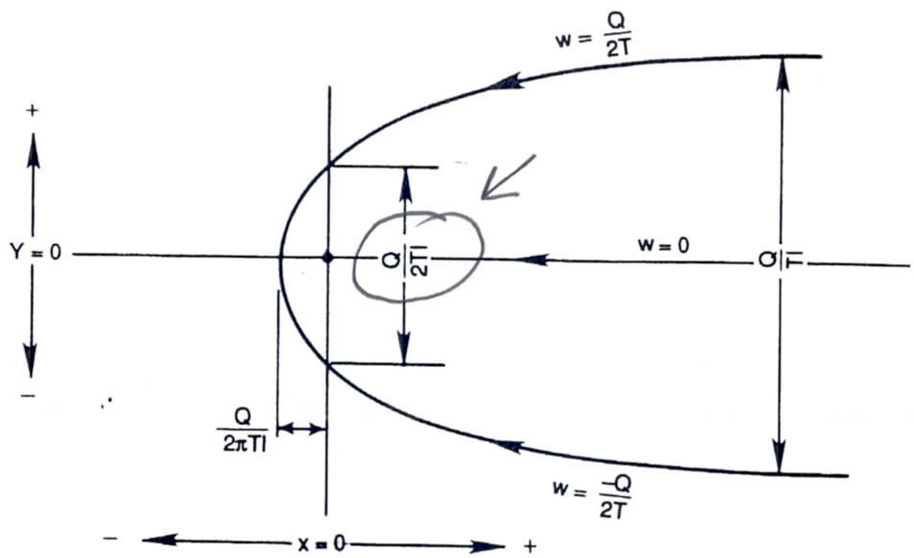

Figure 12. Equation for the dividing streamlines separating the capture zone of a single well from the rest of an aquifer.

and no flow tubes (or contaminants) can slip between the extraction wells. For two or three equally spaced wells, located along a line perpendicular to the regional gradient, and all pumping at the same rate, Javandel and Tsang provide the recommended spacings listed in the right-hand column of Table 5.

The design methodology for a one-, two-, or three-well extraction system using Table 5 involves a trial-and-error procedure with a set of alternative ~~well~~ networks. One tries to identify the lowest cost network that will meet the following specifications, given measured values for aquifer transmissivity, T, and regional hydraulic gradient, I:

1. The capture-zone geometry, as indicated by the values given in Table 5 for the distance between dividing streamlines, must be adequate to encompass the known boundaries of the contaminant plume.
2. The pumping rate, Q, to be applied at each of the wells, must not create drawdowns in excess of any constraints on the available drawdown at the wells.
3. The distances between the wells must be equal to or less than the recommended distances given in Table 5.

It must be emphasized that use of Table 5 to design remedial well networks will *not* lead to an optimal design. The limitations on the analytical solutions on which the table is based are too severe. It will provide a design that works for a pre-specified number of wells, all on a

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Table 5. Parameters for Design of Remedial Well Fields Based on Javandel and Tsang (1986) Capture-Zone Theory. For multiple-well systems, Q is the constant pumping rate applied to each well.

Number of Wells	Distance Between Dividing Stream-lines at Line of Wells	Distance Between Dividing Stream-lines Far Upstream From Wells	Downstream Distance to Stagnation Point at Center Point of Capture Zone	Recommended Distance Between Each Pair of Extraction Wells
1	$\frac{Q}{2TI}$	$\frac{Q}{TI}$	$\frac{Q}{2\pi TI}$	—
2	$\frac{Q}{TI}$	$\frac{2Q}{TI}$	$\frac{Q}{2\pi TI}$	$\frac{Q}{\pi TI}$
3	$\frac{3Q}{2TI}$	$\frac{3Q}{TI}$	$\frac{3Q}{4\pi TI}$	$\frac{\sqrt[3]{2}Q}{\pi TI}$

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CALCULATION COVER SHEET

Client: *Keyspan Corp.* Project Name: *Hempstead Intersection St*

Project / Calculation Number: *111 75 065*

Title: *Containment System - Barrier Wall with Extraction of Ground Water*

Total number of pages (including cover sheet): *37 (36 + cover)*

Total number of computer runs: *0*

Prepared by: Marek Ostrowski Date: May 1, 07

Checked by: Amy Monti Date: 5/1/07

Description and Purpose: ** Preliminary design of the containment system for the source area.*
** Specify the number, locations, depth and diameter of extraction wells, as well as the expected range of extraction rates; and the location and depth of the barrier wall.*

Design bases / references / assumptions: *Water balance method is used, with a well equation for circular area with infiltration. Containment is developed within the Upper Glacial aquifer and the upper unit of the Magothy aquifer. Site is paved. Barrier is a sheet pile wall with sealed joints.*

Remarks / conclusions:
- *Two extraction wells screened in Upper Glacial aquifer are recommended.*
- *Both wells are 6-inch diamter, approximately 70 feet deep.*
- *Expected extraction rate is on the order of 1 to 10 gpm.*
- *The barrier is approximately 1,700 feet long, installed to the depth of 120 to 170 ft.*

Calculation Approved by: [signature] 5/1/07
Project Manager / Date

Revision No:	Description of Revisions	Approved by:

Project Manager / Date

1. PURPOSE

The purpose of this calculation is to perform the preliminary design of the hydraulic containment system for the Keyspan Hempstead Intersection Street site. The system would consist of a barrier wall surrounding the source area and ground water extraction wells located inside the enclosure. The following elements of the system will be specified:

- Lateral and vertical extent of the barrier
- Number of the extraction wells
- Well depth and diameter
- Range of the expected extraction rates

2. SITE DESCRIPTION

Hydrogeology

The hydrogeology of the site (based on reference 1) has been described in Section 2.1 of the previous calculation, entitled *Hydraulic Containment System*. A summary is presented below. A conceptual cross section of the strata occurring at the site is presented on page 12 of this calculation.

The top 60 to 70 feet are composed of glacial outwash sediments of the unconfined Upper Glacial aquifer. These deposits consist mostly of sand and gravel. Some silt lenses are also present; however, they occur mostly above the water table. Ground water table is located within the Upper Glacial aquifer, at the depth of approximately 30 feet below ground surface. The Upper Glacial aquifer is highly permeable.

Below the Upper Glacial aquifer is the Magothy formation. At the site, the Magothy unit can be divided into the upper and lower subunits.

The upper subunit of the Magothy formation consists of interbedded sands, silts and clays. This layer is between approximately 50 and 110 feet thick. The horizontal conductivity of the upper unit is moderate to high: however, the vertical conductivity is much lower.

The lower unit of the Magothy formation consists of deposits ranging from silty sand to clay. The actual thickness of this unit at the site is not known; however, it is expected to be at least 200 feet. The vertical hydraulic conductivity of this unit is very low.

Contamination

The source area is shown on DWG 4D of reference 1 (oversized, not included in this calculation). Information contained on this drawing is summarized on page 13 of this calculation. The vertical cutoff barrier would extend around the source area.

3. METHOD

The objective of the system is to maintain hydraulic gradient from the aquifer into the enclosure. The inward gradient prevents the migration of the dissolved-phase contaminants from the source area into the aquifer. The inward gradient is maintained by means of extracting ground water from the inside of the enclosure.

The flow budget for the enclosure will include the flow entering the enclosure through the flow barrier, the flow entering the enclosure through the bottom, flow entering the enclosure as recharge, and flow exiting the enclosure as water extracted by the wells. See sketch on page 14 of this calculation.

The Magothy formation is characterized by very low vertical hydraulic conductivity. Values on the order of 10^{-7} cm/s were obtained from three undisturbed soil samples collected from the lower subunit of the Magothey (Section 3.4 of reference 1). The subunit is over 200 feet thick. The hydraulic head below the lower Magothy is most likely somewhat lower than in the Upper Glacial aquifer. This is because the only source of water in the Long Island aquifer system is infiltration. The site is located near the center of the island, where the lower aquifers are fed by the downward flow from the upper layers (note: this reverses near the shore line, where water discharges upward into the ocean).

MADE BY: MO DATE: May 1, 07
CHECKED BY: AMM DATE: 5/1/07

PROJECT: Hempstead Intersection Street, Keyspan Corp
SUBJECT: Containment System – Barrier Wall and Extraction of Ground Water

Assuming conservatively that the hydraulic heads underneath the lower Magothy and in the Upper Glacial are equal, the vertical upward gradient will be created by lowering of the water table inside the enclosure, maintained in order to create the inward gradient. Assume that this lowering amounts to 5 feet. From that, the magnitude of the upward flow, using the vertical conductivity one order of magnitude greater than that obtained from the available tests ($K_{vert} = 1*10^{-6}$ cm/s = 0.0028 ft/d), and ignoring the resistance to the vertical flow provided by the upper Magothy subunit, is:

$$q_{up} = K_{vert} * i_{vert} = 0.0028 \text{ ft/d} * 5 \text{ ft} / 200 \text{ ft} =$$

$$= 0.000028 \text{ ft/d}$$

Recharge from infiltration in New York state is typically on the order of 1 ft/yr. As part of the remediation, the site will be paved. The actual recharge will depend on the type of pavement and its deterioration with time (cracking, ponding of water, etc). Typical runoff curve numbers for paved surfaces are approximately 0.9; assume, that the infiltration through pavement will be 10% of the normal infiltration of 1 ft/yr:

$$N = 1/10 \text{ ft/yr} = 0.00027 \text{ ft/d}$$

The vertical flow is a small fraction of the recharge:

$$q_{up} / N = 0.000028 / 0.00027 = 0.1$$

Upward flow can be ignored. Only recharge and flow through the barrier wall will be used in design. For simplicity, flow through the enclosure will be distributed over the entire area of enclosure (i.e. it will be added to recharge).

The calculation assumes that extraction wells are placed within the enclosure on a uniform grid. Each well lowers the water table within its tributary area. All tributary areas are equal. Wells are placed in the Upper Glacial aquifer. The barrier is keyed into the lower subunit of the Magothy.

Flow through the sheet pile barrier

Estimate of the flow rate entering the enclosure through the joints between sheet piles is shown in reference 2, section 4.1). The method covers sheet piles with, or without the joint sealant.

$$Q_{sh} = n\ Q_1$$

$$Q_1 = \rho\ H\ (0.5\ H + h) \quad ; \quad n = L / b$$

$$Q_{sh} = (L / b)\ [\rho\ H\ (0.5\ H + h)]$$

Terms are:

- b - Width of a single sheet pile, [m]
- H - Head differential between water level inside the enclosure and ambient water level in the sand/gravel unit, [m]
- h - Saturated thickness inside the enclosure, [m]
- L - Total length of the sheet pipe wall, [m]
- n - Number of sheet pile joints, [-]
- Q_{sh} - Flow rate entering the enclosure through joints between sheet piles, [m^3/s]
- Q_1 - Flow rate through a single joint, [m^3/s]
- ρ - Inverse joint resistance, [m/s]

This flow is distributed through the entire area of the enclosure (A_{enc}), and added to the recharge (N_r).

$$q_{sh} = Q_{sh} / A_{enc}$$

$$N = N_r + q_{sh}$$

Where:

- A_{enc} - Area of the enclosure, [m]
- N - Total flow into the enclosure, normalized over the enclosure area, [m/d]
- q_{enc} - Flow into the enclosure occurring through the sheet pile wall, normalized over the enclosure area, [m/d]
- N_r - Recharge, [m/d]

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Lowering of water table

A tributary area of each well is approximated as a circle. The distribution of hydraulic heads inside the tributary area is derived on pages 15 to 21 of this calculation (based on references 3 and 4).

$$h(r)^2 - h_w^2 = (N / 2K)\ (r_w^2 - r^2) + (N\ r_w^2 / K)\ \ln(r/r_w)$$

Terms are:

$h(r)$ -	Saturated thickness at distance "r" from the extraction well, [m]
h_w -	Saturated thickness at the well face, [m]
K -	Hydraulic conductivity, [m/s]
N -	Vertical flow rate, [m/s]
r -	distance from extraction well, [m]
r_w -	Diameter of the extraction well, [m]

The imposed condition is a given thickness the perimeter of the tributary area (i.e. the farthest from the well).

$$h(r = R) = h_{req}$$

Where "R" is the radius of the well's tributary area (i.e. half of the well spacing).

$$h_{req}^2 - h_w^2 = (N / 2K)\ (r_w^2 - R^2) + (N\ r_w^2 / K)\ \ln(R/r_w)$$

Because wells will have large tributary areas:

$$R >> r_w$$

$$h_{req}^2 - h_w^2 = -\ (N / 2K)\ R^2 + (N\ r_w^2 / K)\ \ln(R/r_w)$$

$$h_w^2 = h_{req}^2 + (N\ R^2 / K)\ [0.5 - \ln(R/r_w)]$$

By setting the required degree of dewatering (h_{req}) and the size of the well's tributary area (R), the corresponding hydraulic head at the well face (h_w) can be found. If that height is greater than the minimum value that can be accepted, system will be effective. Otherwise, a smaller tributary area has to be assumed and the procedure is repeated.

4. PARAMETERS

- Undisturbed saturated thickness – H_0
  From Section 3.3 of reference 1, the thickness of the Upper Glacial deposits in the study area is 60 to 70 feet (say, 65 ft). Based on Section 3.5 of reference 1, water table occurs at depth of 30 feet. From that, the saturated thickness is:
  $H_0 = 65 - 30 = 35$ ft $= 10.7$ m

- Hydraulic conductivity - K
  Based on Table 1 of reference 5, the hydraulic conductivity of the Upper Glacial aquifer is between 200 and 300 ft/d (outwash deposits, such as those identified at the site – Section 3.3 of reference 1). Lower conductivity is the critical value from the standpoint of dewatering
  $K = 200$ ft/d $= 7*10^{-2}$ cm/s $= 7*10^{-4}$ m/s

- Well radius - r_w
  Use 6-inch wells:
  $r_w = 3$ in $= 0.076$ m

- Width of a single sheet pile – b
  Assume 2 ft:
  $b = 2$ ft $= 0.6$ m

- Head differential across the sheet pile wall – H
  Assume that the water level has to be lowered by 3 feet. Assume a typical water level fluctuation of 3 feet; therefore, at the high water level, the dewatering is 6 feet:
  $H = 6$ ft $= 1.8$ m

- Required saturated thickness inside the enclosure – h_{req}
  Horizontal flow to the wells will occur mostly in the Upper Glacial aquifer, whose saturated thickness is 10.7 m. The required degree of dewatering is 1.8 m. From that:
  $h_{req} = 10.7 - 1.8 = 8.9$ m

- Hydraulic head inside the enclosure
  The saturated thickness of the Upper Glacial aquifer is approximately 35 ft. The thickness of the upper subunit of the Magothy is 50 to 100 ft, say 80 ft on the average. The total hydraulic head inside the enclosure is:

  $$h = 35 + 80 = 105 \text{ ft} = 32 \text{ m}$$

- Length of enclosure - L
  From page 13 :

  $$L = 1{,}700 \text{ feet} = 525 \text{ m}$$

- Recharge - N_r
  Assume 0.1 ft/yr:

  $$R = 0.1 \text{ ft/yr} = 1*10^{-9} \text{ m/s}$$

- Area of enclosure - A_{enc}
  See page 13 :

  $$A = 120{,}000 \text{ ft}^2 = 11{,}360 \text{ m}^2$$

5. CALCULATIONSD

Flow through sheet pile wall

See Table 1 of reference 2 for the values of joint resistance. For empty joints and pressures of 100 to 150 kPa, values are given as $100*10^{-9}$ to $450*10^{-9}$ m/s. Pressures at the site correspond to ≈10 m of water column in the Upper Glacial and 30 m in the Magothy. Use 20 m.

$$P = \rho_w \, g \, H_w = 1{,}000 \text{ kg/m}^3 * 9.81 \text{ m/s}^2 * 20 \text{ m} = \\ = 196{,}200 \text{ N/m}^2 \text{ (Pa)} \approx 200 \text{ kPa}$$

Use:

$$\rho = 450*10^{-9} \text{ m/s}$$

For joints filled with a waterswelling product:

$$\rho = 0.3*10^{-9} \text{ m/s}$$

Calculate flow rate through the wall:

$$Q_{sh} = (L / b) [\rho H (0.5 H + h)]$$

For empty joints:

$$Q_{sh} = (525 / 0.6) [(450*10^{-9})*1.8*(0.5*1.8 + 32)] =$$

$$= 875 * [[(450*10^{-9})*1.8*(32.9)]$$

$$Q_{sh} = 0.023 \text{ m}^3/\text{s} \quad (370 \text{ gpm})$$

For sealed joints:

$$Q_{sh} = (525 / 0.6) [(0.3*10^{-9})*1.8*(0.5*1.8 + 32)] =$$

$$= 875 * [[(0.3*10^{-9})*1.8*(32.9)]$$

$$Q_{sh} = 0.000016 \text{ m}^3/\text{s} \quad (0.25 \text{ gpm})$$

In the previous calculation entitled *Hydraulic Containment System* the extraction rate required for containment without a vertical barrier was estimated to be 150 to 500 gpm. The rate of 370 gpm estimated above for the sheet pile wall with empty joints is of the same order as the rate required without the wall. Therefore, this option will not be pursued further, as the barrier wall does not seem to provide any significant benefits in reducing the extraction rate.

The flow rate of 0.25 gpm, estimated for the case of a sealed sheet pile wall, is negligible. It will be ignored in the subsequent calculations.

The inflow into the enclosure constructed of sheet pile with sealed joints consists mostly of infiltration.

$$N = N_r = 0.1 \text{ ft/yr} = 1*10^{-9} \text{ m/s}$$

Dewatering

The dimension of the area targeted for the enclosure is approximately 500 feet. Therefore, if only one well were to be utilized, its tributary area would have to be the same as the dimension of the enclosure.

$$R = 500 \text{ ft} = 150 \text{ m}$$

$$h_w^2 = h_{req}^2 + (N\ R^2 / K)\ [0.5 - \ln(R/r_w)]$$

$$h_w^2 = 8.9^2 + [(1*10^{-9})*150^2]/(7*10^{-4})\ [0.5 - \ln(150/0.076)]$$

$$h_w^2 = 79.2 + 0.032*(0.5 - 7.6) = 79.19$$

$$h_w = 8.899 \text{ m}$$

The undisturbed saturated thickness "H_0" is approximately 11 m, the saturated thickness at the well required to accomplish the dewatering is approximately 9 m. This is acceptable. One well would be sufficient.

Note that the negligible difference between the saturated thicknesses at the extraction well (h_w = 8.899 m) and at the perimeter of the enclosure (h_{req} = 8.9 m) is the result of a very high hydraulic conductivity of the Upper Glacial aquifer ($K > 5*10^{-2}$ cm/s), and very low infiltration through the pavement (1 in/yr). See, for example, the difference in saturated thicknesses for a case where $K = 5*10^{-3}$ cm/s and N = 6 in/yr:

$$h_w^2 = 8.9^2 + [(6*10^{-9})*150^2]/(5*10^{-5})\ [0.5-\ln(150/0.076)]$$

$$h_w^2 = 79.2 + 2.7*(0.5 - 7.6) = 60$$

$$h_w = 7.8 \text{ m}$$

The difference in saturated thickness between the well face and the perimeter of the enclosure under these conditions would be approximately 1.1 m, or 4 ft (8.9 - 7.8 = 1.1 m). However, even here the saturated thickness at the well of 7.8 m would be sufficient to install the well pump.

The extraction rate of the well would be equal to the infiltration rate over the area of the enclosure. With the infiltration rate through the pavement of 1 in/yr:

$$Q = N\,A_{enc} = 1*10^{-9}\ m/s * 17{,}000\ m^2 = 0.000017\ m^3/s$$

(0.3 gpm)

For the infiltration rate of 6 in/yr, the extraction rate would be approximately 2 gpm.

To dewater an area of 11,360 m^2 to the depth of 1.8 m, the following volume of water would be have to be removed, assuming drainable porosity of 0.3:

$$V = 11{,}360 * 1.8 * 0.3 = 6{,}134\ m^3 = 1{,}600{,}000\ \text{gallons}$$

Assuming that the dewatering would be conducted over a period of one season, this translates into the flow of:

$$Q = 1{,}600{,}000 / (365 * 1440) = 3\ \text{gpm}$$

(on the order of 1 to 10 gpm)

6. SUMMARY AND RECOMMENDATIONS

The horizontal flow barrier would extend approximately along Wendell Street and the inactive L.I.R.R. right of way. It would be roughly triangular in shape, with the perimeter length of approximately 1,700 feet, enclosing an area of approximately 120,000 ft^2. It appears that the capacity of the treatment system required to dewater the area inside of the enclosure and to maintain the inward gradient would have to be approximately 1 to 10 gpm. One 6-inch diameter well, installed through the entire saturated thickness of the Upper Glacial aquifer, would be sufficient. However, as a factor of safety, two wells are recommended.

This is assuming that the sheet pile enclosure would be constructed to high standards, and the joints would be sealed with a high-quality sealant, resulting in a negligible leakage. The barrier would have to be keyed into the low-permeability lower subunit of the Magothy formation, which occurs at depths ranging from approximately 120 to 170 feet.

7. REFERENCES

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URS

Page 12 of 36

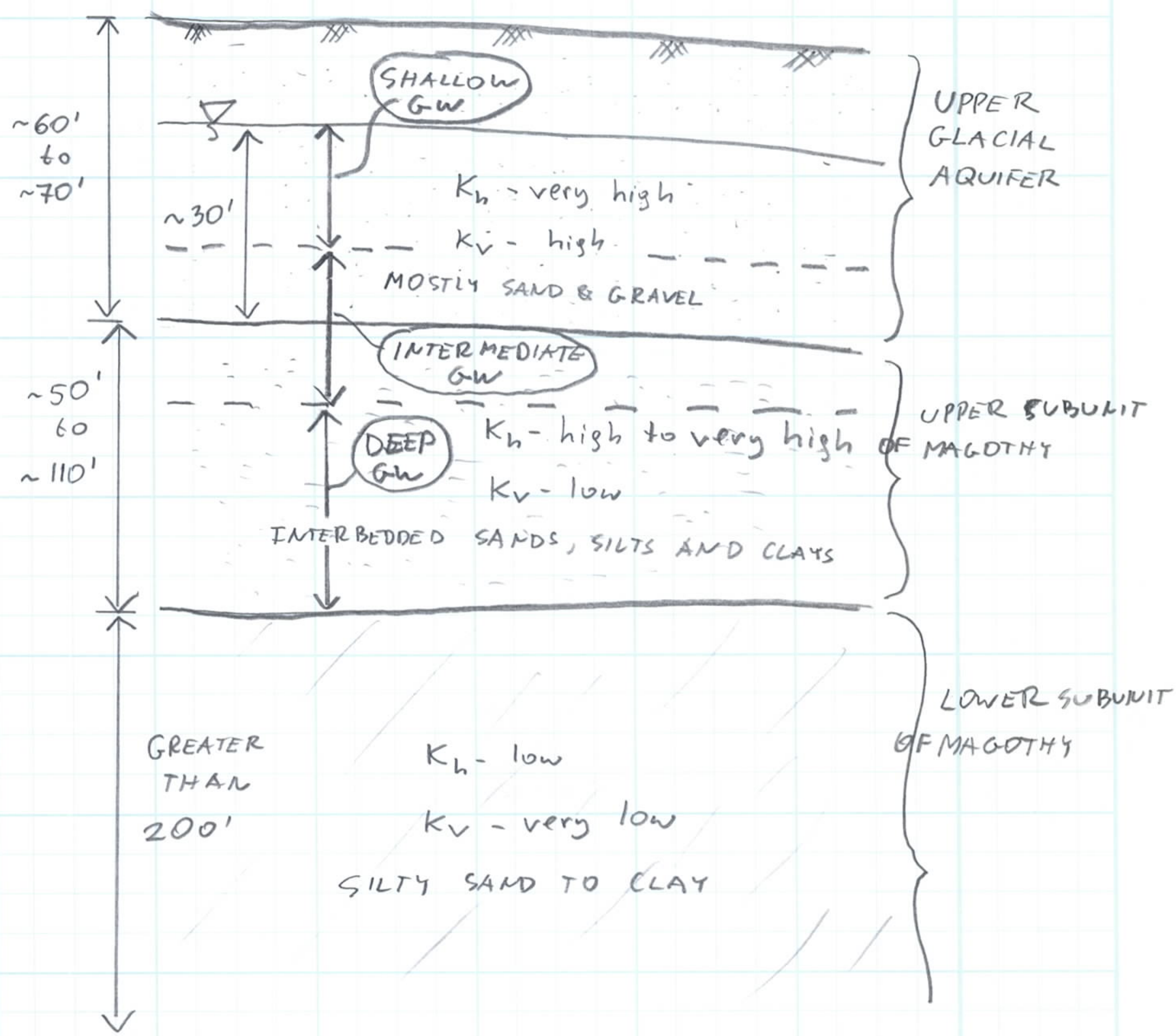
Job Hempstead Intersection St | Project No. 111 75 065 | Sheet ____ of ____

Description Hydraulic Containment and Horizontal Barrier | Computed by M.O. | Date Apr 5, 2007

Checked by AMM | Date 5/1/07

Reference

CONCEPTUAL CROSS SECTION



URS Corporation

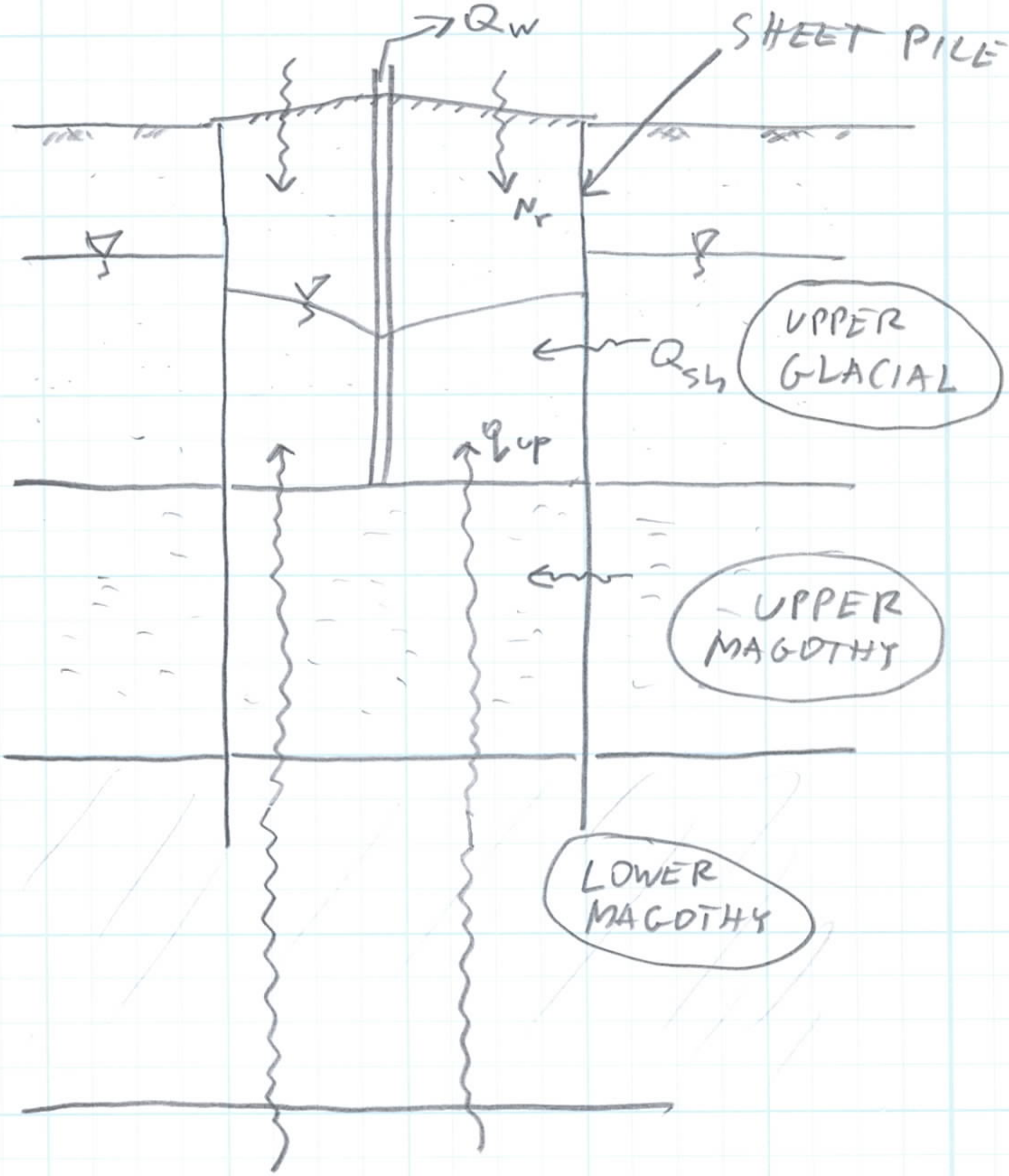
KEYSPAN CORPORATION
HEMPSTEAD INTERSECTION STREET
FORMER MGP SITE
GARDEN CITY/HEMPSTEAD, NY

CONCEPTUAL LAYOUT FOR ALTERNATIVE 2 - SOURCE CONTAINMENT

FIGURE 5-2

Job Hempstead | Project No. 11175065 | Sheet ___ of ___
Description ___ | Computed by UWO | Date May 1, 07
Checked by ___ | Date ___
Reference

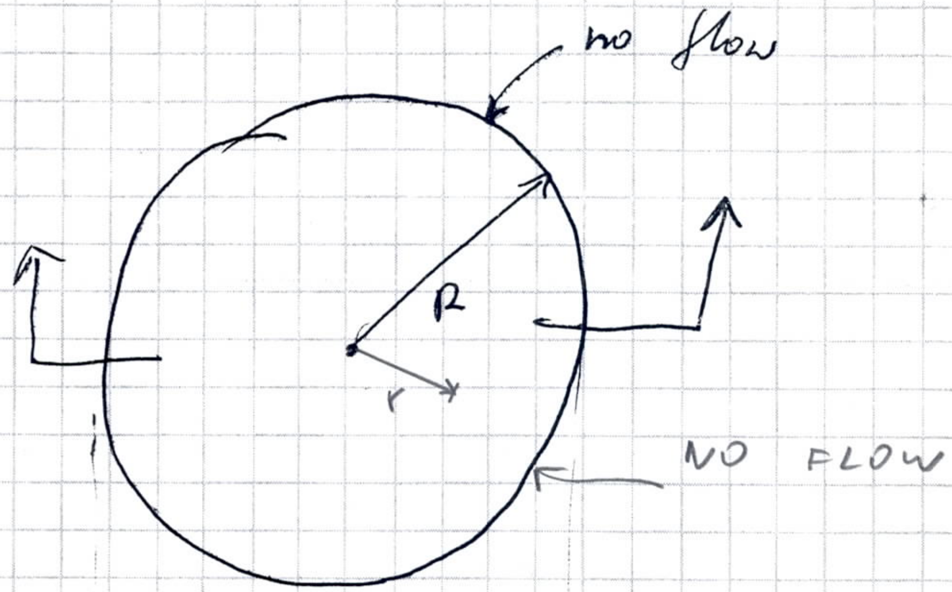
FLOW BUDGET FOR ENCLOSURE

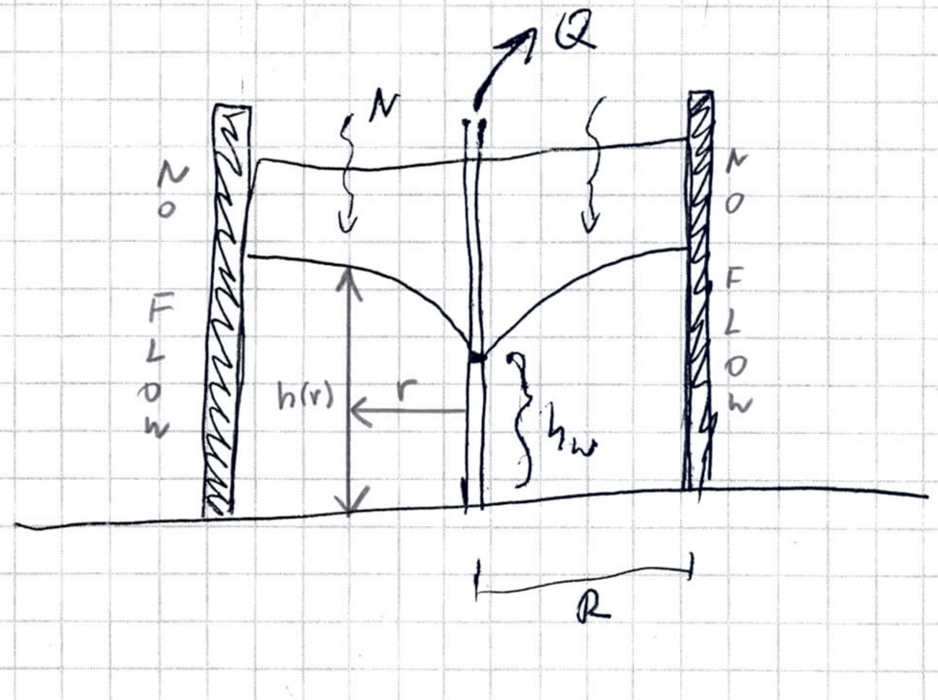


$$Q_w = q_{up} \cdot A_{enc} + N_r \cdot A_{enc} + Q_{sh}$$

Q_w - extraction rate
q_{up} - upward flow
N_r - infiltration
Q_{sh} - flow through sheet pile

REF. PAGE





REF. PAGE

2-D depth averaged eq. for phreatic flow

$$\frac{\partial^2(h^2)}{\partial x^2} + \frac{\partial^2(h^2)}{\partial y^2} + \frac{2N}{K} = \frac{S}{T}\frac{\partial(h^2)}{\partial t}$$ Bear 5-82

Ref 3

For steady state

$$\frac{\partial^2(h^2)}{\partial x^2} + \frac{\partial^2(h^2)}{\partial y^2} = -\frac{2N}{K}$$

$$\nabla^2(h^2) = -\frac{2N}{K}$$

In cylindrical coordinate ~~sys~~ system

$$\nabla^2\phi = \frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2}$$ Bear p 116

Here, assume axi-symmetic case

$$\frac{\partial\phi}{\partial\theta} = 0$$

So;

$$\frac{\partial^2(h^2)}{\partial r^2} + \frac{1}{r}\frac{\partial(h^2)}{\partial r} = -\frac{2N}{K}$$

$$\frac{\partial^2(h^2)}{\partial r^2} + \frac{1}{r}\frac{\partial(h^2)}{\partial r} + \frac{2N}{K} = 0$$

Solve using

REF. PAGE

$$\frac{dy}{dx} + P(x)\,y = Q(x)$$

Wylie p 33

↑

Ref 4

Say $\vartheta = \frac{\partial(h^2)}{\partial r}$; then

$$\frac{\partial \vartheta}{\partial r} + \frac{1}{r}\vartheta + \frac{2N}{k} = 0$$

$$\frac{\partial \vartheta}{\partial r} + \frac{1}{r}\vartheta = -\frac{2N}{k}$$

$$P(r) = \frac{1}{r} \ ; \quad Q(r) = -\frac{2N}{k}$$

Solution is

$$y = e^{-\int P(x)dx} \int Q(x) e^{\int P(x)dx} dx + c\, e^{-\int P(x)dx}$$

$$e^{-\int P(r)dr} = e^{-\int \frac{1}{r}dr} = e^{-\ln r} = \frac{1}{r}$$

$$e^{\int P(r)dr} = e^{\int \frac{1}{r}dr} = e^{\ln r} = r$$

$$\int Q(r) e^{\int P(r)dr} = \int \left(-\frac{2N}{k}\right) r\,dr = -\frac{Nr^2}{k}$$

$$\vartheta = \frac{1}{r}\left(-\frac{Nr^2}{k}\right) + \frac{c}{r}$$

$$\vartheta = -\frac{Nr}{k} + \frac{c}{r}$$

REF. PAGE

$$\frac{\partial^2(h^2)}{\partial r^2} + \frac{1}{r}\frac{\partial(h^2)}{\partial r} + \frac{2N}{K} = 0$$

$$v = \frac{\partial(h^2)}{\partial r}$$

$$\frac{\partial v}{\partial r} + \frac{1}{r}v + \frac{2N}{K} = 0$$

From sheet #3

$$v = -\frac{Nr}{K} + \frac{C_1}{r}$$

B.C. #1

$$\left.\frac{\partial h}{\partial r}\right|_{r=R} = 0$$

$$v = \frac{\partial(h^2)}{\partial r} = 2h\frac{\partial h}{\partial r} = -\frac{Nr}{K} + \frac{C_1}{r}$$

$$0 = -\frac{NR}{K} + \frac{C_1}{R}$$

$$C_1 = \frac{NR^2}{K}$$

B.C. #2

$$h\Big|_{r=r_w} = h_w$$

REF. PAGE

$$\sigma = \frac{\partial(h^2)}{\partial r} = -\frac{Nr}{K} + \frac{NR^2}{Kr}$$

$$h^2 = -\frac{Nr^2}{2K} + \frac{NR^2}{K}\ln r + C_2$$

$$h_w^2 = -\frac{Nr_w^2}{2K} + \frac{NR^2}{K}\ln r_w + C_2$$

$$C_2 = h_w^2 + \frac{Nr_w^2}{2K} - \frac{NR^2}{K}\ln r_w$$

So;

$$h^2 = -\frac{Nr^2}{2K} + \frac{NR^2}{K}\ln r + h_w^2 + \frac{Nr_w^2}{2K} - \frac{NR^2}{K}\ln r_w$$

$$h^2 - h_w^2 = \frac{N}{2K}(r_w^2 - r^2) + \frac{NR^2}{K}\ln\frac{r}{r_w}$$

Note: First, set your h_R & h_w (i.e. $h_R^2 - h_w^2$)
Then, iteratively, determine R

$$h_R^2 - h_w^2 = \frac{N}{2K}(r_w^2 - R^2) + \frac{NR^2}{K}\ln\frac{R}{r_w}$$

$$R = \left\{\frac{K}{N\ln(R/r_w)}\left[(h_R^2 - h_w^2) + \frac{N}{2K}(R^2 - r_w^2)\right]\right\}^{1/2}$$

REF. PAGE

Check

$$h^2 = h_w^2 + \frac{N}{2K}(r_w^2 - r^2) + \frac{NR^2}{K} \ln \frac{r}{r_w}$$

$$\frac{\partial(h^2)}{\partial r} = -\frac{Nr}{K} + \frac{NR^2}{Kr}$$

$$\frac{\partial^2(h^2)}{\partial r^2} = -\frac{N}{K} - \frac{NR^2}{Kr^2}$$

Substitute to gov. eqn

$$\frac{\partial^2(h^2)}{\partial r^2} + \frac{1}{r}\frac{\partial(h^2)}{\partial r} + \frac{2N}{K} = 0$$

$$-\frac{N}{K} - \frac{NR^2}{Kr^2} + \frac{1}{r}\left(-\frac{Nr}{K} + \frac{NR^2}{Kr}\right) + \frac{2N}{K} =$$

$$= \underline{\underline{-\frac{N}{K}}} - \frac{NR^2}{Kr^2} \underline{\underline{-\frac{N}{K}}} + \frac{NR^2}{Kr^2} \underline{\underline{+\frac{2N}{K}}} = 0$$

ok

B.C. # 1

$$\left.\frac{\partial h}{\partial r}\right|_{r=R} = 0 \qquad h = \left\{h_w^2 + \frac{N}{2K}(r_w^2 - r^2) + \frac{NR^2}{K} \ln \frac{r}{r_w}\right\}^{1/2}$$

$$\frac{\partial h}{\partial r} = \frac{-\frac{Nr}{K} + \frac{NR^2}{Kr}}{2\sqrt{\quad}}$$

REF. PAGE

$$\frac{\partial h}{\partial r} = 0 \rightarrow -\frac{N r}{K} + \frac{N R^2}{K r} = 0$$

$$r = R$$

$$-\frac{N R}{K} + \frac{N R^{\cancel{2}}}{K \cancel{R}} = 0 \qquad \text{ok}$$

B.C. # 2

$$h\Big|_{r = r_w} = h_w$$

$$h^2 = h_w^2 + \frac{N}{2K}\left(r_w^2 - r_w^2\right) + \frac{N R}{K} \ln \frac{r_w}{r_w}$$

$$h^2 = h_w^2 \qquad \text{ok}$$

HEMPSTEAD INTERSECTION STREET
FORMER MANUFACTURED GAS PLANT SITE

Reference 1

FINAL REMEDIAL INVESTIGATION REPORT

Prepared for:

KEYSPAN CORPORATION
One MetroTech Center
Brooklyn, New York

MARCH 2006

Prepared by:

PS&S engineering

Paulus, Sokolowski and Sartor Engineering, PC
67A Mountain Boulevard Extension
P.O. Box 4039
Warren (Somerset County), New Jersey 07059

concrete, brick, coal, bluestone, clinker, vesicular slag and wood. The unit is not continuous throughout the site and varies in thickness from approximately 1/2-foot up to 16 feet. However, as indicated by **Drawing 3A**, the unit is fairly continuous along the southern and eastern boundaries of the site where it extends up to 4 feet in thickness at soil boring HISB-35. The unit appears to be thickest in the central-western portion of the site as illustrated on **Drawing 3C**. The unit is up to 16 feet thick at soil boring HISB-14, which is located within the area of the former drip oil tanks, and up to 8 feet thick at soil boring HISB-15, which is located at the former tar separator. It is possible that, after removal of these former MGP structures, the excavations were backfilled with fill material. The north-south cross-sections, illustrated on **Drawings 3E** and **3F**, demonstrate that the fill unit decreases in thickness toward the north end of the site. As mentioned above, the existence and thickness of this unit appears to correlate well with the location and number of former MGP structures, and therefore, could possibly be related to demolition methods that occurred at a particular boring location. With the exception of a thin layer of topsoil, the fill unit does not appear to extend a significant distance south of the site as indicated by **Drawing 3B**. A thin layer of fill does appear to be present at several soil borings located west of the site within the Village of Garden City property, including BBSB-19, 20, 21, 22, 26 and 46.

3.3 Glacial Sediments

Consistent with regional geology, relatively porous glacial outwash deposits consisting of yellow to light brown fine to coarse sand with varying amounts of gravel underlie the site as well as surrounding areas. However, zones or lenses of silty sand and silt were identified within the glacial unit at a number of boring locations. The majority of the silt-sand lenses were encountered from ground surface to a depth of approximately 20 feet. As shown on **Drawing 3B**, one exception to this general observation was at monitoring well HIMW-08D where up to 32 feet of silt and silty sand was observed. The silty sand lenses may limit the vertical movement of groundwater where present at or near the water table, such as in the southern portion of the site (refer to **Drawing 3F**). Additionally, a number of gravel-rich sand lenses were identified in the glacial unit. The majority of these gravel-rich lenses were found from approximately 30 to 50 feet below ground surface. Although encountered throughout the area of investigation, the gravel-rich lenses appear to be more prevalent and continuous in the western half of the site (refer to **Drawings 3A, 3C** and **3E**) and off-site to the west and south (refer to **Drawing 3B**). Where present below the water table, these gravelly zones may act as preferred flow paths for groundwater.

The glacial outwash sediments comprise the entire unconfined Upper Glacial aquifer in the site area. Within the site, the glacial sediments are approximately 60 to 70 feet thick. South of the site, the total thickness of the glacial sediments increases to at least 95 feet as observed at monitoring well HIMW-13D (refer to **Drawing 3B**). The glacial sediments are underlain by the Magothy formation within the site as well as at downgradient areas, at least as far south as Hempstead Lake State Park, approximately 1.3 miles from the site. The interface between the glacial and Magothy formation is characterized by a transition from the glacial sand to a brown to gray layer of silty fine sand, silt and/or silty clay. A review of United States Geologic Service (USGS) reports confirms that this transition has also been recognized as the contact between the two major stratigraphic units in this area of Nassau County.

As discussed in **Section 1.5.8**, the glacial sediments within this area of Long Island exhibit excellent water transmitting properties with horizontal and vertical hydraulic conductivities averaging approximately 250 feet per day (McClymonds and Franke, 1972). Six samples of the glacial sediments were selected for geotechnical analysis (which included grain size analysis by sieving and hydrometer testing, specific gravity and water content) and total organic carbon (TOC). The results of these analyses are summarized on **Table 3-1**. Five of the six samples consist of fine to very coarse sand, typical of the majority of glacial sediments encountered at the site. The effective grain size (d_{10}), which is the grain size at which 90 percent of the sample is larger and 10 percent is finer, for these five samples ranged from 0.17 to 0.38 mm and the amount of the samples finer than 0.073 mm (i.e., grains that may be considered silt or clay) averaged 8 percent. This data indicates that the majority of the glacial sediments consists of fine to coarse sand and has good to excellent water transmitting properties. The remaining glacial sediment sample (HIMW-06 [28 to 30 ft]) consisted of a silty fine sand characteristic of the silty-sand lenses described above. The geotechnical data for this sample indicates a d_{10} of only 0.052 mm with 22 percent of the sample comprised of silt and clay. This would indicate that the silt-sand lenses present in the glacial sediment have poor water transmitting properties. As a result, where present, the silt-sand lenses may act as partial confining units, limiting the vertical migration of water and/or NAPL. Based on the TOC data presented in **Table 3-1**, the outwash deposits are relatively poor in organic matter having an average TOC content of approximately 0.5 percent. The fraction of organic content in soil is the dominant characteristic affecting the adsorption capacity of non-ionic organic compounds such as BTEX and PAHs onto the soil matrix (S.S. Suthersan, 1997). Soil with a very low fraction of organic content will have a limited ability to adsorb and therefore immobilize such organic compounds.

3.4 Magothy Formation Sediments

Prior to the deposition of glacial sediments described above, the underlying Magothy formation was subjected to erosional processes. As a result, the upper surface of this formation is not a flat plain but includes erosional valleys generally trending in a southerly direction towards the Atlantic Ocean. Based on the review of USGS reports, there are no mapped erosional valleys within the site or within two miles downgradient of the site. However, due to the erosional processes and variation in ground surface elevation, the depth at which the upper surface of the Magothy formation may be encountered varies throughout the site area. This variation in the topography of the Magothy formation's upper surface is clearly illustrated by the geologic cross-sections provided in **Drawings 3A** through **3F**. These drawings show that the depth to the Magothy formation generally increases with increasing distance downgradient of the site.

For the purpose of this investigation, the Magothy formation has been further divided into two subunits, with the upper subunit being characterized by a relatively complex sequence of sand, silt and clay, and the lower subunit being characterized by a low permeable gray to black silty fine sand to a gray to black stiff clay. More detailed descriptions of each of these subunits are presented below.

Upper Magothy Subunit

The Upper Magothy formation directly underlies the glacial sediments. The total thickness of the subunit is estimated to range between 49 feet, as determined at monitoring well HIMW-06D, and 110 feet, as determined at monitoring well HIMW-05D. As discussed above, this subunit consists of a relatively complex sequence of sand, silt and clay, and with widely variable sediment color ranging from brown, orange, red, yellow, gray to black. The sediment was also found to be moderately to highly micaceous (i.e., containing mica particles). In addition, lignite, which is a mineralized form of plant matter and considered an intermediary mineral in the formation of coal, was sporadically encountered along with pyrite nodules in soil samples recovered from this unit. While predominantly composed of fine to very fine sand with varying amounts of silt, a number of more permeable lenses of fine to coarse sand were encountered throughout the Upper Magothy subunit. In addition, it is common to encounter lenses of fine to coarse sand interbedded with thin clay layers or laminae of less than 1/8-inch in thickness. The majority of the sand-rich lenses do not appear to be continuous through the site, but rather more lenticular in nature. The majority of the intermediate and deep groundwater monitoring wells installed as part of the RI were screened in the more sand-rich lenses encountered in the Upper Magothy subunit. Because of its diverse stratigraphy and heterogeneous distribution of sediment types and zones, the Upper Magothy sediments are highly anisotropic with the vertical hydraulic conductivity several orders of magnitude less than the horizontal hydraulic conductivity (Franke and Cohen, 1972). As a result, groundwater has a much greater propensity to flow horizontally than vertically within this unit.

Table 3-2 summarizes the geotechnical and Total Organic Carbon (TOC) data obtained from the six samples collected from the Upper Magothy subunit. Note that the majority of these samples were collected from the screen zones of the deep and intermediate wells, and therefore, generally represent the more sand-rich lenses of the subunit described above. As shown in **Table 3-2**, the d_{10} for these samples ranged from 0.0024 mm (clay sized particles) to 0.17 mm (fine sand) and the amount of clay/silt particles in each sample ranged from five to 35 percent. Based on this data, it is concluded that the sand-rich lenses present in the Upper Magothy formation exhibit fairly poor water transmitting properties. However, it should be noted that the grain size analyses are based on composited samples, and therefore, do not reflect the actual in-situ stratigraphy and anisotropic nature of the sediment as described above. The average TOC of the Upper Magothy formation was found to be 3.5 percent. This relatively high TOC may be attributable in part to the presence of lignite in selected samples. As discussed above, lignite was sporadically encountered in samples recovered from this subunit.

Lower Magothy Subunit

As discussed above, the Lower Magothy subunit is comprised of a black silty fine sand to a gray to black stiff clay. Due to its high clay content, the subunit acts as an effective confining layer limiting the vertical migration of groundwater. The majority of the deep groundwater monitoring wells installed as part of this investigation were screened immediately above this subunit. Based on the completed borings, the Lower Magothy subunit is found from 118 ft-bgs, as identified at monitoring well HIMW-06D, to 270 ft-bgs, as identified at temporary well location HITW-02. The actual thickness of this subunit was not determined as part of this investigation; however, based on the review of well logs for the water supply wells located in the vicinity of the site, it is assumed that this subunit is a minimum of 200 feet thick. **Table 3-3** summarizes the geotechnical data obtained through the analysis of the five samples selected from this subunit. As indicated in this table, the average d_{10} for these samples is 0.012 mm and an average of 67 percent of each sample is comprised of silt and/or clay sized particles. Vertical permeability analysis of three undisturbed soil samples collected using a Shelby Tube sampler from the subunit, summarized in **Table 3-4**, confirmed the low permeability of the Lower Magothy subunit with an average vertical hydraulic conductivity of only 2.0×10^{-7} cm/second or 5.8×10^{-4} feet/day.

Rational Analysis of Impervious Steel Sheet Pile Walls

1. Introduction

Until recently no consistent methodology has been available for the assessment of the seepage resistance of steel sheet pile (SSP) walls. The lack of such a methodology can conceivably lead to uneconomic design, especially in cases where the seepage resistance is substantially greater than the specific design requires.

ProfilARBED, the leading European producer of sheet piles, has carried out an exhaustive research project in collaboration with Delft Geotechnics. The aim of the project was to determine the rate of seepage through SSP walls for various joint filler materials, as well as for empty and welded joints.

Two key areas of research were addressed:

- Setting up a consistent theory to describe the leakage behaviour through individual joints.
- In situ experimentation on SSP walls.

In this paper the research results are deployed to enable the practical designer to make a rational assessment of the rate of seepage for a specific case. A range of possibilities is discussed: highly permeable unfilled joints, filled joints for medium permeability and completely impervious welded joints.

The cost involved in each case can be balanced against the seepage resistance requirements and the most appropriate solution will present itself on the basis of the analysis.

Reference 2

4. Practical use of the concept

The key design formula is:

$$q(z) = \rho \bullet \Delta p(z)/\gamma \quad (3)$$

$q(z)$: the discharge per unit of the joint length at level z, [m³/s/m]
$\Delta p(z)$: the pressure drop at level z, [kPa]
ρ: the inverse joint resistance, [m/s]
γ: unit weight of water [kN/m³]

The geometrical definitions are given in Fig. 1 and 2

4.1. The discharge through a SSP wall The simple case

Fig. 6 shows a building pit in which the water table has been lowered about 5 m. The toe of the SSP wall goes right down to the bottom layer; the latter is assumed to be virtually impervious.

This assumption allows to neglect the flow around the toe. (The question as to what K value is required to be able to regard the bottom layer as impervious will be dealt with in section 4.3.)

The resulting hydrostatic pressure diagram is easily drawn (Fig. 6): max $(\Delta p) = \gamma \bullet H$, the total discharge through one joint is obtained:

$$Q_1 = \int_0^{H+h} q(z) \bullet dz = (\rho/\gamma) \bullet \int_0^{H+h} \Delta p(z) \bullet dz \quad (4)$$

With the pressure drop:

$$(\Delta p) = \begin{cases} \gamma \bullet z, & z <= H \\ \gamma \bullet H, & H < z <= H + h \end{cases}$$

Thus the integral in (4) yields the area in the pressure diagramm and a result for Q_1 follows:

$$Q_1 = \rho \bullet H \bullet (0.5\ H + h) \quad (5)$$

The total number of interlocks in the SSP wall for the building pit is:

$$n = L / b \quad (6)$$

L: length of the perimeter of the building pit, [m]
b: system width of the pile, [m]

The total discharge into the pit is:

$$Q = n \bullet Q_1 \quad (7)$$

(7) represents a safe approximation for the discharge, as certain aspects have been neglected, for example the influence of the flow pattern on the geometry of the water table.

NUMERICAL EXAMPLE:

For a building pit with a SSP wall made of AZ18: b = 0.63 m, the perimeter length is L = 160 m.

Fig. 6 shows the geometrical data: H = 5 m and h = 2 m. The joint is fully described by its inverse joint resistance: $\rho = 3.0 \bullet 10^{-10}$ m/s, using a waterswelling filler.

The number of interlocks:

$$n = 160 / 0.63 \cong 254 \quad (6)$$

Discharge per joint:

$$Q_1 = 3.0 \bullet 10^{-10} \bullet 5.0 \bullet (0.5 \bullet 5.0 + 2.0) \quad (5)$$
$$Q_1 = 6.75 \bullet 10^{-9}\ m^3/s$$

Total discharge into the pit:

$$Q = 254 \bullet 6.75 \bullet 10^{-9}\ m^3/s \quad (7)$$
$$Q = 1.715 \bullet 10^{-6}\ m^3/s$$
$$Q = 6.17\ l/h$$

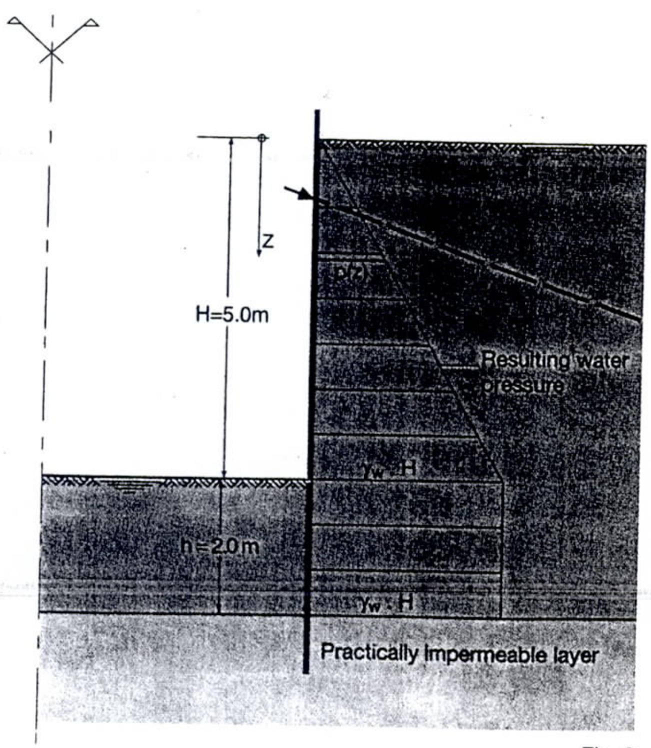


Fig. 6

pg 29
of 36

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London
Madrid
Mexico
Montreal
New Delhi
Panama
Paris
São Paulo
Singapore
Sydney
Tokyo
Toronto

Reference 3

JACOB BEAR

Department of Civil Engineering
Technion—Israel Institute of Technology
Haifa
Israel

Hydraulics of Groundwater

pg 30 of 36

$\mathbf{q}_l \cdot \nabla(z - b_1)$, where $\mathbf{q}_l$ denotes the leakage through b_1. For a horizontal semipervious layer, $\nabla' b_1 = 0$, $\mathbf{q}_l \cdot \nabla z \equiv q_z|_{b_1} \equiv q_{v1} = (\phi - h)/\sigma^{(1)}$.

As was already emphasized above, when we have a system of leaky aquifers, each equation will also include the piezometric head in the underlying and/or overlying aquifer. This means that a continuity equation must be written for each of the aquifers and the system of equations must be solved simultaneously. Sometimes, delayed storage in a semipervious layer is taken into account by writing also a continuity equation for that layer as shown above.

Whenever we consider an inhomogeneous aquifer, with $T = T(x, y)$, the distribution $T(x, y)$ must be continuous up to and including the first derivative. If surfaces of discontinuity in T or in ∇T exist within the considered flow domain, we have to divide the aquifer into subdomains along the lines of discontinuity and solve simultaneously for all subdomains.

It may be of interest to note that when the aquifer is anisotropic, that is $T_x \neq T_y$, a procedure presented in Sec. 5-9 can be employed in order to transform the problem into one dealing with an equivalent isotropic aquifer (Bear, 1972, Sec. 7.4).

Mathematically, (5-58), (5-59), (5-60), (5-81), and (5-82) are second order linear partial differential equations of the parabolic type. They are often called heat conduction equations, or diffusion equations, as they are encountered in these fields. Equation (5-61) is also a second order linear partial differential equation, but of the elliptic type; it is known as the Laplace equation.

When necessary, they can easily be written in any other coordinate system by expressing $\nabla \cdot (T\, \nabla\phi)$ or $\nabla^2\phi$ properly in that coordinate system. For example, in radial coordinates

$$\nabla^2\phi \equiv \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\phi}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2} = \frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2}$$

5-5 COMPLETE MATHEMATICAL STATEMENT OF A GROUNDWATER FLOW PROBLEM

As was already explained in Sec. 5-3, a complete mathematical statement of a groundwater flow problem (and a correct mathematical statement is always the first step of solving a problem, no matter which method of solution is to be applied) consists of five parts.

(*a*) *Specifying the geometry* of the (two-dimensional) flow-domain in the aquifer.

(*b*) *Determining which dependent variable* (*or variables*) is to be used. Usually we use $\phi(x, y, t)$ for flow in confined and in leaky confined aquifers, and $h(x, y, t)$ for flow in phreatic and in leaky phreatic aquifers. When the linearized equation (5-81) is used, we often replace $h(x, y, t)$ by $\phi(x, y, t)$.

(*c*) *Stating the continuity equation* describing the flow in the aquifer (depending on the type of aquifer and on its properties).

(*d*) *Specifying the initial conditions* $\phi = \phi(x, y, 0)$, or $h = h(x, y, 0)$ at some initial time referred to as $t = 0$.

of the phreatic aquifer. However, unlike the transmissivity in a confined aquifer, here it may vary both in space and in time, as $h = h(x, y, t)$.

Two methods of linearization are often applied to (5-75) in order to facilitate a solution.

(i) Assume that $T = \bar{T} + \mathring{T}$; $\bar{T}$ ($\gg \mathring{T}$) is the average constant transmissivity of the phreatic flow and $\mathring{T}$ is a deviation from the average. Then (5-75) reduces to the linear equation in h

$$\bar{T}\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2}\right) + N = S\,\partial h/\partial t; \qquad \bar{T} = K\bar{h} \tag{5-81}$$

to be compared with (5-60).

(ii) We rewrite the right-hand side of (5-76) as $(S/h)\,\partial(h^2/2)/\partial t$ and assume that S/h may be considered as a constant $S/\bar{h}$, where $T = K\bar{h}$. Then (5-76) reduces to

$$\left(\frac{\partial^2 h^2}{\partial x^2} + \frac{\partial^2 h^2}{\partial y^2}\right) + \frac{2N}{K} = \frac{S}{T}\frac{\partial h^2}{\partial t} \tag{5-82}$$

which is a linear equation in h^2.

Equation (5-81) is the one commonly used to describe unsteady groundwater flow in phreatic aquifers. The approximation involved in the linearization (further to that introduced by the Dupuit assumptions) is justified in view of the relatively small changes in h (with respect to the total thickness h) in most phreatic aquifers. Whenever the situation is different, (5-75) or (5-76) should be used.

By replacing h in (5-81) by ϕ (measured from the same datum level as h), (5-60) and (5-81) become identical. We may, therefore, regard (5-81) with h replaced by ϕ, as the general continuity equation describing flow in both phreatic and confined aquifers. For a phreatic aquifer this is true whenever linearization is justified.

Flow in a Leaky Phreatic Aquifer

In this case, the phreatic aquifer is located above a semipermeable layer, which, in turn, overlies a leaky confined aquifer. Figure 5-11 shows such a case. The continuity equation can be easily derived by considering a control box in the phreatic aquifer, taking into account a leakage (q_{v1}) between the leaky confined aquifer and the overlying leaky phreatic one. Obviously, the direction of q_{v1} depends on whether $h > \phi$, or $\phi > h$. We would then obtain

$$\frac{\partial}{\partial x}\left(Kh\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kh\frac{\partial h}{\partial y}\right) + N - \frac{h - \phi}{\sigma^{(1)}} = S\frac{\partial h}{\partial t} \tag{5-83}$$

where the piezometric head in the leaky confined aquifer, ϕ, is measured from the same datum level as h. Here S ($\equiv S_y$) stands for the storativity of the phreatic aquifer. This is the basic continuity equation describing groundwater flow in a leaky phreatic aquifer. It can be obtained by integration. We start from (5-79), noting that n_e ($\equiv S$) $\gg S_0 B$ and that $\mathbf{q}'|_{b_1} \cdot \nabla' b_1 - q_z|_{b_1} \equiv \mathbf{q} \cdot \nabla(z - b_1) =$

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ADVANCED ENGINEERING MATHEMATICS

FIFTH EDITION

C. RAY WYLIE
Emeritus Professor of Mathematics
Furman University

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Montana State University

Reference 4

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(c) If $a^2 + A^2 = 0$ or $b^2 + B^2 = 0$, the given equation is separable and, if $c^2 + C^2 = 0$, it is homogeneous.

Using appropriate substitutions, as described in Exercise 31, solve each of the following equations:

32 $y' = \dfrac{x - y + 5}{x + y - 1}$

33 $y' = \dfrac{2x + 2y + 1}{3x + y - 2}$

34 $y' = (y - x)/(x - y + 2)$

35 $(2x + y)y' = 1$

36 $y' = (y + 2)/(x + y + 1)$

37 $(2x - y)y' = 4x - 2y - 5$

38 Prove that $b + c = 0$ is a sufficient condition for all solution curves of the equation $y' = (ax + by)/(cx + ey)$ to be conics. Prove further that when this is the case, the conics are all ellipses if $c^2 + ae < 0$ and are all hyperbolas if $c^2 + ae > 0$.

39 Show that $b + c = 0$ is not a necessary condition for the solution curves of the equation $y' = (ax + by)/(cx + ey)$ to be conics. *Hint*: Construct a counterexample.

40 If $M(x,y)\,dx = N(x,y)\,dy$ is a homogeneous equation, prove that, if it is expressed in terms of the polar coordinates r and θ by means of the substitutions $x = r\cos\theta$ and $y = r\sin\theta$, it becomes separable.

Solve the next two equations, using the method described in Exercise 40.

41 $y' = \dfrac{x + y}{x - y}$

42 $y' = \dfrac{x + 2y}{2x - y}$

43 If $f(x,y)$ is a homogeneous function of degree n, show that

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} = nf$$

What is the generalization of this result to functions of more than two variables? (Thi commonly referred to as **Euler's theorem for homogeneous functions.**†

44 Show that if the equation $M(x,y)\,dx + N(x,y)\,dy = 0$ is both homogeneous and solutions are given by $xM(x,y) + yN(x,y) = k$.

45 If the equation $M(x,y)\,dx + N(x,y)\,dy = 0$ is homogeneous, show that $1/(xM + y$ integrating factor. *Hint*: Observe that

$$\frac{M\,dx + N\,dy}{xM + yN} = \frac{dx}{x} + \frac{(x\,dy - y\,dx)N}{x(xM + yN)} = \frac{dx}{x} + \frac{(x\,dy - y\,dx)/x^2}{M/N + y/x}$$

1.11 Linear First-Order Equations

First-order equations which are linear form an important class of differential equations which can always be routinely solved by the use of an integrating factor. By definition, a linear, first-order differential equation cannot contain products, powers, or other nonlinear combinations of y or y'. Hence its most general form is

$$F(x)\frac{dy}{dx} + G(x)y = H(x)$$

If we divide this equation by $F(x)$ and rename the coefficients, it appears in the more usual form

$$\frac{dy}{dx} + P(x)y = Q(x) \qquad (1)$$

† Named for the Swiss mathematician Leonard Euler (1707–1783), one of the most prolific, and one of the greatest, mathematicians of all time.

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To determine whether this equation is, or can be made, exact, let us rewrite it in the form

$$[P(x)y - Q(x)]\,dx + dy = 0 \tag{2}$$

Here $M(x,y) = P(x)y - Q(x)$, $N(x,y) = 1$, and the condition for exactness $\partial M/\partial y \equiv \partial N/\partial x$ becomes $P(x) \equiv 0$. This is surely not true in general; and when it is true, Eq. (1) can be solved immediately by integration, and no further investigation is necessary.

Assuming $P(x) \not\equiv 0$, let us now attempt to find an integrating factor $\phi(x)$ for Eq. (2). Applying the test for exactness to the new equation

$$\phi(x)[P(x)y - Q(x)]\,dx + \phi(x)\,dy = 0 \tag{3}$$

it follows that $\phi(x)$ will be an integrating factor provided

$$\phi(x)P(x) = \phi'(x)$$

This is a simple separable equation, any nontrivial solution of which will serve our purpose. Hence, we can write, in particular,

$$\frac{d\phi(x)}{\phi(x)} = P(x)\,dx \qquad \ln|\phi(x)| = \int P(x)\,dx \qquad \phi(x) = e^{\int P(x)\,dx}$$

Thus (2), or equally well (1), possesses the integrating factor $\phi(x) = e^{\int P(x)\,dx}$.

When (1) is multiplied by $e^{\int P(x)\,dx}$, it can be written in the form

$$\frac{d}{dx}\left(ye^{\int P(x)\,dx}\right) = Q(x)e^{\int P(x)\,dx}$$

The left-hand side is now an exact derivative and hence can be integrated at once. Moreover, the right-hand side is a function of x only and therefore can also be integrated, with at most practical difficulties requiring numerical integration. Thus we have, on performing these integrations,

$$ye^{\int P(x)\,dx} = \int Q(x)e^{\int P(x)\,dx}\,dx + c$$

and finally, after dividing by $e^{\int P(x)\,dx}$,

$$y = e^{-\int P(x)\,dx}\int Q(x)e^{\int P(x)\,dx}\,dx + ce^{-\int P(x)\,dx} \tag{4}$$

Equation (4) should *not* be remembered as a formula for the solution of (1). Instead, a linear first-order equation should be solved by actually carrying out the steps we have described:

1. Compute the integrating factor $e^{\int P(x)\,dx}$.
2. Multiply the right-hand side of the given equation by this factor and write the left-hand side as the derivative of [y times the integrating factor].
3. Integrate and then solve the integrated equation for y.

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Simulation of Ground-Water Flow and Pumpage in Kings and Queens Counties, Long Island, New York

By Paul E. Misut and Jack Monti, Jr.

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98-4071

Reference 5

Prepared in cooperation with
NEW YORK CITY DEPARTMENT OF
ENVIRONMENTAL PROTECTION

USGS
science for a changing world

Coram, New York
1999

Table 1. Hydrologic units underlying Kings and Queens Counties, N.Y., and their water-bearing properties as represented by the Long Island regional model

[gal/min, gallons per minute; ft, feet; ft/d, feet per day. Modified from Doriski and Wilde-Katz, 1983. Modeled hydraulic properties from Buxton and Smolensky, in press]

System	Series	Age	Stratigraphic unit (hydrologic unit names are in parentheses)	Approximate range in thickness (feet)	Character	Water-bearing properties, modeled hydraulic conductivity, and anisotropy
QUATERNARY	Holocene	Post glacial	Holocene (recent) deposits (upper glacial aquifer)	0-40	Beach sand and gravel and dune sand, tan to white; black, brown, and gray bay-bottom deposits of clay and silt; artificial fill. Beach and dune deposits are mostly stratified and well sorted. Fill includes earth and rocks, concrete fragments, ashes, rubbish, and hydraulic fill.	Sandy beds of moderate to high permeability beneath barrier beaches, locally yield fresh or salty water from shallow depths. Clayey and silty beds beneath bays retard saltwater encroachment and confine underlying aquifers.
	Pleistocene	Wisconsinan	Upper Pleistocene deposits (upper glacial aquifer)	0-300	Till composed of clay, sand, gravel, and boulders, forms Harbor Hill and Ronkonkoma terminal moraines. Outwash consisting mainly of brown fine to coarse sand and gravel, stratified. Interbedded with clays.	Till is poorly permeable. Sand and gravel part of outwash highly permeable; yields of individual wells are as much as 1,700 gal/min. Specific capacities of wells as much as 109 gal/min per foot of drawdown. Water fresh except near shorelines. Horizontal hydraulic conductivity: 20-80 ft/d (moraine), 200-300 ft/d (outwash). Horizontal to vertical anisotropy is 10:1. Specific yield is 0.25 (moraine), 0.3 (outwash).
			unconformity	0-40	Clay and silt, gray and grayish green; some lenses of sand and gravel. Contains shells, foraminifera, and peat. Altitude of top of unit about 20 ft below sea level. Interbedded with outwash in southern part of area.	Relatively impermeable confining unit. Retards saltwater encroachment in shallow depths. Confines water in underlying outwash deposits when present.
		Sangamon interglaciation	Gardiners Clay unconformity	0-150	Clay and silt, grayish-green; some lenses of sand and gravel. Contains lignitic material, shells, glauconite, foraminifera, and diatoms. Interglacial deposit. Altitude of surface 50 ft or more below sea level.	Relatively impermeable confining layer above Jameco aquifer. Locally contains moderately to highly permeable sand and gravel lenses. Confines water in underlying Magothy aquifer. Vertical hydraulic conductivity is 0.001 - 0.0029 ft/d.
		Illinoisan(?)	Jameco Gravel (Jameco aquifer)	0-200	Sand, coarse, granule to cobble gravel, generally dark brown and dark gray. A stream deposit in a valley cut in Matawan Group-Magothy Formation undifferentiated deposits. Buried valley of ancestral Hudson River.	Highly permeable. Yields as much as 1,500 gal/min to individual wells. Specific capacities as high as 135 gal/min per foot of drawdown. Contains water under artesian pressure. Water commonly has high iron content and is salty near shoreline. Horizontal hydraulic conductivity is 200-300 ft/d. Horizontal to vertical anisotropy is 10:1. Specific storage is 1×10^{-6} per ft.

APPENDIX B

FINGERPRINT ANALYSIS RESULTS

INTEGRATED ANALYTICAL LABORATORIES, LLC.

GC FINGERPRINT ANALYSIS

Client/Project: URS Corp/Keyspan - Hempstead

Date Received: 4/17/07
Date Analyzed: 4/20/07

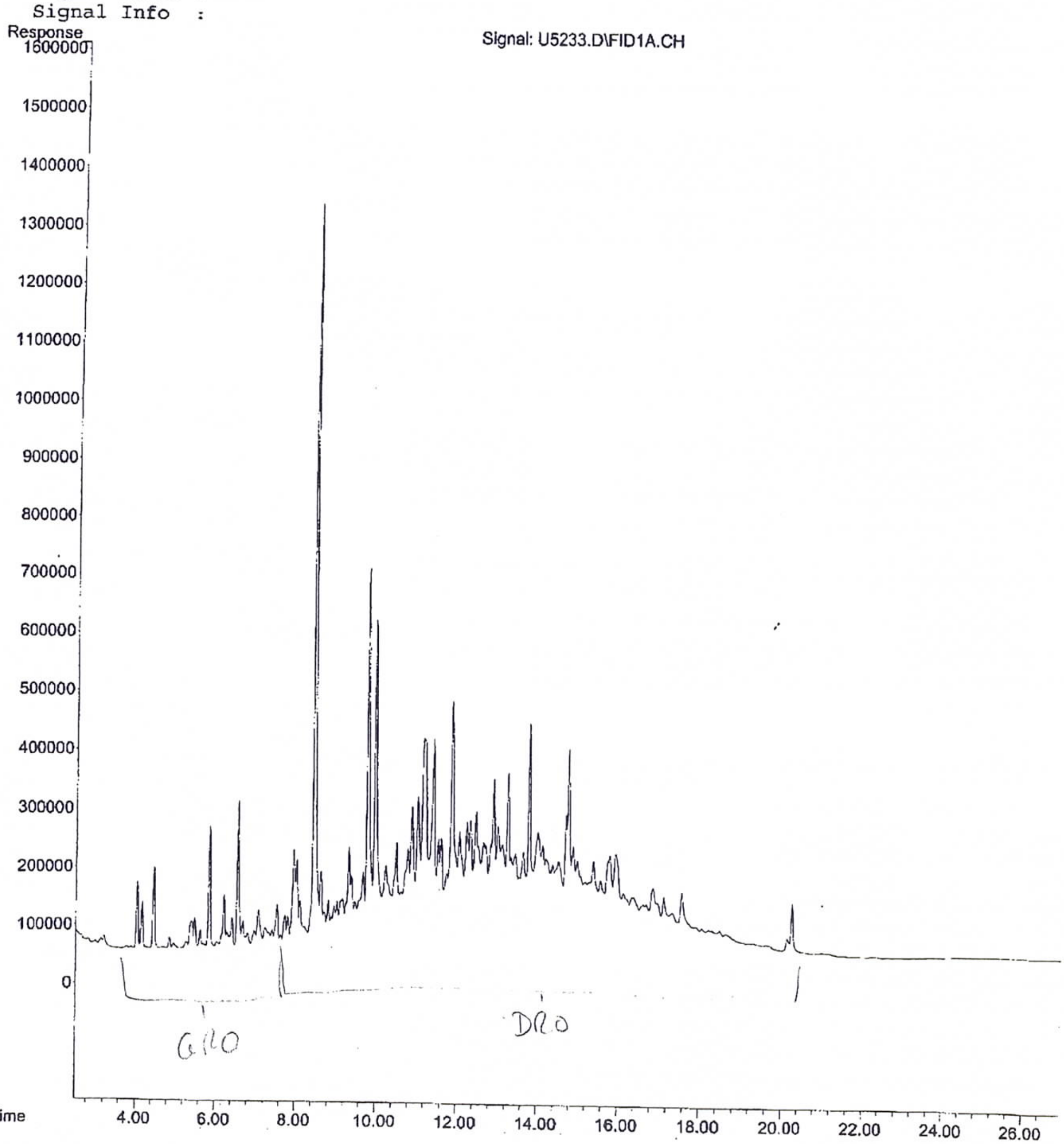
Lab ID	Client ID	RESULTS
03728-008	HIMW-11S	This sample closely approximates but is not an exact match of Fuel Oil Standard #2. Variations in the sample as compared to the standards may be attributed to weathering, evaporation, contamination and/or degradation.

Quantitation Report (QT Reviewed)

Data File : C:\MSDCHEM\1\DATA\04-20-07\U5233.D Vial: 7
Acq On : 20 Apr 2007 11:22 Operator: MJ
Sample : HIMW-11S,03728-008,A,500ml,100,04/19/07, Inst : GC_U
Misc : URS-WAYNE/KEYSPAN_,04/17/07,04/17/07,10 Multiplr: 1.00
IntFile : autoint1.e
Quant Time: Apr 20 13:08 2007 Quant Results File: UGRO0416.RES

Quant Method : C:\MSDCHEM\1\METHODS\UGRO0416.M (Chemstation Integrator)
Title :
Last Update : Tue Apr 17 10:28:47 2007
Response via : Multiple Level Calibration
DataAcq Meth : UGRO0416.M

Volume Inj. :
Signal Phase :
Signal Info :



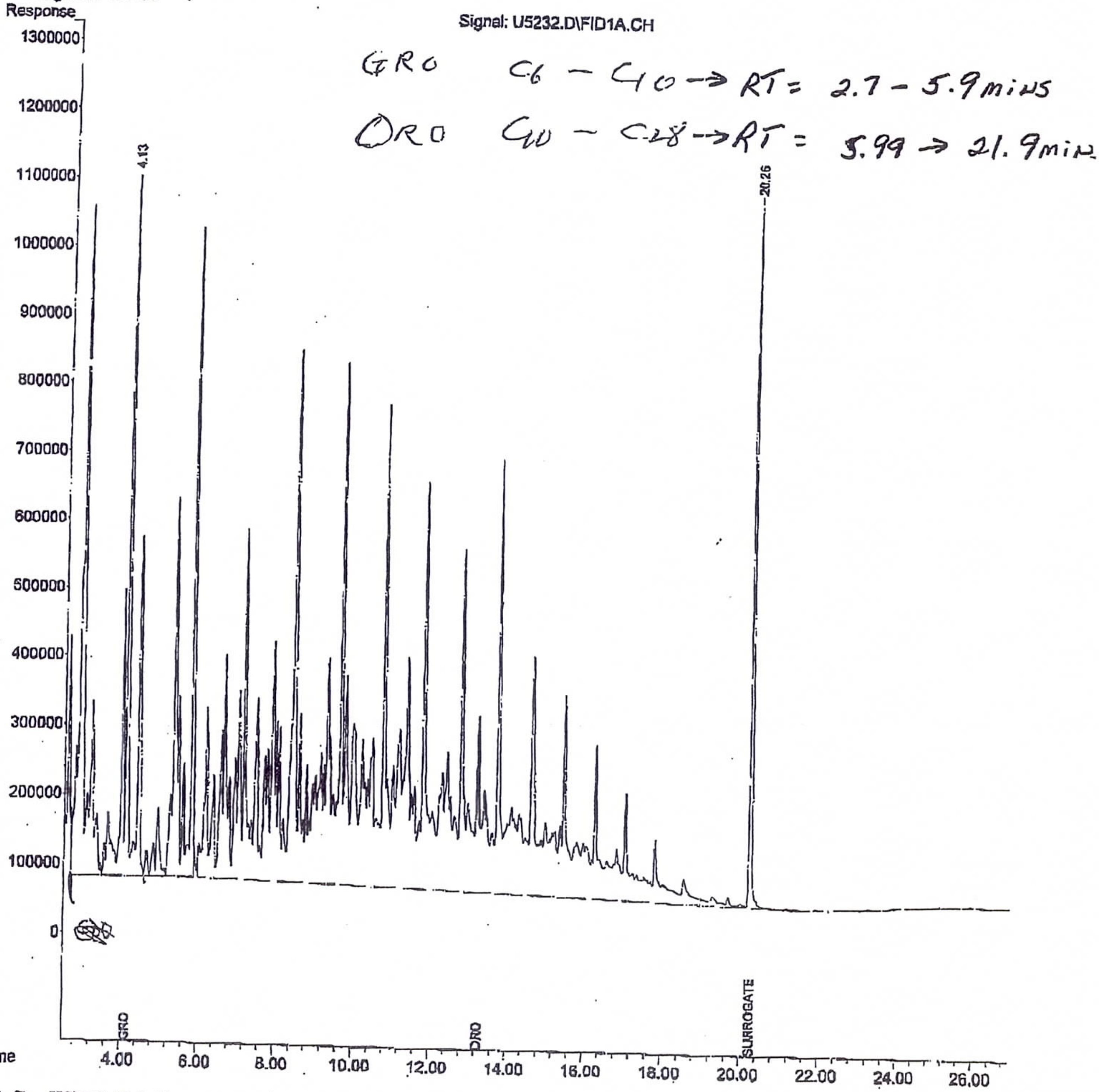
Quantitation Report (QT Reviewed)

Data File : C:\MSDCHEM\1\DATA\04-20-07\U5232.D
Acq On : 20 Apr 2007 10:49
Sample : DRO/GRO_IAS_2814,1000_PPM
Misc : NA,NA,NA,1
IntFile : autoint1.e
Quant Time: Apr 20 11:19 2007 Quant Results File: UGRO0416.RES

Vial: 3
Operator: MJ
Inst : GC_U
Multiplr: 1.00

Quant Method : C:\MSDCHEM\1\METHODS\UGRO0416.M (Chemstation Integrator)
Title :
Last Update : Tue Apr 17 10:28:47 2007
Response via : Multiple Level Calibration
DataAcq Meth : UGRO0416.M

Volume Inj. :
Signal Phase :
Signal Info :

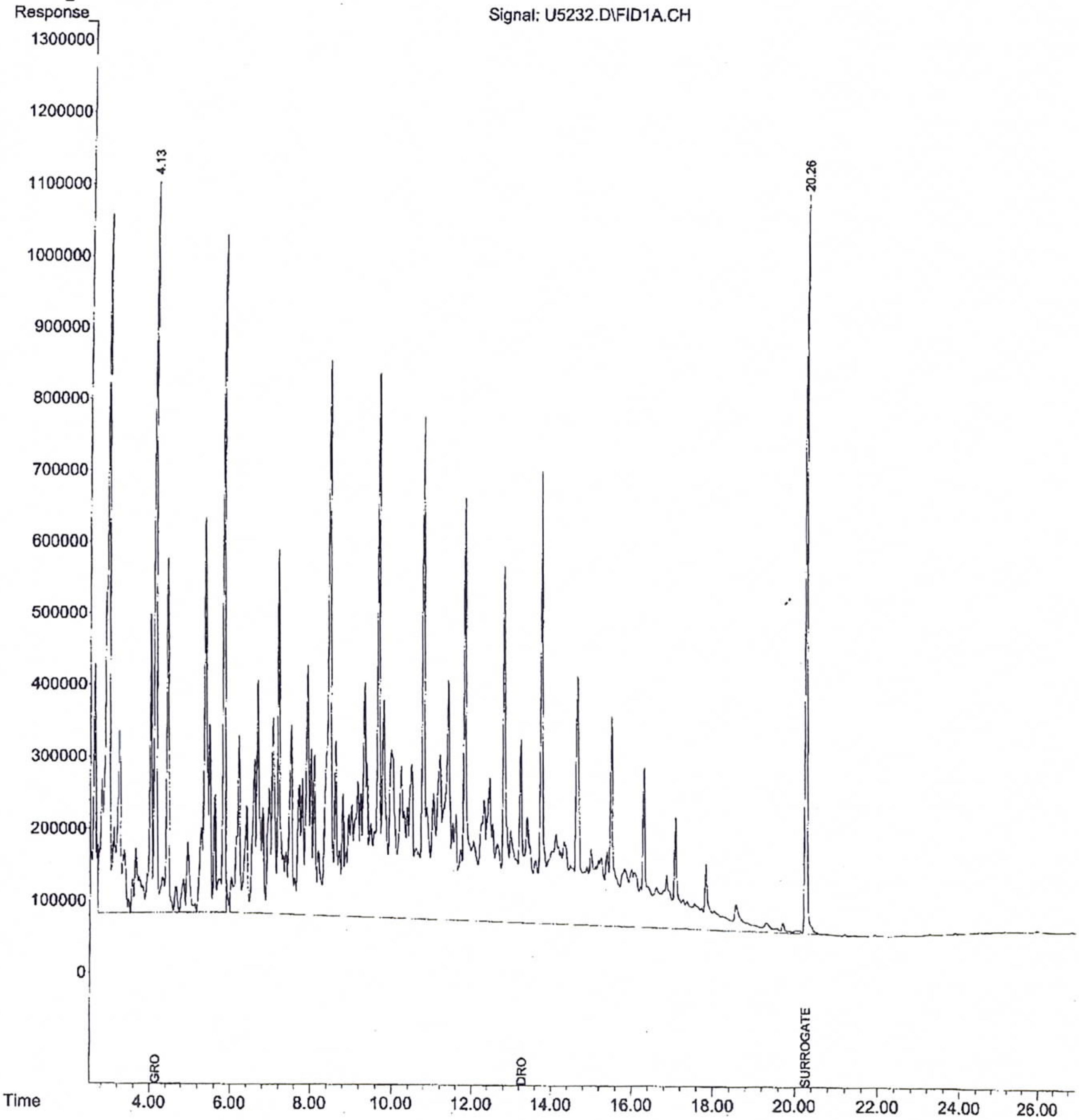


Quantitation Report (QT Reviewed)

Data File : C:\MSDCHEM\1\DATA\04-20-07\U5232.D Vial: 3
Acq On : 20 Apr 2007 10:49 Operator: MJ
Sample : DRO/GRO_IAS_2814,1000_PPM Inst : GC_U
Misc : NA,NA,NA,1 Multiplr: 1.00
IntFile : autoint1.e
Quant Time: Apr 20 11:19 2007 Quant Results File: UGRO0416.RES

Quant Method : C:\MSDCHEM\1\METHODS\UGRO0416.M (Chemstation Integrator)
Title :
Last Update : Tue Apr 17 10:28:47 2007
Response via : Multiple Level Calibration
DataAcq Meth : UGRO0416.M

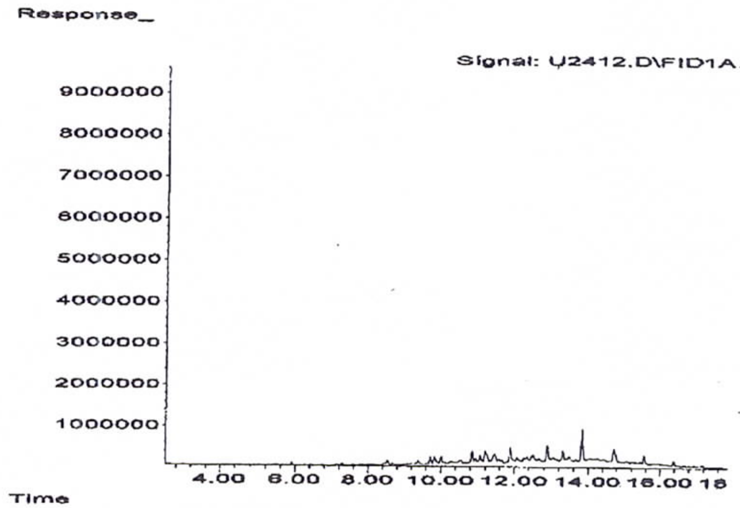
Volume Inj. :
Signal Phase :
Signal Info :



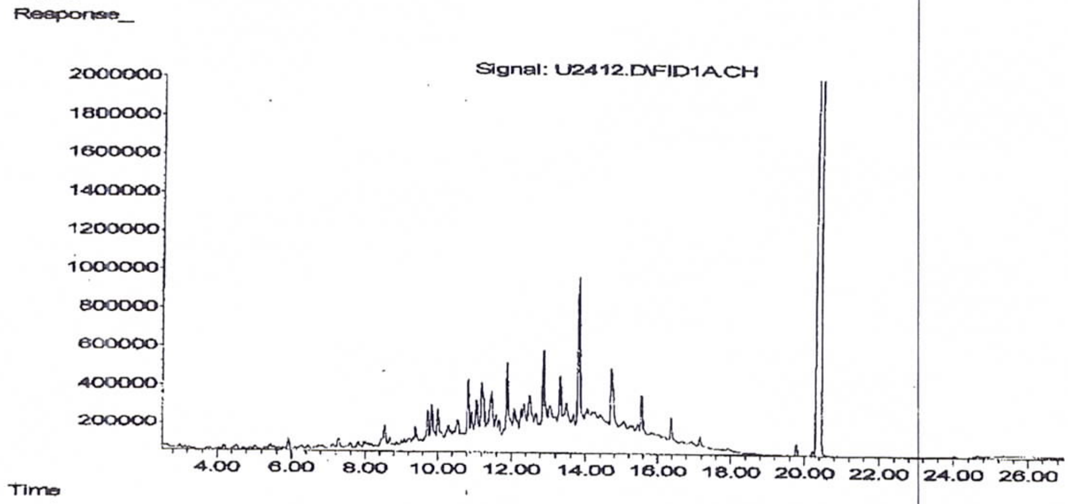
Quantitation Report (QT Reviewed)

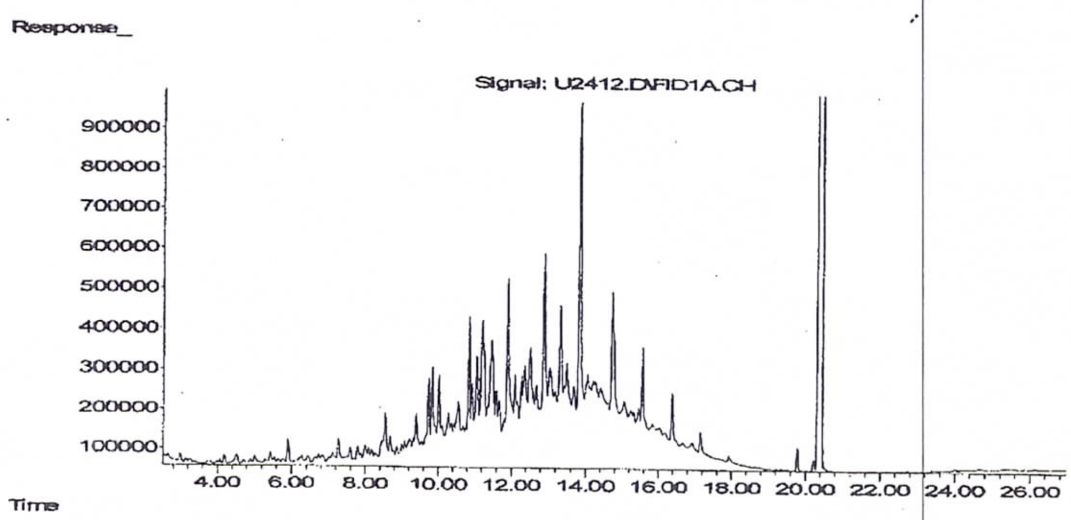
```
Data File : C:\MSDCHEM\1\DATA\04-20-07\U5232.D          Vial: 3
Acq On    : 20 Apr 2007  10:49                       Operator: MJ
Sample    : DRO/GRO_IAS_2814,1000_PPM                Inst    : GC_U
Misc      : NA,NA,NA,1                               Multiplr: 1.00
IntFile   : autoint1.e
Quant Time: Apr 20 11:17:05 2007  Quant Results File: UGRO0416.RES

Quant Method  : C:\MSDCHEM\1\METHODS\UGRO0416.M (Chemstation Integrator)
Title         :
Last Update   : Tue Apr 17 10:28:47 2007
Response via  : Initial Calibration
DataAcq Meth  : UGRO0416.M

Volume Inj.   :
Signal Phase  :
Signal Info   :

    Compound                       R.T.      Response    Conc Units
-------------------------------------------------------------------------

  System Monitoring Compounds
 1) S   SURROGATE                 20.27f     33690317    95.006 ng
Spiked Amount   100.000                  Recovery    =   95.01%

  Target Compounds
 2) H   GRO                        4.15     267677974 1032.593 ng
 3) H   DRO                       13.28     917792592 1106.999 ng
```

#2 Fuel oil



#2 FUEL OIL STANDARD





Phone # (973) 361-4252
Fax # (973) 989-5288

INTEGRATED ANALYTICAL LABORATORIES
CHAIN OF CUSTODY

273 Franklin Rd
Randolph, NJ 07869

CUSTOMER	REPORTING INFO
Company: URS CORPORATION	REPORT TO: MIKE AKERBERGS
Address: 201 WILLOWBROOK BLVD	Address:
WAYNE, NJ 07474	michael_akerbergs@
Telephone #: 973-785-0700	Attn: urscorp.com
Fax #: 973-785-0023	FAX #
Project Manager: MIKE AKERBERGS	INVOICE TO:
Sampler: TT/IM/HBS/AL	Address:
Project Name: KEYSPAN HEMPSTEAD	
Project Location (State): NY	
Bottle Order #:	Attn:
Quote #:	PO #

Turnaround Time (starts the following day if samples rec'd at lab > 5PM)

Lab notification is required for RUSH TAT prior to sample arrival. RUSH TAT IS NOT GUARANTEED WITHOUT LAB APPROVAL. RUSH SURCHARGES WILL APPLY IF ABLE TO ACCOMMODATE**

Conditional TPHC				Results needed by:	Rush TAT Charge **	Report Format	DISKETTE
24 hr*	48 hr	72 hr	NA		24 hr - 100%...	Results Only	SRP. dbf format
Verbal/Fax		2 wk/Std			48 hr - 75%....	Reduced	SRP.wk1 format
24 hr*	48 hr*	72 hr*	1 wk*		72 hr - 50%....	Regulatory	lab approved custom EDD
Hard Copy		3 wk/Std			96 hr - 35%....	Other (describe)	NO DISK/CD REQ'D
2 wk* call for price					5 day - 25%....	CAT. A	EMAIL
					6-9 day 10%		

Cooler Temp 3 °C

SAMPLE INFORMATION

Sample Matrix
DW - Drinking Water AQ - Aqueous WW - Waste Water
OI - Oil LIQ - Liquid (Specify) OT - Other (Specify)
S - Soil SL - Sludge SOL - Solid W - Wipe

ANALYTICAL PARAMETERS / # BOTTLES & PRESERVATIVES

Client ID	Depth	Sampling Date	Sampling Time	Matrix	# container	IAL #	BTEX	PAH	GC Fingerprint	HCl	NaOH	HNO3	H2SO4	MeOH	Other	None	Encore
HIMW-02I		4-16-07	1110	AQ	4	1	X	X		2						2	
HIMW-02D		4-16-07	1210	AQ	4	2	X	X		2						2	
HIMW-11I		4-16-07	1430	AQ	4	3	X	X		2						2	
HIMW-11D		4-16-07	1438	AQ	4	4	X	X		2						2	
TB-041607		4-16-07	—	AQ	2	5	X			2							
HIMW-08S		4-17-07	1005	AQ	2	6		X								2	
HIMW-02S		4-17-07	1200	AQ	4	7	X	X		2						2	
HIMW-11S		4-17-07	1230	AQ	1	8			X							1	

Known Hazard: Yes or No Describe:

Conc. Expected: Low Med High

Please print legibly and fill out completely. Samples cannot be processed and the turnaround time will not start until any ambiguities have been resolved.

MDL Req: Old GWQS - 11/05 GWQS - SCC - OTHER (SEE COMMENTS)

	Signature/Company	Date	Time		Signature/Company
Relinquished by:	Tammy Tralucco	4/17/07	1445	Received by:	Ray Mayo
Relinquished by:	Ray Mayo	4/17/07	1700	Received by:	[illegible]
Relinquished by:				Received by:	
Relinquished by:				Received by:	
Relinquished by:				Received by:	

Comments:

Lab Case # 3228

PAGE: 1 of 1

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0094

05/2006

APPENDIX C

ALTERNATIVE COST ANALYSES

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	2-May-07
Description:	**ALTERNATIVE 1**	Updated and	Checked By: WS/AM	Date:	15-Nov-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(CONSTRUCTION) SUBTOTAL 1	**$0**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$0**
(CONSTRUCTION) SUBTOTAL 2	**$0**
Contingency (30% of Subtotal 2)	**$0**
TOTAL CONSTRUCTION COSTS	**$0**
Engineering Design (5% of Total Construction Costs)	**$0**
Total Capital Costs	**$0**
Present Worth Annual O&M - 30 Years	**$460,000**
TOTAL COST	**$460,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	2-May-07
Title:	ALTERNATIVE 1	Updated and	Checked by: WS/AMM	Date:	15-Nov-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Annual O & M - 30 Years				
1	Monitoring well sampling labor (19 wells @ 1 event /year)	80	MH	$75	$6,000
2	Sample analysis - annual	19	Each	$700	$13,300
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
	SUBTOTAL 1	**Annual**			**$22,100**
	Note: Total Cost rounded up to the nearest $1,000.				
	SUBTOTAL 2	**Annual**			**$23,000**
	Contingency @ 30%	**Annual**			**$6,900**
	SUBTOTAL 3	**Annual**			**$29,900**
	Present Worth of Subtotal 3 (30-year @ 5% discount rate)	mult. by	15.37		**$460,000**
	TOTAL COST				**$460,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Description:	**ALTERNATE 2 - EXCAVATION**	Updated and	Checked By: WO/AM	Date:	15-Nov-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(1) Mobilization and Demobilization	**$302,000**
(2) Excavation and Backfill	**$43,391,000**
(4) Bioremediation	**$1,334,000**
(CONSTRUCTION) SUBTOTAL 1	**$45,027,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$2,252,000**
(CONSTRUCTION) SUBTOTAL 2	**$47,279,000**
Contingency (30% of Subtotal 2)	**$14,184,000**
TOTAL CONSTRUCTION COSTS	**$61,463,000**
Engineering Design (5% of Total Construction Costs)	**$3,074,000**
Total Capital Costs	**$64,537,000**
Present Worth Annual O&M - 10 Years	**$231,000**
TOTAL COST	**$64,768,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**ALTERNATE 2 - EXCAVATION**	Updated and	Checked By: WO/AM	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Mobilization and Demobilization				
1	Submittals:				
1a	Health and Safety Plan - Allowance	1	LS	$5,000	$5,000
1b	Shop Drawings -Allowance	1	LS	$5,000	$5,000
1c	Schedules - Allowance	1	LS	$3,000	$3,000
1d	Record Drawings - Allowance	1	LS	$6,000	$6,000
2	Survey	4	Day	$1,400	$5,600
3	Temporary Security Fence	800	LF	$25	$20,000
4	Permits and Easements - Allowance	1	LS	$2,500	$2,500
5	Equipment Mobilization - Allowance	1	LS	$100,000	$100,000
6	Temporary Offices	27	Month	$1,000	$27,000
7	Site restoration - Allowance	1	LS	$25,000	$25,000
8	Equipment Demobilization - Allowance	1	LS	$50,000	$50,000
	SUBTOTAL				**$249,100**
	Location cost adjustment	**1.21**			**$302,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$302,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**ALTERNATE 2 - EXCAVATION**	Checked By:	RW	Date:	1-May-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(2) Excavation and Backfill				
1	Abandon, relocate, and decommission utilities - Allowance	1	LS	$25,000	$25,000
2	Demolition and disposal of misc. structures - Allowance	1	LS	$10,000	$10,000
3	Excavate and dispose MGP Remnant Structures (concrete)	1,500	CY	$125	$187,500
4	Sheet Pile, AZ-18 @ 20 feet x 120 LF	2,400	SF	$22	$52,800
5	Heavy shoring with bracing from 0 to 34 feet	72,000	SF	$42	$3,024,000
6	Sprung Structure				
6a	Delivery	1	LS	$6,700	$6,700
6b	Lease (see note below on purchase price)	24	Month	$36,500	$876,000
6c	Sprung consultant	1	LS	$8,700	$8,700
6d	Set-up and Break-down	1	LS	$110,000	$110,000
6e	Replacement membrane	1	LS	$14,400	$14,400
7	Sprung Structure Air Scrubbing (6 units) (see note below on purchase)				
7a	Mob/Demob	1	LS	$115,000	$115,000
7b	Installation Specialist	5	Day	$5,000	$25,000
7c	Monthly rental	24	Month	$33,000	$792,000
7d	Carbon changeout/disposal	4	Ea Pair	$177,000	$708,000
8	Protect Gas Line - Timber Cribbing - Allowance	1	LS	$25,000	$25,000
9	On-site excavation to 34 feet and load onto trucks	171,000	CY	$25	$4,275,000
10	Off-site transportation and disposal	256,500	Ton	$80	$20,520,000
11	Backfill/compact 30 to 34 feet with imported stone	25,000	CY	$25	$625,000
12	Backfill/compact 0 to 30 feet with imported soil	146,000	CY	$15	$2,190,000
13	Pavement repair	2,700	SY	$26	$70,200
14	Groundwater treatment plant (24 months)	1	LS	$1,000,000	$1,000,000
15	O&M groundwater tretament plant (24 months)	2	Year	$600,000	$1,200,000
	SUBTOTAL				**$35,860,300**
	Location cost adjustment	**1.21**			**$43,391,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	Note: Sprung structure purchase price is approx. $850,000				
	Note: 24-month rental +/- will equal air scubbers (2) purchase price $1,800,000.00				
	TOTAL COST				**$43,391,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client: Keyspan	Project Number: 11175065		
Project: Hempstead Intersection Street Former MGP	Calculated By: RJP	Date: 1-May-07	
Title: **ALTERNATE 2 - EXCAVATION**	Checked By: AM	Date: 15-Nov-07	

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3) Annual O & M - 10 Years				
1	Monitoring well sampling - Labor:	80	MH	$75	$6,000
2	Sample analysis - annual	19	Each	$700	$13,300
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
	SUBTOTAL 1	**Annual**			**$22,100**
	Note: Total Cost rounded up to the nearest $1,000.				**$23,000**
	SUBTOTAL 2	**Annual**			**$23,000**
	Contingency @ 30%	**Annual**			**$6,900**
	SUBTOTAL 3	**Annual**			**$29,900**
	Present Worth of Subtotal 3 (10-year @ 5% discount rate)	mult. by	7.72		**$231,000**
	TOTAL COST				**$231,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065
Project:	Hempstead Intersection Street Former MGP	Calculated By:	BBV
Title:	**ALTERNATE 2 - EXCAVATION**	Checked By:	AMM

Date: 19-Jul-07
Date: 1-Aug-07

ITEM	DESCRIPTION	Aerobic	Total Cost	Anaerobic	Total Cost	Anaerobic	Total Cost
	(4) Bioremediation 10 Years						
1	Bench Scale Testing	1 event	$40,000	1 event	$40,000	1 event	$40,000
2	Injection Well Installation	40 wells	$100,000	40 wells	$100,000	40 wells	$100,000
	10-yr w/ 5 gpm assumed gravity feed flow rate						
3	see notes next page	36 events @	$1,152,000	36 events @	$691,200	36 events @	$380,160
		$32,000/event		$19,200/event		$10,560/evnet	
4	Addt'l material cost per event (3L) for yrs 1&2			12 events@$18K/event	$216,000	12 events@$18K/event	$216,000
5	Labor: 2 people, 1hr/well, 10-hr day	$7000/event*36	$252,000	$7000/event*48	$336,000	$7000/event*48	$336,000
	SUBTOTAL 1		**$1,544,000**		**$1,383,200**		**$1,072,160**
	Average of aerobic and anaerobic costs					$1,333,120	
	AVERAGE TOTAL COST					**$1,334,000**	

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Description:	**Alternative 3 ISCO**	Updated and	Checked By: WO/AM	Date:	15-Nov-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(1) Mobilization and Demobilization	$198,000
(2) Excavation and Backfill	$6,696,000
(3) In-Situ Chemical Oxidation	$7,500,000
(4) Bioremediation	$1,334,000
SUBTOTAL 1	$15,728,000

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	$787,000
SUBTOTAL 2	$16,515,000
Contingency (30% of Subtotal 2)	$4,955,000
SUBTOTAL 3	$21,470,000
Engineering Design (5% of Subtotal 3)	$1,074,000
Total Capital Costs	$22,544,000
Present Worth Annual O&M - 10 Years	$3,925,000
TOTAL COST	$26,469,000

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client: Keyspan	Project Number: 11175065		
Project: Hempstead Intersection Street Former MGP	Calculated By: RJP	Date: 1-May-07	
Title: **Alternative 3 ISCO**	Updated and Checked By: WO/AM	Date: 1-Aug-07	

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Mobilization and Demobilization				
1	Submittals:				
1a	Health and Safety Plan - Allowance	1	LS	$5,000	$5,000
1b	Shop Drawings -Allowance	1	LS	$5,000	$5,000
1c	Schedules - Allowance	1	LS	$3,000	$3,000
1d	Record Drawings - Allowance	1	LS	$6,000	$6,000
2	Survey	10	Day	$1,400	$14,000
3	Temporary Security Fence	800	LF	$25	$20,000
4	Permits and Easements - Allowance	1	LS	$2,500	$2,500
5	Equipment Mobilization - Allowance	1	LS	$50,000	$50,000
6	Temporary Offices	8	Month	$1,000	$8,000
7	Site restoration - Allowance	1	LS	$25,000	$25,000
8	Equipment Demobilization - Allowance	1	LS	$25,000	$25,000
	SUBTOTAL				**$163,500**
	Location cost adjustment	**1.21**			**$198,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$198,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client: Keyspan	Project Number: 11175065		
Project: Hempstead Intersection Street Former MGP	Calculated By: RJP	Date: 1-May-07	
Title: **Alternative ISCO**	Checked By: RW	Date: 1-May-07	

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(2) Excavation and Backfill 0 - 8 ft Remaining Source Material				
1	Abandon, relocate, and decommission utilities - Allowance	1	LS	$75,000	$75,000
2	Demolition and disposal of misc structures - Allowance	1	LS	$10,000	$10,000
3	Excavate and dispose MGP Remnant Structures (concrete)	1,500	CY	$125	$187,500
4	Sheet Pile, AZ-18 @ 20 feet x 540 LF	10,800	SF	$22	$237,600
5	Sprung Structure				
5a	Delivery	1	LS	$6,700	$6,700
5b	Lease (see note below on purchase price)	3	Month	$36,500	$109,500
5c	Sprung consultant	1	LS	$8,700	$8,700
5d	Set-up and Break-down	1	LS	$110,000	$110,000
5e	Replacement membrane	1	LS	$14,400	$14,400
6	Sprung StructureAir Scrubbing				
6a	Mob/Demob	1	LS	$58,000	$58,000
6b	Installation Speialist	5	Day	$1,000	$5,000
6c	Monthly Rental	3	Month	$11,000	$33,000
6d	Carbon Changeout/Disposal	1	Pair	$59,500	$59,500
7	Protect Gas Line - Timber Cribbing - Allowance	1	LS	$100,000	$100,000
8	On-site excavation to 8 feet and load onto trucks	29,000	CY	$20	$580,000
9	Off-site transportation and disposal	43,500	Ton	$80	$3,480,000
10	Backfill/compact excavation with imported soil	29,000	CY	$15	$435,000
11	Pavement repair	900	SY	$26	$23,400
	SUBTOTAL				**$5,533,300**
	Location cost adjustment	**1.21**			**$6,696,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	Note: Sprung structure purchase price is approx. $850,000				
	TOTAL COST				**$6,696,000**

PCE site
Multiply by 2 for MGP site
ISOTEC as high

PER EVENT

			(20 points with 2 screens/well)	
			per 10 injection wells	**does not include well installation**
$ 117,000.00	10 wells	2 - 15' inj screens	4 days per injection event	Drilling alone (per well based upon 64 total - Vironex)
$ 234,000.00	10 wells		+ 2 days mob/demob per event	at $35 per foot -> round to $40 per foot

PER EVENT

drilling using direct push rig (all injection wells to 34 ft bgs - conservative)

$1,170,000	50 wells	2 - 15' inj screens	20 days + 2 mob/demob	3,400 feet	$ 136,000.00	50 wells * 2 inj screens/wells * TD @ 34 ft @ $40/ft
$2,340,000	100 wells	2 - 15' inj screens	40 days + 2 mob/demob	6,800 feet	$ 272,000.00	100 wells * 2 inj screens/ wells * TD @ 34 ft @ $40/ft
$3,369,600	144 wells	2 - 15' inj screens	58 days + 2 mob/demob	9,792 feet	$ 391,680.00	144 wells * 2 inj screens/wells * TD @ 34 ft @ $40/ft
$4,071,600	174 wells	2 - 15' inj screens	70 days + 2 mob/demob (high)	11,832 feet	$ 473,280.00	174 wells * 2 inj screens/wells * TD @ 34 ft @ $40/ft
		348 inj screens	10 per day => 35 days per event			
			=> 37 w/mobdemob			

Drilling + 3 events		**material cost contingency of 10%**
$ 3,646,000	50 wells	$4,010,600
$ 7,292,000	**100 wells**	$8,021,200
$ 10,500,480	144 wells	$11,550,528
$ 12,688,080	174 wells	$13,956,888

111	days	
22	weeks	5 days per week
6	months	4 weeks per month

360
210
75600
302400

4.4 acres

PER EVENT - does not include well installation					3 INJECTION EVENTS		4 INJECTION EVENTS		3 modified Fenton's + 1 KMnO4
Alternative	Number of injection wells	Estimated number of days	mod Fenton's est cost (ISOTEC)	KMnO4 est cost* (Vironex)	mod Fenton's est cost (ISOTEC)	KMnO4 est cost* (Vironex)	mod Fenton's est cost (ISOTEC)	KMnO4 est cost* (Vironex)	combination
3A									
	50	22	$585,000	$382,000	$1,755,000	$1,146,000	$2,340,000	$1,528,000	$2,137,000
	60	26	$702,000	$459,000	$2,106,000	$1,377,000	$2,808,000	$1,836,000	$2,565,000
3B									
in addition	70	28	$819,000	$535,000	$2,457,000	$1,605,000	$3,276,000	$2,140,000	$2,992,000
in addition	80	32	$939,000	$612,000	$2,817,000	$1,836,000	$3,756,000	$2,448,000	$3,429,000
4									
	30	14	$351,000	$229,000	$1,053,000	$687,000	$1,404,000	$916,000	$1,282,000
	40	18	$468,000	$306,000	$1,404,000	$918,000	$1,872,000	$1,224,000	$1,710,000

other costs provided

Drilling alone (per well based upon 64 total - Vironex)
at $35 per f $ 3,500 per well

* includes cost of KMnO4 at ~$1.80 per pound, approximately 2,000 pounds KMnO4 per location

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	BBV	Date:	8-May-07
Title:	**Alternative 3 ISCO**	Checked By:	AMM	Date:	8-May-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3) In-Situ Chemical Oxidation				
1	Drilling and 3 injection events	1	LS	$7,300,000	$7,300,000
2	Bench- and pilot-scale testing	1	LS	$200,000	$200,000
	TOTAL COST				**$7,500,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client: Keyspan | Project Number: 11175065
Project: Hempstead Intersection Street Former MGP | Calculated By: BBV | Date: 19-Jul-07
Title: ALTERNATIVE 3 - ISCO | Checked By: AMM | Date: 1-Aug-07

ITEM	DESCRIPTION	Aerobic	Total Cost	Anaerobic	Total Cost	Anaerobic	Total Cost
	(4) Bioremediation 10 Years						
1	Bench Scale Testing	1 event	$40,000	1 event	$40,000	1 event	$40,000
2	Injection Well Installation	40 wells	$100,000	40 wells	$100,000	40 wells	$100,000
	10-yr w/ 5 gpm assumed gravity feed flow rate						
3	see notes next page	36 events @	$1,152,000	36 events @	$691,200	36 events @	$380,160
		$32,000/event		$19,200/event		$10,560/evnet	
4	Addt'l material cost per event (3L) for yrs 1&2			12 events@$18K/eve	$216,000	12 events@$18K/event	$216,000
5	Labor: 2 people, 1hr/well, 10-hr day	$7000/event*36	$252,000	$7000/event*48	$336,000	$7000/event*48	$336,000
	SUBTOTAL 1		**$1,544,000**		**$1,383,200**		**$1,072,160**
	Average of aerobic and anaerobic costs					$1,333,120	
	AVERAGE TOTAL COST					**$1,334,000**	

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	2-May-07
Title:	**Alternative 3 ISCO**	Updated and	Checked By:WO/AM	Date:	15-Nov-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(5) Annual O & M - 10 Years				
1	Monitoring well sampling - Labor:	80	MH	$75	$6,000
2	Sample analysis - annual	19	Each	$700	$13,300
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
5	NAPL Collection and Disposal (per year) (36 wells)				
5a	Client representative on-site (48 hr. per month)*	1152	Hr	$75	$87,000
5b	Subcontractor - pump/containerize NAPL	1152	Hr	$75	$87,000
5c	- 20 gallon DOT shipping container	288	container	$78	$23,000
5d	- Service truck w/ small electrical generator	1152	Hr	$35	$41,000
5e	- Transport and Disposal**	288	continer	$335	$97,000
5f	Miscellaneous	24	events	$150	$4,000
5g	Monthly Report	24	Each	$1,200	$29,000
	* Sr. Field Technician (local) Rate of ~ $30/hr. x 2.5 multiplier				
	** RS Means 2005 cost of $795/55 gallon drum adjusted to				
	2007(+15%) and 20 gallon size container.				
	SUBTOTAL 1	**Annual**			**$390,100**
	SUBTOTAL 2	**Annual**			**$391,000**
	Contingency @ 30%	**Annual**			**$117,300**
	SUBTOTAL 3	**Annual**			**$508,300**
	Present Worth of Subtotal 3 (10-year @ 5% discount rate)	mult. by	7.72		**$3,925,000**
	TOTAL COST				**$3,925,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Description:	ALTERNATE 4 - SOLIDIFICATIAON	Updated and	Checked By: AM/TP	Date:	15-Nov-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(1) Mobilization and Demobilization	**$495,000**
(2) Excavation and Backfill	**$7,936,000**
(3) Solidification	**$16,360,000**
(4) Bioremediation	**$1,334,000**
(CONSTRUCTION) SUBTOTAL 1	**$26,125,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$1,307,000**
(CONSTRUCTION) SUBTOTAL 2	**$27,432,000**
Contingency (30% of Subtotal 2)	**$8,230,000**
TOTAL CONSTRUCTION COSTS	**$35,662,000**
Engineering Design (5% of Total Construction Costs)	**$1,784,000**
Total Capital Costs	**$37,446,000**
Present Worth Annual O&M - 10 Years	**$231,000**
TOTAL COST	**$37,677,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**ALTERNATE 4 - SOLIDIFICATION**	Updated and	Checked By: WO/AM	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Mobilization and Demobilization				
1	Submittals:				
1a	Health and Safety Plan - Allowance	1	LS	$5,000	$5,000
1b	Shop Drawings -Allowance	1	LS	$5,000	$5,000
1c	Schedules - Allowance	1	LS	$3,000	$3,000
1d	Record Drawings - Allowance	1	LS	$6,000	$6,000
2	Survey - Allowance	10	Day	$1,400	$14,000
3	Temporary Security Fence	840	LF	$25	$21,000
4	Permits and Easements - Allowance	1	LS	$10,000	$10,000
5	Equipment Mobilization - Allowance	1	LS	$250,000	$250,000
6	Temporary Offices	20	Month	$1,000	$20,000
7	Site restoration - Allowance	1	LS	$25,000	$25,000
8	Equipment Demobilization - Allowance	1	LS	$50,000	$50,000
	SUBTOTAL				**$409,000**
	Location cost adjustment	**1.21**			**$495,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$495,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**ALTERNATE 4 - SOLIDIFICATION**	Checked/Updated By:	RW/TP	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(2) Excavation and Backfill				
1	Abandon, relocate, and decommission utilities - Allowance	1	LS	$75,000	$75,000
2	Demolition and disposal of misc structures - Allowance	1	LS	$10,000	$10,000
3	Excavate and dispose MGP Remnant Structures (concrete)	1,500	CY	$125	$187,500
4	Sheet Pile, AZ-18 @ 20 feet x 540 LF	10,800	SF	$22	$237,600
5	Sprung Structure				
5a	Delivery	1	LS	$6,700	$6,700
5b	Lease (see note below on purchase price)	5	Month	$36,500	$182,500
5c	Sprung consultant	1	LS	$8,700	$8,700
5d	Set-up and Break-down	1	LS	$110,000	$110,000
5e	Replacement membrane	1	LS	$14,400	$14,400
6	Sprung Structure Air Scrubbing (2 units) (see note below on purchase)				
6a	Mob/Demob	1	LS	$58,000	$58,000
6b	Installation Specialist	5	Day	$1,000	$5,000
6c	Monthly rental	5	Month	$11,000	$55,000
6d	Carbon changeout/disposal	1	Pair	$59,500	$59,500
7	Protect Gas Line - Timber Cribbing - Allowance	1	LS	$100,000	$100,000
8	On-site excavation to 8 feet and load onto trucks	29,000	CY	$20	$580,000
9	Off-site transportation and disposal	58,500	Ton	$80	$4,680,000
10	Backfill/compact excavation with imported soil	11,000	CY	$15	$165,000
11	Pavement repair	900	SY	$26	$23,400
	SUBTOTAL				**$6,558,300**
	Location cost adjustment	**1.21**			**$7,936,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	Note: Sprung structure purchase price is approx. $850,000				
	Note: Air scrubber pair to purchase is $327,000				
	TOTAL COST				**$7,936,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	TP	Date:	1-Aug-07
Title:	**ALTERNATE 4 - SOLIDIFICATION**	Checked By:	MO	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3) Solidification				
1	Bench scale pre-construction testing	1	LS	$30,000	$30,000
2	In-situ Solidification	142,000	CY	$95	$13,490,000
	SUBTOTAL				**$13,520,000**
	Location cost adjustment	**1.21**			**$16,360,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	ISS mixing @ $25/cy				
	Reagent addition $4 to $5%cy				
	at 10% ration $40 to $50/cy				
	at 20% ratio $80 - $100/cy				
	Range $65 - $125/cy				
	assume 15% mix at $4.50 equals $92.50/cy				
	use $95/cy				
	Assume no Sprung Structure enclosure.				
	TOTAL COST				**$16,360,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065	
Project:	Hempstead Intersection Street Former MGP	Calculated By:	BBV	Date: 19-Jul-07
Title:	ALTERNATE 4 - SOLIDIFICATION	Checked By:	AMM	Date: 20-Jul-07

ITEM	DESCRIPTION	Aerobic	Total Cost	Anaerobic	Total Cost	Anaerobic	Total Cost
	(4) Bioremediation 10 Years						
1	Bench Scale Testing	1 event	$40,000	1 event	$40,000	1 event	$40,000
2	Injection Well Installation	40 wells	$100,000	40 wells	$100,000	40 wells	$100,000
	10-yr w/ 5 gpm assumed gravity feed flow rate						
3	see notes next page	36 events @	$1,152,000	36 events @	$691,200	36 events @	$380,160
		$32,000/event		$19,200/event		$10,560/evnet	
4	Addt'l material cost per event (3L) for yrs 1&2			12 events@$18K/event	$216,000	12 events@$18K/event	$216,000
5	Labor: 2 people, 1hr/well, 10-hr day	$7000/event*36	$252,000	$7000/event*48	$336,000	$7000/event*48	$336,000
	SUBTOTAL 1		**$1,544,000**		**$1,383,200**		**$1,072,160**
	Average of aerobic and anaerobic costs					$1,333,120	
	AVERAGE TOTAL COST					**$1,334,000**	
	TOTAL COST						

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	2-May-07
Title:	**ALTERNATE 4 - SOLIDIFICATION**	Updated and	Checked By: WO/AM	Date:	15-Nov-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(4) Annual O & M - 10 Years				
1	Monitoring well sampling - Labor:	80	MH	$75	$6,000
2	Sample analysis - annual	19	Each	$700	$13,300
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
	SUBTOTAL 1	**Annual**			**$22,100**
	Note: Total Cost rounded up to the nearest $1,000.				**$23,000**
	SUBTOTAL 2	**Annual**			**$23,000**
	Contingency @ 30%	**Annual**			**$6,900**
	SUBTOTAL 3	**Annual**			**$29,900**
	Present Worth of Subtotal 3 (10-year @ 5% discount rate)	mult. by	7.72		**$231,000**
	TOTAL COST				**$231,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RW/BBV	Date:	9-May-07
Description:	**ALTERNATE 5 - Containment and Gate**	Checked By:	AMM	Date:	15-Nov-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(1) Mobilization and Demobilization	**$168,000**
(2) Excavation and Backfill	**$6,811,000**
(3) Containment	**$13,096,000**
(4) Ozone Injection with SVE (Gate)	**$500,000**
(CONSTRUCTION) SUBTOTAL 1	**$20,575,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$1,029,000**
(CONSTRUCTION) SUBTOTAL 2	**$21,604,000**
Contingency (30% of Subtotal 2)	**$6,482,000**
TOTAL CONSTRUCTION COSTS	**$28,086,000**
Engineering Design (5% of Total Construction Costs)	**$1,405,000**
Total Capital Costs	**$29,491,000**
Present Worth Annual O&M - 30 Years	**$15,805,000**
TOTAL COST	**$45,296,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RW	Date:	2-May-07
Title:	**ALTERNATE 5 - Containment and Gate**	Checked By:	AMM	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Mobilization and Demobilization				
1	Submittals:				
1a	Health and Safety Plan - Allowance	1	LS	$5,000	$5,000
1b	Shop Drawings -Allowance	1	LS	$5,000	$5,000
1c	Schedules - Allowance	1	LS	$3,000	$3,000
1d	Record Drawings - Allowance	1	LS	$6,000	$6,000
2	Survey	5	Day	$1,400	$7,000
3	Temporary Security Fence	200	LF	$25	$5,000
4	Permits and Easements - Allowance	1	LS	$2,500	$2,500
5	Equipment Mobilization - Allowance	1	LS	$50,000	$50,000
6	Temporary Offices	5	Month	$1,000	$5,000
7	Site restoration - Allowance	1	LS	$25,000	$25,000
8	Equipment Demobilization - Allowance	1	LS	$25,000	$25,000
	SUBTOTAL				**$138,500**
	Location cost adjustment	**1.21**			**$168,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$168,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RW	Date:	2-May-07
Title:	**ALTERNATE 5 - Containment and Gate**	Checked By:	AMM	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(2) Excavation and Backfill				
1	Abandon, relocate, and decommission utilities - Allowance	1	LS	$75,000	$75,000
2	Demolition and disposal of misc structures - Allowance	1	LS	$10,000	$10,000
3	Excavate and dispose MGP Remnant Structures (concrete)	1,500	CY	$125	$187,500
4	Sheet Pile, AZ-18 @ 20 feet x 540 LF	10,800	SF	$22	$237,600
5	Sprung Structure				
5a	Delivery	1	LS	$6,700	$6,700
5b	Lease (see note below on purchase price)	5	Month	$36,500	$182,500
5c	Sprung consultant	1	LS	$8,700	$8,700
5d	Set-up and Break-down	1	LS	$110,000	$110,000
5e	Replacement membrane	1	LS	$14,400	$14,400
6	Sprung Structure Air Scrubbing (2 units) (see note below on purchase)				
6a	Mob/Demob	1	LS	$58,000	$58,000
6b	Installation Specialist	5	Day	$1,000	$5,000
6c	Monthly rental	5	Month	$11,000	$55,000
6d	Carbon changeout/disposal	1	Pair	$59,500	$59,500
7	Protect Gas Line - Timber Cribbing - Allowance	1	LS	$100,000	$100,000
8	On-site excavation to 8 feet and load onto trucks	29,000	CY	$20	$580,000
9	Off-site transportation and disposal	43,500	Ton	$80	$3,480,000
10	Backfill/compact excavation with imported soil	29,000	CY	$15	$435,000
11	Pavement repair	900	SY	$26	$23,400
	SUBTOTAL				**$5,628,300**
	Location cost adjustment	**1.21**			**$6,811,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	Note: Sprung structure purchase price is approx. $850,000				
	Note: Air scrubber pair to purchase is $327,000				
	TOTAL COST				**$6,811,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RW	Date:	2-May-07
Title:	**ALTERNATE 5 - Containment and Gate**	Checked By:	AMM	Date:	9-May-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3) Containment				
1	Grout Curtain @ 130 feet deep	240,500	SF	$45	$10,822,500
	SUBTOTAL				**$10,822,500**
	Location cost adjustment	**1.21**			**$13,096,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$13,096,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	BBV	Date:	19-Jul-07
Title:	ALTERNATE 5 - CONTAINMENT AND GATE	Checked By:	AMM	Date:	20-Jul-07

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST
	(4) Ozone Injection with SVE				
1	Installation of 3 rows of injection wells on 8-10 ft centers screens 2-3 ft length along approx. 70 ft length	1	LS	$500,000	$500,000
	SUBTOTAL 1				**$500,000**
	Average of aerobic and anaerobic costs				
	AVERAGE TOTAL COST				**$500,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RW/BV	Date:	9-May-07
Title:	**ALTERNATE 5 - Containment and Gate**	Checked By:	AM	Date:	15-Nov-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(6) Annual O & M - 30 Years				
1	Monitoring well sampling - Labor:	80	MH	$75	$6,000
2	Sample analysis - annual	19	Each	$700	$13,300
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
5	NAPL Collection and Disposal (per year) (10 wells)				
5a	Client representative on-site (48 hr. per month)*	1152	Hr	$75	$87,000
5b	Subcontractor - pump/containerize NAPL	1152	Hr	$75	$87,000
5c	- 20 gallon DOT shipping container	288	container	$78	$23,000
5d	- Service truck w/ small electrical generator	1152	Hr	$35	$41,000
5e	- Transport and Disposal**	288	continer	$335	$97,000
5f	Miscellaneous	24	events	$150	$4,000
5g	Monthly Report	24	Each	$1,200	$29,000
6	Ozone Injection, Monitoring and SVE as Necessary	1	LS	$400,000	$400,000
	* Sr. Field Technician (local) Rate of ~ $30/hr. x 2.5 multiplier				
	** RS Means 2005 cost of $795/55 gallon drum adjusted to				
	2007(+15%) and 20 gallon size container.				
	SUBTOTAL 1	**Annual**			**$790,100**
	Note: Total Cost rounded up to the nearest $1,000.				
	SUBTOTAL 2	**Annual**			**$791,000**
	Contingency @ 30%	**Annual**			**$237,300**
	SUBTOTAL 3	**Annual**			**$1,028,300**
	Present Worth of Subtotal 3 (30-year @ 5% discount rate)	mult. by	15.37		**$15,805,000**
	TOTAL COST				**$15,805,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	WMS	Date:	31-Jul-07
Description:	IRM	Checked By:	MO	Date:	31-Jul-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
(1) Mobilization and Demobilization	**$103,000**
(2) Excavation and Backfill	**$2,995,000**
(3) NAPL Recovery Well Installation	**$713,000** *
(4) NAPL Collection and Disposal	**$368,000** **
*If pumps for all 24 wells are purchased. $414,000 if not purchased	
**If pumps for all 24 wells are purchased. $580,000 if not purchased	
(CONSTRUCTION) SUBTOTAL 1	**$4,179,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$209,000**
(CONSTRUCTION) SUBTOTAL 2	**$4,388,000**
Contingency (30% of Subtotal 2)	**$1,317,000**
TOTAL CONSTRUCTION COSTS	**$5,705,000**
Engineering Design (10% of Total Construction Costs)	**$571,000**
TOTAL COST	**$6,276,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	WMS	Date:	30-Jul-07
Title:	**IRM**	Checked By:	MO	Date:	31-Jul-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(1) Mobilization and Demobilization				
1	Submittals:				
1a	Health and Safety Plan - Allowance	1	LS	$5,000	$5,000
1b	Shop Drawings -Allowance	1	LS	$5,000	$5,000
1c	Schedules - Allowance	1	LS	$3,000	$3,000
1d	Record Drawings - Allowance	1	LS	$6,000	$6,000
2	Survey	4	Day	$1,400	$6,000
3	Temporary Security Fence	900	LF	$25	$22,500
4	Permits and Easements - Allowance	1	LS	$2,500	$3,000
5	Equipment Mobilization - allowance	1	LS	$15,000	$15,000
6	Temporary Offices for 4 months	4	Month	$1,000	$4,000
7	Site restoration (Hydroseeding)	1	LS	$5,000	$5,000
8	Equipment Demobilization - Allowance	1	LS	$10,000	$10,000
	SUBTOTAL				**$84,500**
	Location cost adjustment	**1.21**			**$103,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$103,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client: Keyspan	Project Number: 11175065		
Project: Hempstead Intersection Street Former MGP	Calculated By: WMS	Date: 30-Jul-07	
Title: **IRM**	Checked By: MO	Date: 31-Jul-07	

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(2) Excavation and Backfill				
1	Abandon, relocate, and decommission utilities - Allowance	1	LS	$25,000	$25,000
2	Demolition and disposal of structures - Allowance	1	LS	$10,000	$10,000
3	Sheet Pile, AZ-18	11,940	SF	$22	$263,000
4	Shoring from 8 to 24 feet	4,800	SF	$22	$106,000
5	Sprung Structure				
5a	Delivery	1	LS	$6,700	$6,700
5b	Lease (see note below on purchase price)	3	Month	$36,500	$109,500
5c	Sprung consultant	1	LS	$8,700	$8,700
5d	Set-up and Break-down	1	LS	$110,000	$110,000
5e	Replacement membrane	1	LS	$14,400	$14,400
6	Sprung Structure Air Scrubbing (2 units) (see note below on purchase)				
6a	Mob/Demob	1	LS	$58,000	$58,000
6b	Installation Specialist	5	Day	$1,000	$5,000
6c	Monthly rental	3	Month	$11,000	$33,000
6d	Carbon changeout/disposal	1	Ea Pair	$59,500	$59,500
7	Protect Gas Line - Timber Cribbing - Allowance	1	LS	$25,000	$25,000
8	On-site excavation to 24 feet and load onto trucks	10,492	CY	$20	$210,000
9	Off-site transportation and disposal	15,738	Ton	$80	$1,260,000
10	Backfill and compact excavations with imported soil	10,492	CY	$15	$158,000
11	Pavement repair	1	LS	$13,000	$13,000
	SUBTOTAL				**$2,474,800**
	Location cost adjustment	**1.21**			**$2,995,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$2,995,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	WMS	Date:	30-Jul-07
Title:	**IRM**	Checked By:	MO	Date:	31-Jul-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3a) NAPL Recovery Well Installation				
1	Well auger, casing and packing (24 x 6" wells to 40 feet deep)	24	Each	$9,765	$235,000
2	Precast concrete vault including excavation, bedding and backfill	24	Each	$3,090	$75,000
3	Dispose drill cuttings off site	72	Drum	$300	$22,000
4	NAPL pump	24	Each	$10,000	$240,000
5	Pump installation	24	Each	$700	$17,000
	SUBTOTAL				**$589,000**
	Location cost adjustment factor	**1.21**			**$713,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$713,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	WMS	Date:	30-Jul-07
Title:	**IRM**	Checked By:	MO	Date:	31-Jul-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(3b) NAPL Recovery Well Installation				
1	Well auger, casing and packing (24 x 6" wells to 40 feet deep)	24	Each	$9,765	$235,000
2	Precast concrete vault including excavation, bedding and backfill	24	Each	$3,090	$75,000
3	Dispose drill cuttings off site	72	Drum	$300	$22,000
4	NAPL pump	1	Each	$10,000	$10,000
	SUBTOTAL				**$342,000**
	Location cost adjustment factor	**1.21**			**$414,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$414,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client: Keyspan	Project Number: 11175065		
Project: Hempstead Intersection Street Former MGP	Calculated By: WMS		Date: 30-Jul-07
Title: **IRM**	Checked By: MO		Date: 31-Jul-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(4a) NAPL Collection and Disposal				
1	Monthly collection and disposal (24 months)				
2	Allow:				
3	Client representative on-site (48 hr. per month)*	1152	Hr	$75	$87,000
4	Subcontractor - pump/containerize NAPL	1152	Hr	$75	$87,000
5	- 20 gallon DOT shipping container	288	container	$78	$23,000
6	- Service truck w/ small electrical generator	1152	Hr	$35	$41,000
7	- Transport and Disposal**	288	continer	$335	$97,000
8	Miscellaneous	24	events	$150	$4,000
9	Monthly Report	24	Each	$1,200	$29,000
	* Sr. Field Technician (local) Rate of ~ $30/hr. x 2.5 multiplier				
	** RS Means 2005 cost of $795/55 gallon drum adjusted to 2007(+15%) and 20 gallon size container.				
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$368,000**

Keyspan
Hempstead Intersection Street Former MGP
IRM
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	WMS	Date:	30-Jul-07
Title:	**IRM**	Checked By:	MO	Date:	31-Jul-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	(4b) NAPL Collection and Disposal				
1	Monthly collection and disposal (24 months)				
2	Allow:				
3	Client representative on-site (96 hr. per month)*	2304	Hr	$75	$173,000
4	Subcontractor - pump/containerize NAPL	2304	Hr	$75	$173,000
5	- 20 gallon DOT shipping container	288	container	$78	$23,000
6	- Service truck w/ small electrical generator	2304	Hr	$35	$81,000
7	- Transport and Disposal**	288	continer	$335	$97,000
8	Miscellaneous	24	events	$150	$4,000
9	Monthly Report	24	Each	$1,200	$29,000
	* Sr. Field Technician (local) Rate of ~ $30/hr. x 2.5 multiplier				
	** RS Means 2005 cost of $795/55 gallon drum adjusted to 2007(+15%) and 20 gallon size container.				
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$580,000**

Keyspan

Hempstead Intersection Street Former MGP

Feasibility Study

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Description:	**HYDRAULIC CONTAINMENT - 5 gpm**	Checked By:	AM/DM/RW	Date:	1-Aug-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
Groundwater Treatment System	**$330,000**
Groundwater Extraction Well Installation (2 total)	**$67,000**
(CONSTRUCTION) SUBTOTAL 1	**$397,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$20,000**
(CONSTRUCTION) SUBTOTAL 2	**$417,000**
Contingency (30% of Subtotal 2)	**$126,000**
TOTAL CONSTRUCTION COSTS	**$543,000**
Engineering Design (10% of Total Construction Costs)	**$55,000**
Total Capital Costs	**$598,000**
Present Worth Annual O&M - 30 Years	**$9,251,300**
TOTAL COST	**$9,849,300**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**HYDRAULIC CONTAINMENT - 5 gpm**	Checked By:	AM/DM/RW	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	Groundwater Treatment System				
1	Air stripper - horiz. tray, 15 gpm w/ blower an dcontrols	1	Each	$54,000	$54,000
2	Oil water separator 20 gpm	1	Each	$6,600	$6,600
3	Aqueous phase carbon units (2 in series)	1	Each	$14,400	$14,400
4	Bag filter system (100 gpm ca)	4	Each	$1,200	$4,800
5	Chemical feed pump and tanks, etc.	1	LS	$2,000	$2,000
6	Recuperative thermal oxidizer (5,000 scfm)	1	LS	$56,300	$56,300
7	System controls	1	Each	$15,000	$15,000
8	Electrical power drop - 230V - 3 phase (within 50 feet)	1	LS	$20,000	$20,000
9	Electrical installation	1	LS	$15,000	$15,000
10	Natural gas connection (within 50 feet)	1	LS	$15,000	$15,000
11	Sanitary sewer discharge connection (within 600 feet)	1	LS	$38,000	$38,000
12	Installation, including pipe, valves, fittings (Allowance)	1	LS	$8,000	$8,000
13	System start-up	1	LS	$20,000	$20,000
14	Concrete pad - 25 ft x 10 ft x 1 ft	10	CY	$350	$3,500
	SUBTOTAL				**$272,600**
	Location cost adjustment	**1.21**			**$330,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	Ref: ECHOS 2005				
	TOTAL COST				**$330,000**

Keyspan
Hempstead Intersection Street Former MGP
Feasibility Study
Construction Cost Estimate

Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Title:	**HYDRAULIC CONTAINMENT - 5 gpm**	Checked By:	AM/DM/RW	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	GW Extraction Well Installation (2 total)				
1	Sawcut pavement	25	LF	$2	$50
2	Excavation - trench and vault	100	LF	$10	$1,000
3	Extraction well installation (70 ft)	70	VLF	$190	$13,300
4	Precast concrete vault with road cover - 6 x 6 x 6 feet	1	Each	$4,900	$4,900
5	Pipe bedding	100	LF	$2	$200
6	Discharge line - 4-inch HDPE pipe	300	LF	$10	$3,000
7	Pump - 10 HP, 150 gpm, 80-ft head	1	Each	$4,800	$4,800
8	Electrical conduit - 2-inch PVC	100	LF	$20	$2,000
9	Pump - electric and controls (Allowance)	1	LS	$13,000	$13,000
10	Pump - pipe, valves, fittings (Allowance)	1	LS	$3,000	$3,000
11	Pavement restoration	50	SY	$26	$1,300
12	Traffic control (Allowance)	1	Week	$7,000	$7,000
13	Drill cuttings disposal	6	Drum	$300	$1,800
	SUBTOTAL				**$55,350**
	Location cost adjustment factor	**1.21**			**$67,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$67,000**

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Title:	**HYDRAULIC CONTAINMENT - 5 gpm**	Checked By:	DM/AM/RW	Date:	1-Aug-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	Annual O & M - 30 Years				
1	Monitoring well sampling - Labor:	40	MH	$75	$3,000
2	Sample analysis - annual	10	Each	$700	$7,000
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
5	GW treatment plant operation - Labor: 20 hrs/week x 52 weeks	1,040	MH	$70	$72,800
6	Pumping system repairs/maintenance (Allowance)	1	LS	$5,000	$5,000
7	Utilities - Electric (Allowance)	1	Year	$17,700	$17,700
8	Utilities - Natural Gas (Allowance)	1	Year	$232,300	$232,300
9	Oxidizer maintenance	1	Year	$10,000	$10,000
10	Aqueous-phase carbon changeout	5,000	Year	$1	$5,900
11	Sanitary sewer discharge ($2.5-$3.3/1000 gal per KeySpan)	1	Year	$31,536	$31,600
	SUBTOTAL 1	**Annual**			**$356,500**
	Location cost adjustment	**1.21**			**$431,400**
	Add item 11 no location cost adjustment needed				**$463,000**
	SUBTOTAL 2		**Annual**		**$463,000**
	Contingency @ 30%		**Annual**		**$138,900**
	SUBTOTAL 3		**Annual**		**$601,900**
	Present Worth of Subtotal 3 (30-year @ 5% discount rate)		mult. by	15.37	**$9,251,300**
	TOTAL COST				**$9,251,300**

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Client:	Keyspan	Project Number:	11175065		
Project:	Hempstead Intersection Street Former MGP	Calculated By:	RJP	Date:	1-May-07
Description:	**HYDRAULIC CONTAINMENT - 500 gpm**	Checked By:	RW	Date:	1-May-07

Construction Cost Estimate Summary

DESCRIPTION	ESTIMATED COST
Groundwater Treatment System	**$1,399,000**
Groundwater Extraction Well Installation (2 total)	**$145,000**
(CONSTRUCTION) SUBTOTAL 1	**$1,544,000**

SUPPLEMENTAL PROJECT COSTS	
Overhead and Profit (5% of Subtotal 1)	**$78,000**
(CONSTRUCTION) SUBTOTAL 2	**$1,622,000**
Contingency (30% of Subtotal 2)	**$487,000**
TOTAL CONSTRUCTION COSTS	**$2,109,000**
Engineering Design (10% of Total Construction Costs)	**$211,000**
Total Capital Costs	**$2,320,000**
Present Worth Annual O&M - 30 Years	**$28,795,000**
TOTAL COST	**$31,115,000**

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Title:	**HYDRAULIC CONTAINMENT - 500 gpm**	Checked By:	RW	Date:	1-May-07

ITEM	DESCRIPTION	QTY.	UNITS	UNIT COST	TOTAL COST
	Groundwater Treatment System				
1	Air stripper - horiz. tray, 250 gpm w/ blower an dcontrols	2	Each	$54,000	$108,000
2	Oil water separator	1	Each	$22,000	$22,000
3	Aqueous phase carbon units (2 in series)	2	Each	$160,000	$320,000
4	Bag filter system (100 gpm ca)	10	Each	$5,000	$50,000
5	Chemical feed pump and tanks, etc.	1	LS	$10,000	$10,000
6	Recuperative thermal oxidizer (5,000 scfm)	1	LS	$500,000	$500,000
7	System controls	1	Each	$20,000	$20,000
8	Electrical power drop - 230V - 3 phase (within 50 feet)	1	LS	$20,000	$20,000
9	Electrical installation	1	LS	$15,000	$15,000
10	Natural gas connection (within 50 feet)	1	LS	$15,000	$15,000
11	Sanitary sewer discharge connection (within 600 feet)	1	LS	$38,000	$38,000
12	Installation, including pipe, valves, fittings (Allowance)	1	LS	$14,000	$14,000
13	System start-up	1	LS	$20,000	$20,000
14	Concrete pad - 25 ft x 10 ft x 1 ft	10	CY	$350	$3,500
	SUBTOTAL				**$1,155,500**
	Location cost adjustment	**1.21**			**$1,399,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$1,399,000**

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	GW Extraction Well Installation (2 total)				
1	Sawcut pavement	50	LF	$2	$100
2	Excavation - trench and vault	300	LF	$10	$3,000
3	Extraction well installation (70 ft & 150 ft)	220	VLF	$190	$41,800
4	Precast concrete vault with road cover - 6 x 6 x 6 feet	2	Each	$4,900	$9,800
5	Pipe bedding	300	LF	$2	$600
6	Discharge line - 4-inch HDPE pipe	300	LF	$10	$3,000
7	Pump - 10 HP, 150 gpm, 80-ft head	2	Each	$4,800	$9,600
8	Electrical conduit - 2-inch PVC	300	LF	$20	$6,000
9	Pump - electric and controls (Allowance)	2	LS	$13,000	$26,000
10	Pump - pipe, valves, fittings (Allowance)	2	LS	$3,000	$6,000
11	Pavement restoration	100	SY	$26	$2,600
12	Traffic control (Allowance)	1	Week	$7,000	$7,000
13	Drill cuttings disposal	12	Drum	$300	$3,600
	SUBTOTAL				**$119,100**
	Location cost adjustment factor	**1.21**			**$145,000**
	Note: Total Cost rounded up to the nearest $1,000.				
	TOTAL COST				**$145,000**

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	Annual O & M - 30 Years				
1	Monitoring well sampling - Labor:	40	MH	$75	$3,000
2	Sample analysis - annual	10	Each	$700	$7,000
3	Reports	1	LS	$2,500	$2,500
4	Repair security fence (Allowance)	1	LS	$250	$300
5	GW treatment plant operation - Labor: 20 hrs/week x 52 weeks	1,040	MH	$70	$72,800
6	Pumping system repairs/maintenance (Allowance)	1	LS	$5,000	$5,000
7	Utilities - Electric (Allowance)	1	Year	$17,700	$17,700
8	Utilities - Natural Gas (Allowance)	1	Year	$232,300	$232,300
9	Oxidizer maintenance	1	Year	$10,000	$10,000
10	Aqueous-phase carbon changeout	160,000	Year	$1	$188,800
11	Sanitary sewer discharge ($2.5-$3.3/1000 gal per KeySpan)	1	Year	$788,400	$788,400
	SUBTOTAL 1	**Annual**			**$539,400**
	Location cost adjustment	**1.21**			**$652,700**
	Add item 11 no location cost adjustment needed				**$1,441,100**
	SUBTOTAL 2		**Annual**		**$1,441,100**
	Contingency @ 30%		**Annual**		**$432,330**
	SUBTOTAL 3		**Annual**		**$1,873,430**
	Present Worth of Subtotal 3 (30-year @ 5% discount rate)		mult. by	15.37	**$28,794,700**
	TOTAL COST				**$28,795,000**