GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL HEMPSTEAD INTERSECTION STREET FORMER MANUFACTURED GAS PLANT SITE VILLAGES OF GARDEN CITY AND HEMPSTEAD, LONG ISLAND, NEW YORK

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1.0 BACKGROUND

1.1 INTRODUCTION

This report presents the groundwater flow and solute transport model developed to support the design evaluation of the source area remedial design for the Hempstead Intersection Street Former Manufactured Gas Plant Site (the Site), located in Nassau County, New York (Figure 1-1). The groundwater flow and solute transport model was used to simulate study area conditions and evaluate remedial alternatives and their long-term effects on Site constituents in groundwater.

1.2 SITE HISTORY

Manufactured Gas Plant (MGP) operations began at the Site in the early 1900's and continued until the 1950s. Historic releases of coal gasification related materials (i.e., coal tar) from former MGP processes at the Site have impacted soils and groundwater. Non-aqueous-phase liquid (NAPL) extends approximately 400 feet (ft) downgradient of the Site at the depth of the water table, approximately 30 feet below ground surface (ft bgs). A dissolved phase groundwater plume containing volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) extends approximately 3,800 feet downgradient of the Site. A site plan is presented in Figure 1-2.

1.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

The regional geology of Nassau County on Long Island is typified by three major aquifer units:

- the Upper Glacial,
- the Magothy, and
- the Lloyd.

Unconsolidated medium to coarse grained Pleistocene glacial deposits comprise the Upper Glacial aquifer, which is exposed at the ground surface and ranges in thickness from 50 ft to 100 ft. The Cretaceous Magothy aquifer underlies the Upper Glacial aquifer. The Magothy aquifer ranges in thickness from 400 ft to 600 ft, and consists of unconsolidated quartz sands with layers and lenses of silt, clay, coarse sand and gravel. The Magothy aquifer comprises the Magothy Formation, which can be divided into two sub-units, the Upper Magothy and the Lower Magothy, based on lithology. The Upper Magothy contains fine to medium sands, silt and clay layers, while the Lower Magothy consists of generally coarser material.

The Magothy aquifer is underlain by the Raritan Formation, which consists of two members, the lower Lloyd Sand Member (the Lloyd aquifer) and an upper clay member (the Raritan Clay). The Lloyd aquifer ranges in thickness from 200 ft to 300 ft and consists of coarse to fine sands. The Raritan Clay is approximately 300 ft thick, consists of a massive silty clay with lenses of sand and lignite, and acts as a confining unit effectively separating groundwater flow between the Lloyd and Magothy aquifers. Crystalline bedrock underlies the Raritan Formation. Bedrock has negligible permeability and functions as a hydrogeologic boundary, or base, for the Long Island groundwater flow system.

The Upper Glacial and Magothy aquifers are unconfined and these two aquifers function as a hydrogeologically continuous medium. In general, the potentiometric surface in the Magothy is slightly lower than the Upper Glacial, with downward vertical hydraulic gradients moving groundwater from the Upper Glacial into the Magothy. The Lloyd aquifer is confined by the Raritan Clay.

The unconsolidated aquifers of Long Island contain highly conductive sands and gravels, interbedded with layers and lenses of less permeable silty sands, silt and clay. Typical published values for the hydraulic conductivities of each geologic unit are presented in Table 1-1. In general, horizontal hydraulic conductivities for the Upper Glacial aquifer are about five times higher than the underlying Magothy and Lloyd aquifers, while the Magothy and Lloyd aquifers have similar hydraulic characteristics (URS, 2008). The Raritan Clay has very low conductivity due to its high silt and clay content. Interbedded silty sands, silt and clay yield highly anisotropic conditions within the unconsolidated aquifers, resulting in preferential movement of groundwater in the horizontal direction. In general, vertical hydraulic conductivities range from 1% to 10% of horizontal hydraulic conductivities.

Regional groundwater flow on Long Island is controlled by topography, precipitation, permeability of unconsolidated deposits, and the slope of unconsolidated deposits and bedrock. The three aquifer units of Long Island are bounded above by the water table and below by crystalline bedrock. Laterally, usable fresh water in the aquifers is bounded by a freshwater-saltwater transition zone that surrounds the island. A regional groundwater divide runs generally southwest to northeast along the long axis of Long Island. Groundwater to the north of the divide flows towards Long Island Sound, whereas groundwater south of the divide flows towards the Atlantic Ocean.

Recharge to the Long Island groundwater flow system occurs exclusively via the infiltration of precipitation through porous soils. Long Island receives an average of 44 inches of rain, or its equivalent in snow, per year. It has been estimated that approximately 50% of precipitation is returned to the atmosphere via evapotranspiration, 20% is lost to surface flow, and the other 30% recharges the groundwater flow system (LIRPB, 1993). Groundwater recharge is estimated to be 30% of annual precipitation (i.e., 13.2 in/yr).

1.4 SITE GEOLOGY AND HYDROGEOLOGY

From the ground surface downward, the primary unconfined geologic units present at the Site include:

- fill/topsoil,
- glacial sediments,
- Upper Magothy, and
- Lower Magothy.

The fill/topsoil unit is encountered throughout and adjacent to the Site and 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, and where present it ranges in thickness from approximately 0.5 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. HIMW-8D), 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.

Underlying the glacial outwash sediments is the Upper Magothy. The Upper Magothy can be further divided into two subunits: the Upper subunit of the Upper Magothy and the Lower subunit of the Upper Magothy. Within the Site area, the upper subunit of the Upper Magothy is characterized by a sequence of sand, silt and clay layers, with a thickness ranging between 49 ft and 110 ft. 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 (URS, 2008). The lower subunit of the Upper Magothy is found from approximately 118 ft bgs and below, and is characterized by a low permeability silty fine sand and stiff clay. The presence of the lower subunit was identified during the Remedial Investigation (RI) conducted at the Site (PS&S, 2006). Due to its high clay content, the lower subunit of the Upper Magothy generally acts as a confining layer, limiting the vertical migration of groundwater. However, the lower subunit of the Upper Magothy appears to be highly heterogeneous, with lateral variability in horizontal and vertical hydraulic conductivity. This spatial variability in the conductivity of the lower subunit of the Upper Magothy has a significant effect on localized hydraulic gradients, as wells as on migration of dissolved-phase contaminants.

Based on the results of three undisturbed soil samples collected during the RI using a Shelby Tube sampler, the average vertical hydraulic conductivity of the lower subunit of the Upper Magothy was estimated to be 5.8E-04 ft/day (2.0E-07 cm/s). This estimate appears to be too low for silty fine sands and stiff clays and is therefore not thought to be representative of the lower subunit of the Upper Magothy. No Site geologic or hydrogeologic information is available for units below the Upper Magothy.

Groundwater in the vicinity of the Site flows generally from north to south, with depth to groundwater ranging from approximately 15 ft bgs to 30 ft bgs. The groundwater flow system beneath the Site and above the lower subunit of the Upper Magothy was divided into three zones, approximately according to the screen elevations of the monitoring wells:

- shallow groundwater (water table to 45 ft bgs),
- intermediate groundwater (45 ft bgs to 95 ft bgs) and
- deep groundwater (greater than 95 ft bgs).

Vertical hydraulic gradients are generally downward, with groundwater moving from the shallow flow system into the intermediate flow system, and from the intermediate flow system into the deep flow system.

1.5 REGIONAL GROUNDWATER WITHDRAWALS

Regional groundwater uses in the vicinity of the Site include municipal water supply wells and private wells used for commercial applications such as irrigation, cooling, auto washing and laundry. All of the municipal water supply and private wells are screened in the Upper Glacial or the Magothy aquifers. Two municipal water supply wells (wells N-10033 and N-10034), operated by the Village of Garden City, are located about 200 feet west of the Site and screened at depths of 439 to 541 ft, and 489 to 570 feet, within the Magothy aquifer (URS, 2008). Six wells (wells N-00079, N-00080, N-00082, N-00083, N-04425 and N-07298), operated by the Village of Hempstead, are situated about 4,000 feet east of the Site and are screened in the Magothy aquifer (H2M Group, 2006). Two additional municipal water supply well fields, both screened in the Magothy aquifer between 450 and 625 feet bgs are situated approximately 1.3 miles southeast of the Site and 1.6 miles southwest of the Site, respectively (URS, 2008).

1.6 NATURE AND EXTENT OF CONTAMINATION

Site conditions include MGP-related impacts to soils within the saturated and unsaturated zones. Source areas contain NAPL and NAPL-saturated soils, while groundwater impacts include NAPL in groundwater and a plume of dissolved-phase benzene, toluene, ethylbenzene and total xylenes (BTEX) and low molecular weight polycyclic aromatic hydrocarbons (PAHs) extending from the Site towards downgradient areas.

1.6.1 Soil

Areas of soil contamination were presented in the RI report based on field (visual and olfactory) observations, total PAH concentrations and total BTEX concentrations. Surface and near-surface soils containing site-related contaminants were found 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 onandoff-site. Based on information provided in the RI report (PS&S, 2006), source materials are identified as significant zones of NAPL-saturation in soils and the presence of NAPL in groundwater along with areas of high concentrations of dissolved-phase PAHs and BTEX.

1.6.2 Non-Aqueous Phase Liquid

Measurable amounts of dense non-aqueous phase liquid (DNAPL) and sheens of Light NAPL (LNAPL) were observed during the RI and pre-design investigations, in both on-Site and off-Site monitoring wells (PS&S, 2006). A DNAPL plume delineation based on information gathered during the RI, and subsequent investigations, identifies the migration pathway of NAPL extending approximately 400 ft downgradient to the south, generally bounded by the Long Island Railroad Right-of-Way and Wendell Street, and extending beneath an adjacent medical office building to the west.

1.6.3 Groundwater Contaminant Plumes

Groundwater plumes of dissolved-phase BTEX and PAHs exist both on-site and downgradient in the shallow, intermediate, and deep groundwater flow systems, extending in a southerly direction, consistent with the regional groundwater flow direction (Figure 1-3).

In general, the highest levels of contamination in groundwater 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 porous media. Concentrations of BTEX and PAHs across the plume are highly variable. Downward migration of the dissolved-phase plume is being retarded locally (in the vicinity of the Site) by low permeability layers in the lower subunit of the Upper Magothy. However, in areas downgradient from the Site (i.e. south of HIMW-8), downward migration of the dissolved-phase plumes from the shallow groundwater flow regime to the intermediate, and deep, groundwater flow regimes has been observed.

Total organic carbon (TOC) data collected during the RI (PS&S, 2006) indicate that the near-surface glacial outwash deposits are relatively low in organic matter content, having an average TOC content of approximately 0.5%, or a geometric mean of 0.4%. The underlying Upper Magothy deposits have a higher TOC content, with an average value of 3.5%, or a geometric mean of 1.1%. The organic content fraction in soil is the dominant characteristic affecting the adsorption capacity of non-ionic organic compounds such BTEX and PAHs onto the soil matrix (Suthersan, 1997). Soils with a very low fraction of organic content will have a limited ability to adsorb and immobilize organic compounds.

During the RI, a comparison of measurements of dissolved oxygen (DO) was made between upgradient areas and areas within the plume. The comparison indicated that a significant reduction in dissolved oxygen occurs within the plume. 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.

An assessment of the concentration of BTEX in the monitoring well cluster situated furthest downgradient from the Site (HIMW-15) suggests that that the dissolved-phase plume is stable, has reached its maximum extent, and is fluctuating in response to climatic factors such as precipitation and changes in groundwater levels. This conclusion is based on samples collected at HIMW-15I in 2003 and 2009. In 2003, the concentration of BTEX at HIMW-15I was 110 micrograms per liter (µg/L), and the plume was interpreted as extending to just past HIMW-15I, which is located approximately 3,800 feet from the Site. In 2009, the concentration of BTEX in HIMW-15I was 14 µg/L.

The observation that the dissolved-phase plume is stable is further supported by considering the velocity of contaminant migration and the time when the source originated. The glacial aquifer materials in the vicinity of the Site are very coarse and permeable, and characterized by high groundwater flow velocities. Furthermore, the adsorption of contaminants onto the soil matrix is predicted to be 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 expected to be 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 are limiting the extent of the plume.

For the purpose of groundwater modeling, benzene and naphthalene were selected as indicator parameters to represent the nature and extent of groundwater contaminants because they are key constituents of the MGP source material, and because of their groundwater transport characteristics and regulatory criteria. The physical and chemical properties of benzene and naphthalene are presented in Table 1-2.

Interpreted dissolved-phase plumes of benzene and naphthalene were developed for the shallow, intermediate, and deep groundwater flow systems using analytical results from monitoring wells and direct push samples collected from the Site and surrounding areas. Analytical results from July 2000 to February 2009 were compiled, and the maximum concentration at each sample location was selected to derive a contaminant distribution in groundwater representative of conservative conditions (Figures 1-4 to 1-9).

Interpreted benzene plumes are presented in Figures 1-4 to 1-6. The shallow benzene plume is about 2,000 feet long and 500 feet wide, with the highest observed concentrations of 56,000 μg/L at well HIMW-6S, which is situated in the source zone. The intermediate plume is longer than the shallow plume, and extends about 4,300 feet in length and 850 feet in width. Most of the benzene concentrations in the intermediate groundwater system directly beneath the source area are non-detect, except for a concentration of 320 μg/L at well HIMW-18I. This indicates downward migration of dissolved-phase contaminants within the source zone is limited. This may be due to the zones and lenses of silty sand and silt within the glacial outwash that prevent vertical migration of the plume from the shallow zone into the intermediate zone. Comparison of the shallow and the intermediate benzene plumes suggests that the shallow plume migrates downward into the intermediate and deep groundwater flow zones primarily downgradient of well HIMW-8I. The deep benzene plume has a similar extent as the intermediate plume.

Interpreted naphthalene plumes are presented in Figures 1-7 to 1-9. The shallow naphthalene plume extends about 1,900 feet in length, with concentrations within the plume ranging up to 2,800,000 μg/L, which exceeds the typical solubility of naphthalene of 30,000 μg/L (Table 1-2). Similar to the benzene plume, the intermediate naphthalene plume is about 4,000 feet long. Different from the benzene plume, the intermediate naphthalene concentrations beneath the source zone are very high, ranging up to 7,100 μg/L at HIGP-024 (Figure 1-8), which is 24% of the naphthalene solubility (30,000 μg/L). This suggests that the DNAPL phase of naphthalene may be present in the deeper portions of the shallow zone within the source area. The deep naphthalene plume is shorter than the intermediate naphthalene plume and shorter than the deep benzene plume. This may be attributed to the relative lower solubility, higher adsorption potential, and faster biodegradation of naphthalene relative to benzene (Table 1-2).

The interpreted benzene and naphthalene concentration distributions suggest that:

- Dissolved-phase plume migration direction is generally linear, from north to south.
- Direct downward migration of the dissolved-phase plume in the source area is limited.
- Heterogeneity of the aquifer has altered the plume migration pathway in the horizontal direction, so that the plume extent in the shallow groundwater zone is shorter than in the intermediate and deep groundwater zones.
- NAPL distribution (either DANPL or LNAPL) in the source area is complicated, so that the concentrations in, and downgradient, of the source area vary significantly.

2.0 GROUNDWATER FLOW AND TRANSPORT MODELING PURPOSE AND OBJECTIVES

The groundwater flow and fate and transport models were developed for the Site to support remedial alternative design analyses. The specific purpose and objectives are as follows.

2.1 PURPOSE

The purpose of groundwater modeling is to function as a design analysis tool for the source area remedial alternatives, which include in-situ solidification of soils containing MGP source material.

2.2 OBJECTIVES

The proposed remedial alternative is expected to affect the groundwater flow regime in the vicinity of the area undergoing in-situ solidification, as well as the behavior of the dissolved-phase plume extending downgradient from the Site, in the following ways:

- Solidified soils will have a lower permeability than surrounding native materials, forming a monolith within the unsaturated and saturated zones, and will therefore likely alter localized horizontal and vertical groundwater flow patterns;
- The upper surface of the monolith will be located in the unsaturated zone and it may be possible that water infiltrating from above the footprint of the in-situ solidification area could perch on top of the monolith, until it drains away from the monolith and continues downward infiltration; and
- The mass flux of contaminants from the monolith into the flow system is anticipated to be significantly lower than the mass flux occurring under current conditions, and this decrease in the source will likely influence the behavior of the dissolved-phase plume into the future.

The objective of the groundwater flow and transport models is to evaluate these potential effects as well as to provide a numerical flow model which can be coupled to a groundwater fate and transport model to predict the nature and extent of impacts under varying source-area remedial simulations. In order to accomplish this objective, the following steps were implemented:

- a conceptual model of hydrogeologic conditions, including hydrostratigraphic units, groundwater flow patterns, boundary conditions and recharge rates, was developed for the Site and surrounding areas;
- the conceptual model was put into a framework suitable for modeling, which included grid design and discretization, setting of boundary conditions and selection of preliminary values for aquifer properties such as hydraulic conductivity and porosity;
- a steady-state groundwater flow model was developed and calibrated to groundwater elevations measured in wells situated throughout the Site area;
- a fate and transport model was developed and calibrated to plume conditions for identified key Site constituents; and
- the calibrated steady-state groundwater flow model and fate and transport model were used for predictive models simulating pre- and post-solidification flow regimes and solute transport.

As discussed in Section 1.6.3, the benzene and naphthalene concentration distributions are significantly influenced by the local heterogeneity of the geologic materials in the glacial sediments. The modeling effort would be significant if the detailed heterogeneities in the flow field and in the concentration distribution need to be simulated.

Considering the specific modeling objectives, which focus on understanding of (1) the potential impact of the proposed solidification to the groundwater flow system and (2) the potential remedial effect to the groundwater contaminant plumes, the modeling effort focused on:

- to reasonably simulate the dissolved-phase plume migration direction and pathways, as well as the fate and transport of the plumes, and
- to reasonably simulate the proposed remedial alternatives at the Site and the effect of these alternatives on controlling and reducing the dissolved-phase plume migration.

Given the emphasis of the modeling effort, attention was not given to details that were deemed not important in meeting the modeling objectives.

3.0 MODEL DEVELOPMENT

The flow model was developed using the Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW) developed by the United States Geological Survey (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). The fate and transport model was developed using the MODFLOW-coupled solute transport model MT3DMS, developed for the US Army Corps of Engineers (Zheng and Wang, 1999). MODPATH (Pollock, 1989), a particle tracking code, was used during groundwater flow model calibration to evaluate whether the adjustment of hydraulic parameters allowed simulated flow paths to approximate observed conditions. Model structure and input parameters include the physical dimensions of the model and boundary conditions, as well as aquifer parameters and transport properties, are described in the following sections.

3.1 MODEL DOMAIN AND GRID

An existing model for the Site was previously created by the H2M Group (2006) for National Grid using the Nassau County Regional Groundwater Model as its basis. This H2M model was developed to evaluate the potential for the former MGP Site to impact adjacent municipal water supply wells screened in the lower Magothy aquifer. The model parameters developed in the H2M model were used as a starting point to develop the model presented in this report.

The model grid was established based on the H2M model domain. The model covers an area of 3,590 acres, or approximately 5.6 square miles. The Site is in the center of the model domain. The model extends outward from the Site sufficiently so as not to allow for model boundary conditions to influence simulated conditions within the area of interest. The grid discretization of the H2M model was not fine enough to achieve the objectives of the current modeling effort. Therefore, the original grid was revised to include a variable grid-size, with the smaller cells in the vicinity of the Site to be uniformly 20 ft by 20 ft and larger cells on the outer edges of the model domain. The cell sizes used in the model grid were selected based on consideration of field-scale variability of geologic units across the model domain and the delineation of source material present in the subsurface. The grid is orthogonal and oriented north/south, parallel to the principal groundwater flow direction. It consists of 200 rows and 154 columns. Computational limitations were considered because computation time was found to increase significantly with increasing node/cell counts.

3.2 MODEL LAYERS

The model simulates groundwater flow in unconsolidated deposits overlying bedrock and includes the major hydrostratigraphic units found in the portion of Long Island where the Site is situated. Vertical discretization of the model includes 13 layers, which allowed for simulation of the regional groundwater flow system as well localized conditions resulting from implementation of the proposed remedial alternative. A north-south cross-section through the model domain is presented in Figure 3-1.

The relationships between hydrostratigraphy and model layers are described below and presented in Figure 3-1:

- Layers 1, 2, 3 and 4 - Fill/topsoil and Glacial Outwash. Layers 1, 2, 3, and 4 are considered as shallow zone, corresponding to shallow monitoring wells.
- Layers 5 and 6 - Upper subunit of Upper Magothy. Layers 5 and 6 are considered as intermediate zone, corresponding to intermediate monitoring wells.
- Layer 7 - Upper subunit of Upper Magothy. Layer 7 is considered as deep zone, corresponding to deep monitoring wells.
- Layer 8 - Lower subunit of Upper Magothy. Layer 8 is a low permeability layer, which acts as a confining layer at the bottom of Upper Magothy.
- Layers 9, 10, and 11 - Lower Magothy.
- Layer 12 - Raritan Clay.
- Layer 13 - Lloyd Aquifer.

Detailed separation of the fill/topsoil and Glacial Outwash into four layers was necessary to simulate the vertical delineation of the proposed soil solidification to variable depths. Layers 1, 2, 3 and 4 represent the shallow groundwater flow system. Layer 1 represents the unsaturated portion of the Glacial Outwash or fill/topsoil. Inclusion of an unsaturated layer was necessary to simulate potential groundwater mounding into the unsaturated zone in response to the proposed remedial alternative. Layers 2, 3, and 4 represent the saturated portion of the Glacial Outwash. The upper subunit of Upper Magothy is represented by Layers 5, 6 and 7. Layers 5 and 6 correspond to the intermediate groundwater flow system, while Layer 7 corresponds to the deep groundwater flow system. The lower subunit of the Upper Magothy was simulated as a discrete layer (Layer 8) in this modeling effort, based on the occurrence of this low permeability unit throughout the Site area. It should be noted that H2M model did not include the lower subunit of the Upper Magothy.

Elevations of ground surface for portions of the model domain within the Site boundary were obtained from Site topographic survey data. Ground surface elevations for areas of the model domain for which no topographic survey data were available were obtained from the H2M model. A similar approach was taken for assigning elevations to the bottom of layers representing hydrostratigraphic contacts. If Site data regarding the depth of hydrostratigraphic contact were available, then these data were used in conjunction with values employed in the H2M model to define bottom of layer elevations.

3.3 FLOW MODEL BOUNDARY CONDITIONS

The following boundary conditions were incorporated into the model: no-flow and constant head.

3.3.1 No Flow Boundary

A no-flow boundary was assigned for the interface between overburden and bedrock, which represents the base of the model. The elevations for top of bedrock were obtained from the H2M model. In accordance with the conceptual model, bedrock is assumed to be equivalent to a no-flow boundary due to its low permeability relative to overlying unconsolidated deposits. No flow boundaries were defined by the eastern and western boundaries of the model grid, where groundwater flow is inferred to be nearly parallel to the edge of the model domain.

3.3.2 Constant Head Boundary

Constant head boundaries were specified along the northern and southern borders of the model domain from model Layers 2 through 13 to simulate groundwater flow into, and out of, the model. Groundwater elevation values for constant head boundaries were estimated during calibration of the steady-state model, as direct water level measurements were not available. The estimation approximately followed the regional average hydraulic gradient (0.0015),. No boundary condition was specified for Layer 1, as it represents an unsaturated layer and will only be locally saturated in response to the potential groundwater mounding resulting from the proposed solidification.

3.4 GROUNDWATER RECHARGE

In accordance with the conceptual model, groundwater recharge from infiltration of precipitation is inferred to be 13.2 inches per year, 30% of long-term annual precipitation, across the model domain.

3.5 GROUNDWATER EXTRACTION

Eight water supply wells are simulated in Layers 10 and 11. Their locations, screen elevations, and average pumping rates were obtained from the H2M model (H2M, 2006), and are listed in Table 3-1. The total average pumping rate of the simulated water supply wells was 3,402 gallon per minute (gpm).

3.6 HYDRAULIC PARAMETERS

Hydraulic conductivity for the model domain was estimated during model calibration, with references of the values used in the H2M model as well as from slug test results performed on wells screened in the Upper Glacial and Upper Magothy aquifers as part of pre-design investigations (Table 1-1).

3.7 TRANSPORT MODEL STRUCTURE

Benzene and naphthalene were selected as representative indicator compounds for the MT3DMS simulations to evaluate source area remedial design. This selection was based upon the following considerations:

- Benzene exhibits the most extensive downgradient distribution in groundwater of any of the site MGP constituents due to the elevated concentrations present in the MGP source materials and its high mobility in the aquifer.
- Of the MGP site constituents identified downgradient of the Site, benzene has the lowest New York State criteria for the protection of groundwater (1 μg/L).
- Naphthalene exhibits an extensive downgradient distribution in groundwater and has its groundwater mobility conservatively representative of the PAHs present in the MGP source material.
- Transport characteristics for both benzene and naphthalene have been extensively researched and are well understood.
- Benzene and naphthalene are among the most frequently detected MGP source material constituents in groundwater downgradient of the Site.

4.0 MODEL CALIBRATION

Model calibration is a process which consists of adjusting the physical and hydraulic model parameters to achieve a best fit between the observed data and simulated results. Model calibration is an iterative process of steady-state flow model calibration, particle tracking simulation, and transport model simulation. The process is repeated until the simulated plume migration approximately matches the interpreted plume.

4.1 STEADY-STATE FLOW MODEL CALIBRATION

The primary goal of the steady-state calibration was to achieve groundwater flow patterns that best match the observed distribution of hydraulic heads in the shallow, intermediate and deep groundwater flow systems in the vicinity of the Site, as well as to approximately match the extent of the interpreted dissolved-phase plumes. The parameters that were adjusted during calibration included:

- Constant head values at constant head boundaries,
- Horizontal hydraulic conductivity, and
- Vertical anisotropic ratio of hydraulic conductivity.

Adjustment of these hydraulic parameters focused on (1) matching observed hydraulic heads at monitoring wells and (2) matching the flow paths (particle tracking simulation) to the observed/interpreted plume migration (MT3DMS simulation).

4.1.1 Simulated Hydraulic Heads

Model calibration was assessed by comparing simulated water levels at model cells to the observed water levels measured at 52 monitoring wells on 04/15/2007. Figure 4-1 shows the calibrated groundwater potentiometric surface of the shallow (Layer 2) zone in the vicinity of the Site. A comparison between the observed and the simulated heads are presented in Table 4-1. The calibration residual standard deviation is 0.46 ft, the residual mean is 0.34 ft, and the residual standard deviation vs. the observed range in head is 4.9%, which is within the commonly accepted calibration criterion (5 to 10%). Comparison of the observed and computed head values are also shown in Figure 4-2 for shallow, intermediate, and deep wells.

4.1.2 Model Water Budget

The steady state flow model water budget is balanced with groundwater recharge, groundwater extraction, and lateral inflow and outflow through boundaries. The constant head inflow from the northern boundary is 8,922 gpm, and the constant head outflow through the southern boundary is 7,829 gpm. The total groundwater recharge is 2,300 gpm and the total water supply well pumping of 3,402 gpm.

4.1.3 Flow Migration Pathways

Simulated groundwater flow horizontal pathways are straightforward from north to south, while the vertical pathways are sensitive to the flow model calibration (Figure 4-1), and critical to the simulation of plume migration pathways (MT3DMS). The particles were initiated upgradient of the contaminant source area, in model Layer 2. The particles move downgradient horizontally, and at the same time gradually sink from shallow layers into intermediate and deep layers. Particle tracks in different layers are represented with different colors (Figure 4-1). As shown in the figure, particle tracks start moving from Layer 4 (the bottom layer of the shallow layers) into Layer 5 (the top layer of the intermediate layers) between HIMW-012 and HIMW-013. This is consistent with the observed benzene and naphthalene concentration distributions. The extents of the shallow plumes start to shrink between the two well clusters, while the intermediate and deep plumes are much longer than the shallow plumes (Figures 1-4 to 1-9). However, particle tracks do not move across model Layer 8, which behaves as a vertical barrier to flow due to its low permeability.

4.1.4 Calibrated Constant Head at Boundaries

The constant head value along the northern constant head boundary was adjusted to 51.5 feet for all layers. The constant head values along the southern constant head boundary were adjusted as a decreasing pattern from upper layers to lower layers, in order to simulate the downward vertical hydraulic gradient observed at HIMW-14 and HIMW-15 (Table 4-1). The decrease of the constant head at the southern boundary was assumed to be attributable to the water supply pumping at the two public water supply well fields screened in the Magothy aquifer, and situated approximately 1.3 miles southeast and 1.6 miles southwest of the Site (Section 1.5). The locations of these wells are just beyond the southern boundary of the model domain. Due to lack of data regarding the influence of pumping at these wells on the groundwater flow regime, constant head values at the southern constant head boundaries was assumed to decrease 0.5 feet for each layer, from 33.5 feet in Layers 2 and 3 to 31.5 feet in Layer 7, and decrease 1.0 feet for each layer from 26.5 feet in Layer 8 to 23.5 feet in Layer 11. The constant head values for Layers 12 and 13 were assumed to be 24.5 feet and 25.5 feet, respectively.

4.1.5 Calibrated Hydraulic Conductivity and Vertical Anisotropic Ratio

The horizontal hydraulic conductivity was generally assumed to be uniform for each layer. The calibrated hydraulic conductivity for the Upper Glacial aquifer and the upper subunit of the Magothy (Layers 1 to 7) was calibrated to be 150 ft/day, which is within the range of literature and the slug test results (Table 1-1). However, the hydraulic conductivity downgradient of HIMW-12 in the shallow layers (Layers 2 to 4) was adjusted to be 60 ft/day to simulate increased resistance to horizontal flow, which is believed to be the cause of the observed sinking of the shallow plume between wells HIMW-8 and HIMW-12 (Figures 1-4 and 1-7). The hydraulic conductivity of Layer 8 was calibrated to be 0.3 ft/day (1.0E-4 cm/s) at the Site and 0.6 ft/day (2.0E-04 cm/s) downgradient of HIMW-12, respectively.

The horizontal-to-vertical anisotropy ratio was estimated to be 100:1 in the glacial aquifer and in the upper subunit of the Magothy (Layers 1 to 7). The ratio in the lower unit of Magothy and the deeper layers (Layers 9 to 13) was estimated to be 10:1. The vertical anisotropy ratio was calibrated to be 50:1 in Layer 8, which results in the vertical hydraulic conductivity of 0.006 ft/day (2.1E-06 cm/s) at the Site and of 0.012 ft/day (4.2E-06 cm/s) downgradient of HIMW-12. This estimate is higher than the Shelby Tube sampler result of 5.8E-04 ft/day (2.0E-07 cm/s), but appears to be reasonable in comparison with the literature value for silt and clay.

The horizontal-to-vertical anisotropy ratio was estimated to be 100:1 in the glacial aquifer and in the upper subunit of the Magothy (Layers 1 to 7). The ratio in the lower unit of Magothy (Layers 9 to 13) was estimated to be 10:1. The vertical anisotropy ratio was calibrated to be 50:1 in Layer 8, which results in the vertical hydraulic conductivity of 0.006 ft/day (2.1E-06 cm/s) at the Site and of 0.012 ft/day (4.2E-06 cm/s) downgradient of HIMW-012. This estimate is higher than the Shelby Tube sampler result of 5.8E-04 ft/day (2.0E-07 cm/s) (Section 1.4), but appears to be reasonable in comparison with the literature value for silt and clay.

Locally beneath the source area, the vertical anisotropy ratio in Layers 4 and 5 was reduced from 100:1 to 10:1 with intention to increase the vertical plume migration from the shallow zone to the intermediate zone. It was found that the vertical flow pathways were not sensitive to such localized adjustment of the vertical anisotropy.

4.1.6 Simulated Vertical Hydraulic Gradient

The simulated vertical hydraulic head differences were also compared to the observed hydraulic head differences at well clusters (Table 4-1). The simulated directions of vertical hydraulic gradients are all downward, which is consistent with observed conditions. The magnitude of the vertical downward gradients is generally consistent with observed conditions. However, in certain off-Site areas, precise matching of the vertical hydraulic gradients was not achieved. Specifically, the strong downward gradient observed between the intermediate and deep well clusters at HIMW-12, HIMW-14, and HIMW-15 could not be simulated. These wells are located off-Site, in an area where insufficient data exists to properly characterize subsurface conditions. The observed vertical hydraulic gradients may be associated with some unknown, less-permeable, subunit buried between permeable layers.

4.2 TRANSPORT MODEL CALIBRATION

The transport model was calibrated through history matching simulations of benzene and naphthalene plume migration. The objective of the transport model calibration is to approximately match the interpreted benzene and naphthalene plumes through a 100-year simulation of plume migration (from 1909 to 2009). The focus of historical matching is to simulate the extent of the dissolved-phase benzene and naphthalene plumes in the shallow,

intermediate and deep groundwater flow systems, and to approximate the observed constituent concentrations. The calibrated transport parameters include:

- Source extent and source concentrations
- Soil-water distribution coefficient
- Biodegradation half-life
- Dispersion coefficient
- Effective porosity

To be computational efficient during the long-term (100 years) transport model calibration, inactive zones were assigned to model layers, or areas, where dissolved-phase constituents were not observed within the model domain. Specifically, Layers 10 to 13 were set to be inactive. In addition, the northern, western, and the eastern areas surrounding the plume were designated as inactive zones from model layers 1 to 9. The active zones of computation are focused in the plume area extending to southern boundary within layers 1 to 9.

4.2.1 Contaminant Source Area Assumptions

The contaminant source area for transport simulations was assumed to be the same as the area identified as “limit of MGP source material” in the Pre-Design Investigation Report (URS, 2010). The source area was simulated conservatively using constant concentration cells. Five constant concentration zones were assigned to Layer 2: one representing on-Site source material, one representing source material in the parking lot immediately south of the Site, one representing source material in a small area on the northeastern portion of the Site, one representing source material in the Long Island Railroad right-of-way (LIRR ROW), and one representing source material beneath the Medical Office Building (Figure 4-3). Additional constant concentrations cells were assigned to Layer 3 and/or Layer 4 to represent deeper source material identified in the northwestern portion of the Site. Values assigned to the constant concentration cells were based on available data and were adjusted during model calibration. Constant concentration cells were assumed to be active for the entire duration of the transport simulation.

Benzene Source Extent and Concentrations

For benzene transport simulations, constant concentration cells were assigned the following values (Figure 4-3):

- 50,000 µg/L for on-Site source material (Layer 2),
- 20,000 µg/L for source material in the parking lot immediately south of the Site (Layer 2),
- 5,000 µg/L for source material beneath the Medical Office Building (Layer 2),
- 10,000 µg/L for source material in the small area on the northeastern portion of the Site (Layer 2),
- 50,000 and 20,000 µg/L for source material in the LIRR ROW (Layer 2), and
- 50,000 µg/L for deep source material in the northwestern portion of the Site (Layer 3).

Naphthalene Source Extent and Concentrations

For naphthalene transport simulations, constant concentration cells were assigned the following values (Figure 4-3):

- 20,000 µg/L for on-Site source material (Layer 2),
- 10,000 µg/L for source material in the parking lot immediately south of the Site (Layer 2),
- 5,000 µg/L for source material beneath the Medical Office Building (Layer 2),

- 10,000 µg/L for source material in the small area on the northeastern portion of the Site (Layer 2),
- 20,000 and 10,000 µg/L for source material in the LIRR ROW (Layer 2), and
- 20,000 µg/L for deep source material in the northwestern portion of the Site (Layers 3 and 4).

The depth of source material in the northwestern portion of the Site was assumed to be deeper for naphthalene simulations than for benzene simulations. The naphthalene source zone was extended down to model Layer 4, whereas the benzene source zone was extended to Layer 3 only. As shown in Figures 1-5 and 1-8, naphthalene concentrations in the intermediate zone beneath the source area are high, ranging from 17 µg/L to 7,100 µg/L. However, the benzene concentrations in the same zone are lower, ranging from non-detect to 320 µg/L. It is reasonable to assume that the naphthalene source zone is deeper than the benzene source zone, because naphthalene is a DNAPL whereas benzene is an LNAPL. The depth of the naphthalene source assumption is consistent with the proposed remedial depth in the source zone (URS, 2010).

4.2.2 History Matching of Plume Migration

The history matching simulation of plume migration was initiated 100 years ago (1909). The benzene plumes for the 5-year, 20-year and 100-year simulations in the shallow (Layer 2), intermediate (Layer 5) and deep (Layer 7) zones are presented in Figure 4-4. As the simulation proceeds, the benzene plume gradually grows laterally and sinks downward into deeper layers. After 20 years, the shallow plume extent remains almost constant, while the intermediate and deep plumes continue to grow. After 100 years, the extents of the intermediate and deep plumes also stabilize, as the constant contaminant mass fluxes are balanced with dilution, dispersion, adsorption, and biodegradation.

The naphthalene plumes for the 5-year, 20-year and 100-year simulations in the shallow (Layer 2), intermediate (Layer 5) and deep (Layer 7) zones are presented in Figure 4-5. The simulated extents of the naphthalene plumes are similar to the simulated benzene plumes, except that the intermediate naphthalene plume has high concentrations beneath the source area, which is consistent with the observed naphthalene concentration distribution in the intermediate zone (Figure 1-8).

4.2.3 Estimated Fate and Transport Parameters

The estimated fate and transport parameters obtained through model calibration are presented in Table 4-2 and are discussed below.

Soil-Water Distribution Coefficient

The soil-water distribution coefficient, K_d, describes the partitioning of the dissolved phase contaminant onto soil. The value of K_d is often estimated as the product of the organic carbon partition coefficient (K_{oc}) and the weight fraction of organic carbon in saturated soil (f_{oc}) (Wong, 1997) as shown in the following equation.

$$K_d = (K_{oc})\ (f_{oc})$$

The K_{oc} values for benzene and naphthalene are typically reported to be 87 L/kg and 1,288 L/kg, respectively (Knox, et al., 1993; Montgomery and Welkom, 1990). With the site-specific f_{oc} values based on the geometric means (Section 1.6.3), the calculated K_d values for benzene would range from 0.35 L/kg to 0.96 L/kg, and the calculated K_d values for naphthalene would range from 5.1 L/kg to 14 L/kg. Comparing to the interpreted benzene plumes (Figures 1-4 to 1-6) and the interpreted naphthalene plumes (Figures 1-7 to 1-9), the retardation factors calculated based these K_d values appear to be too high, which would not allow for a reasonable history matching of plume migration.

Literature search has found that the K_{oc} and K_d values of benzene and naphthalene may vary significantly when multiple organic compounds are present. As reported by Chen, et al. (2006), laboratory tests indicate that competitive sorption of mixed organic contaminants by soils can be observed. With the presence of phenanthrene, the naphthalene K_{oc} value decreases as the concentration of phenanthrene increases. Chen, et al. (2006) also points out that sorption competition is related to the heterogeneity of natural organic matter associated with the soil.

Larsen, et al. (2003) conducted laboratory batch experiments on benzene, 1, 1, 1-trichloroethane, and naphthalene sorption on various types of aquifer materials of low organic carbon content (0.006 – 0.21%), which show that the equilibrium distribution expressed by the distribution coefficients range: K_d (benzene): 0.05 – 0.65 ml/g and K_d (naphthalene): 0.1-15.7 ml/g. These values are substantially lower than the calculated values simply based on the k_{oc} values and f_{oc} values.

Given the complexity and the possible variability of the K_{oc} and K_d values of benzene and naphthalene when multiple compounds are present, which is the case for the Site, the K_d values were estimated through the transport model calibration instead of using calculated values. The estimated benzene K_d values are 0.1 L/kg for the shallow layers and 0.25 L/kg for the intermediate/deeper layers, respectively. The estimated naphthalene K_d values are 0.2 L/kg for the shallow layers and 0.5 L/kg for the intermediate/deep layers, respectively.

Biodegradation

Both benzene and naphthalene are subject to biodegradation under aerobic or anaerobic conditions. Site conditions are expected to be aerobic, given the high groundwater recharge from incident precipitation and the observed depletion of DO within the dissolved-phase plume (URS, 2008). It is also expected that the rate of aerobic degradation is greater in shallow layers relative to deep layers, as dissolved oxygen is generally more available in shallow layers. Published values for the half-life of benzene range from 10 days to 2 years, whereas half-life values for naphthalene range from 1 to 258 days (Howard, et al. 1991).

The estimated half-life for benzene through model calibration is 182 days for shallow model layers (Layers 1 to 4) and 640 days for the intermediate and deep layers (Layers 5 to 9), respectively. The estimated half-life for naphthalene is 137 days for shallow model layers and 548 days for the intermediate and deep layers.

Dispersivity

Longitudinal (10 feet), transverse (1 foot) and vertical (0.01 foot) dispersivity values were estimated through model calibration. In the source area, an increased vertical dispersivity of 0.5 feet was assumed locally in Layers 2 and 3, in order to enhance vertical plume migration. However, the simulated benzene plume in the shallow zone does not migrate downward into the intermediate zone (Layers 5 and 6) (Figure 4-4), because of the strong vertical anisotropic ratio of hydraulic conductivity. This result is consistent with the observed intermediate benzene concentrations (Figure 1-5).

Effective Porosity

Effective porosity of the glacial materials and the Magothy aquifer was assumed to be 20%, a commonly assumed effective porosity for relatively permeable materials. The effective porosity for Layer 8, which is composed of silt and clay, was assumed to be 10 percent.

Computation Method

Total Variation Diminishing (TVD) scheme and Generalized Conjugate Gradient (GCG) method (Zheng and Wang, 1998) were selected as the computation method in the MT3DMS simulation in order to achieve better mass balance, and to minimize numerical dispersion.

5.0 MODEL PREDICTION SIMULATIONS

The calibrated flow and transport models were used to evaluate the following remedial alternatives:

- No action
- In-situ remediation, under three scenarios:
  1. Scenario 1 (SC1) – in-situ solidification (ISS) excluding treatment of source material under the Medical Office Building, with addition of one oxygen injection line downgradient of source material in the LIRR ROW,
  2. Scenario 2 (SC2) - ISS including treatment of source material under the Medical Office Building, with addition of one oxygen injection line downgradient of source material in the LIRR ROW, and
  3. Scenario 3 (SC3) - ISS excluding treatment of source material under the Medical Office Building, with addition of one oxygen injection line downgradient of source material in the LIRR ROW and two oxygen injection lines downgradient of the Site.

In-situ solidification of source area materials (i.e. treatment) was simulated via a low permeability unit with hydraulic conductivity of 0.002835 ft/day (1.0E-6 cm/sec). As shown in Figure 4-3, for all remedial alternative scenarios, the source material on the northeastern portion of the Site was simulated as solidified material (treated), whereas the source material in the LIRR ROW was simulated as unsolidified (not treated). The simulation assumptions and results for each of these evaluations are discussed in Section 5.1 to 5.4.

The effects of oxygen injection were simulated in the model as a short biodegradation half-life in model cells situated along the oxygen injection lines. Based on literature review, the benzene degradation half-life in groundwater under oxygen injection can vary from 7 to 10 days, and the naphthalene degradation half-life can be even shorter (Chiang, et. al., 1989 and Newell et. al, 2002). To be conservative, a degradation half-life of 10 days was assumed for both benzene and naphthalene. The oxygen injection lines were assumed to have effect in the shallow groundwater system (Layers 2, 3, and 4). The lateral effective zone was assumed to be approximately 40 feet, or two model cells, along each injection line. The oxygen injection was assumed to be operational for the entire simulation period.

For the purpose of comparing the effects of the proposed remedial alternatives, an assumed alternative for complete source removal was simulated (Section 5.5). Comparison of the effects of the remedial alternatives at a select location downgradient of the plumes is discussed in Section 5.6.

5.1 NO ACTION

Simulation Assumptions

The assumptions for the No-Action case include:

- Groundwater flow conditions are the same as the calibrated steady-state condition.
- Contaminant sources are assumed to be constant, as was assumed in the transport model calibration.
- The initial plumes (starting condition) for the predictive simulations are the history matching results of the 100-year simulation.
- Natural fate and transport parameters are the same as calibrated in the history matching simulations (Table 4-2).

The source assumption of constant concentration is a conservative assumption for the future prediction because, after source releases stopped in 1950s, NAPL sources should have slowly weathered away and are expected to continue to weather as the soluble components, such as BTEX and naphthalene, of the NAPL are depleted.

Simulated Plume Fate and Transport

The predicted benzene and naphthalene plumes after 20 years and 50 years of simulation for the shallow, intermediate, and deep groundwater zones are presented in Figures 5-1 and 5-2, respectively. As shown in Figure 5-1, the extents of the 20-year and 50-year simulated shallow benzene plume are identical, indicating that the shallow plume has reached equilibrium, whereas the intermediate and deep benzene plumes appear to lengthen over time. The equilibrated state of the shallow plume is likely attributed to a shorter degradation half-life of contaminants in the shallow zone, relative to deeper zones, that is in balance with the constant mass flux of contaminants out of the source zone. It is expected that the biotransformation rate in the intermediate and deep layers is slower than the generation of the mass fluxes into the intermediate and deep zones. The predicted naphthalene plumes exhibit similar migration patterns as the predicted benzene plumes, except that the intermediate naphthalene plume has higher concentrations attributable to the deep source zone in the northwestern portion of the Site (Layer 4). In addition, the naphthalene plumes migrate at a slower rate due to the higher K_d values for naphthalene.

5.2 SCENARIO 1

For SC1, solidified areas were assumed to include on-Site source material, as well as source material in the area immediately downgradient from the Site (parking lot) and source material on the northeastern portion of the Site. Source material remaining under the Medical Office Building and in the LIRR ROW was not simulated as solidified material. A short oxygen injection line was simulated downgradient of source material in the LIRR ROW.

Simulation Assumptions

This scenario simulates the proposed remedial action, under the same basic assumptions as the No-Action scenario, except for the following:

- The hydraulic conductivity in the proposed solidification zones in Layers 2, 3 and 4 (Figure 4-3) are assumed to be 1.0E-6 cm/s, or 2.835E-03 ft/day. This reduced permeability is applied to the entire source area, except for source material under the Medical Office Building zone and under the LIRR ROW.

- Groundwater recharge in the proposed treatment zone is assumed to be 1 inch/year, or 2.28E-4 ft/day. This assumption was made based on the understanding that, once the area is solidified, percolation of infiltrated water through the treatment zone would be significantly reduced.

Simulated Groundwater Mounding

Simulated groundwater mounding in the solidification area is shown in Figure 5-3. The simulated groundwater mounding in response to ISS is up to 57 ft in Layer 2, which is about 14 feet higher than the surrounding groundwater table. The extremely low hydraulic conductivity also results in groundwater mounding from Layer 2 to Layer 1, where the previously unsaturated zone (inactive model cells) becomes saturated. The simulated groundwater elevations in Layer 1 are up to 70 ft, which is about 10 ft higher than the top of the proposed ISS materials. This indicates that there may be a perched saturated zone above the ISS materials as the result of solidification.

Groundwater flow pathways in the vicinity of the ISS area are altered in response to the solidification of the source material, as illustrated by simulated particle tracks shown in Figure 5-3. Particles initiated upgradient of the source area in Layer 2 either move laterally around the solidification zone, or move downward into Layer 3 beneath the solidification zone, and then move downgradient. This differs from the particle tracks under natural flow conditions, where all particles move linearly downgradient within Layer 2, until reaching HIMW-8 (Figure 4-1).

Simulated Plume Fate and Transport

The predicted benzene and naphthalene plumes after 20 years and 50 years of simulation for the shallow, intermediate and deep groundwater zones are presented in Figures 5-4 and 5-5, respectively. The contaminant plumes in Figures 5-1 and 5-2 (No-Action scenario) were compared to the contaminant plumes after implementation of ISS (Figures 5-4 and 5-5). The extents and the concentrations of the post-ISS plumes in the intermediate and deep zones are significantly reduced. The extents of the shallow plumes are only slightly reduced, but the concentrations in the downgradient area of the source zone are significantly reduced. The effect of the short oxygen injection line downgradient of the LIRR ROW is evident in the simulated shallow plumes, where contaminant concentrations drop significantly downgradient of the injection line. Because the LIRR ROW was assumed to be a constant source in the model, the effect of the portion of the oxygen injection line that cuts across the LIRR ROW was not simulated. Therefore, simulation results regarding the effect of the oxygen injection in this part of the model are overly conservative.

5.3 SCENARIO 2

For SC2, solidified areas were assumed to include on-Site source material, as well as source material in the area immediately downgradient from the Site (parking lot) and source material on the northeastern portion of the Site. In addition, source material under the Medical Office Building was simulated as solidified material. Source material in the LIRR ROW was not simulated as solidified material. A short oxygen injection line was simulated downgradient of source material in the LIRR ROW.

Simulated Plume Fate and Transport

The predicted benzene and naphthalene plumes after 20 years and 50 years of simulation for the shallow, intermediate, and deep groundwater zones are presented in Figures 5-6 and 5-7, respectively. Results of the simulation including solidification of source material below the Medical Office Building do not vary significantly from the results of the simulation excluding solidification of source material below the Medical Office Building.

5.4 SCENARIO 3

For this simulation, solidified areas were assumed to be the same as for SC1. In addition to the short northeastern oxygen injection line, two long oxygen injection lines were added downgradient of the Site.

Simulated Plume Fate and Transport

The predicted benzene and naphthalene plumes after 20 years and 50 years of simulation for the shallow, intermediate and deep groundwater zones are presented in Figures 5-8 and 5-9, respectively. Simulation results indicate that the shallow plume does not move beyond the oxygen injection lines, and that the extent of the intermediate and deep plumes is substantially reduced due to a reduction in contaminant mass migration from the shallow zone to the intermediate and deep zones in response to the in-situ oxygen injection.

5.5 SOURCE MATERIAL SOLIDIFICATION AND SOURCE REMOVAL

The purpose of this simulation was to evaluate the effects of ISS, coupled with complete removal of source materials, on the concentrations of dissolved-phase contaminant plumes. Complete source removal was simulated by turning off the constant concentration cells used to represent source materials. The results of this simulation were used to evaluate the effectiveness of the proposed remedial alternatives (i.e. no action, SC1, SC2 and SC3).

5.6 COMPARISON OF REMEDIAL ALTERNATIVES

Simulated 50-year benzene and naphthalene concentration trends for the shallow groundwater zone are compared between the remedial alternatives, no-action, and assumed source-removal condition. The concentrations at an imaginary monitoring well situated at the intersection of Atlantic Avenue and Wendell Street, a location immediately downgradient of the source area, are presented in Figures 5-10 and 5-11, respectively. The location of the imaginary monitoring well is depicted in Figures 5-4 to 5-9.

Figures 5-10 and 5-11 indicate that:

- ISS of source material results in a significant decrease in the concentration of benzene and naphthalene, when compared to the No Action scenario.

- There is no significant difference in the remedial outcome between ISS including source material under the Medical Office Building and ISS excluding source material under the Medical Office Building.

- Use of oxygen injection lines substantially reduces concentrations downgradient of the source zone.

6.0 CONCLUSIONS AND MODEL UNCERTAINTY

Modeling results indicate that solidification in the source zone by reducing the permeability of the source material to a hydraulic conductivity of 1.0E-6 cm/s via ISS would:

- Reduce groundwater flow through the solidified zone, thereby significantly reducing the dissolved-phase contaminant mass flux migrating from the source zone to downgradient areas.
- Create limited groundwater mounding in the vicinity of the source area, which may result in a perched groundwater zone above the solidified material. However, this localized effect does not alter the overall dissolved-phase contaminant plume migration pathway.

Comparison of the results of the remedial alternatives evaluated via modeling indicates that:

- ISS of source material would effectively reduce future benzene and naphthalene concentrations in the shallow, intermediate and deep groundwater systems downgradient of the Site.
- The difference in the remedial outcome between ISS including source material under the Medical Office Building, and ISS excluding source material under the Medical Office Building, appears to be insignificant, based on the assumed contaminant concentrations in the Medical Office Building area.
- Use of oxygen injection lines substantially reduces concentrations downgradient of the Site.

It is important to note that model simulations assume that source material in the LIRR ROW will not undergo ISS. Therefore, this source area will continue to contribute contaminant mass to dissolved-phase groundwater impacts. Based on modeling results, the use of oxygen injection has been demonstrated to be an effective alternative for treating contaminant mass from the LIRR ROW. The operation and maintenance period of any proposed oxygen injection lines may be significant, and will be dependent on actual field conditions.

The simulated extent of groundwater plumes have uncertainties that are attributed to uncertainties associated with model assumptions and estimated hydraulic parameters and fate and transport parameters. These uncertainties primarily affect the predicted extents of groundwater plumes, concentration levels within the plumes, and the longevity of the plumes. These uncertainties may not prevent the model conclusion that ISS of source material is an effective remedy, as long as the solidification can effectively reduce the permeability of the source materials to the assumed values. There will also be uncertainty in the simulated biodegradation effect of the proposed oxygen injection lines. The actual effect may not be as uniform as simulated in the model, and could be greater or less than model simulations predict, depending on actual performance.

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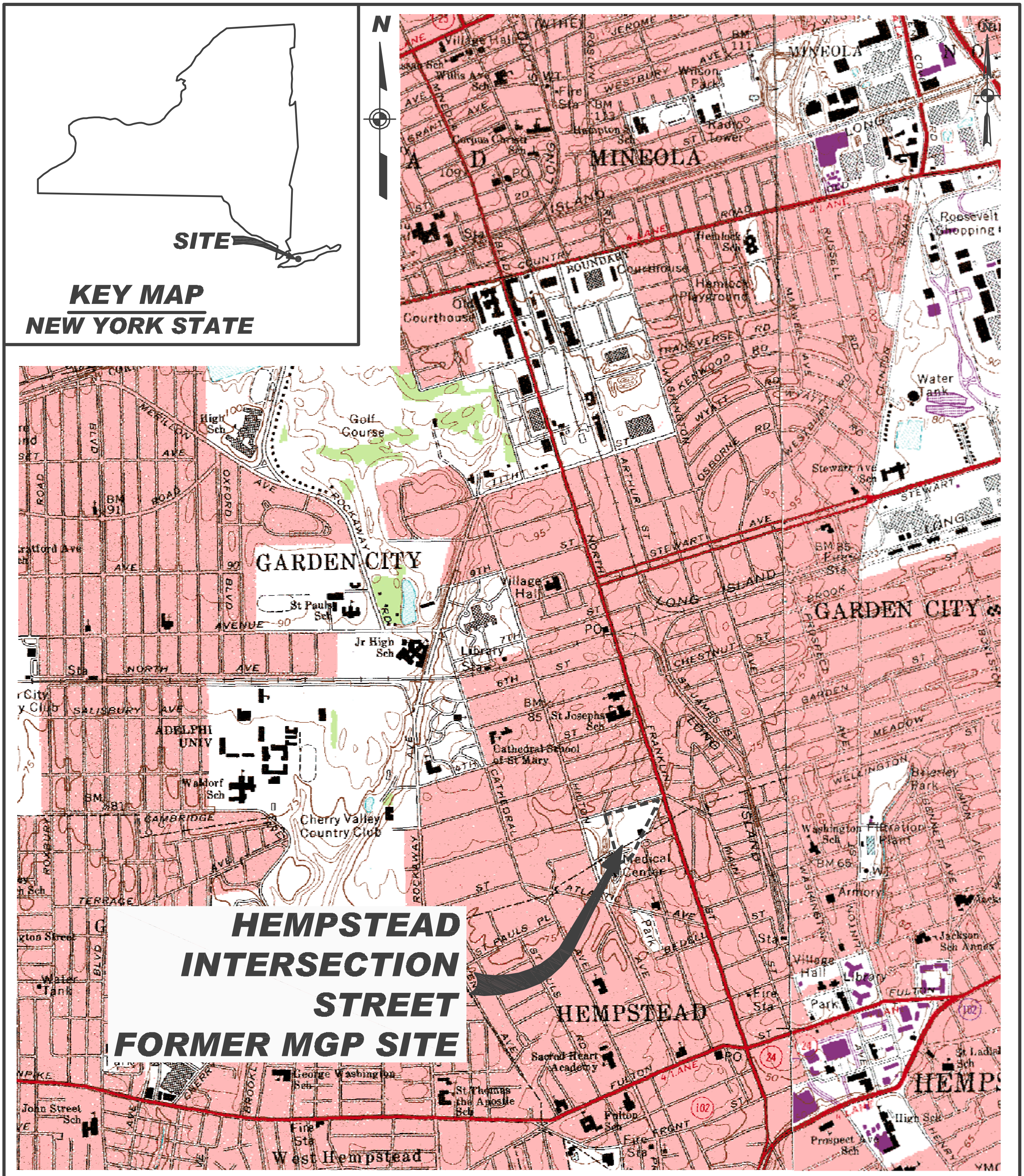
FIGURES



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DRAWN:	FS

CLIENT: NATIONAL GRID

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

PROJECT NO: 11176098

TITLE: SITE LOCUS

FIGURE NO.: 1-1

P:\acad-project\Keyspan-Hempstead-NY\dwg\SiteLocus.dwg, SiteLocus, 9/1/2010 1:44:12 PM

LEGEND

▬ ▬ ▬	NATIONAL GRID PROPERTY BOUNDARY
⌖	MONITORING WELL
⌖	SIMULATED MONITORING WELL LOCATION

N

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0 300 600
SCALE IN FEET

PROJECT NO:	11176098		
DESIGN:	FS	SCALE:	1" = 300'
APPROVED:	GJB	DATE:	AUG 2010
DRAWN:	FS	FILE NO:	GwModel

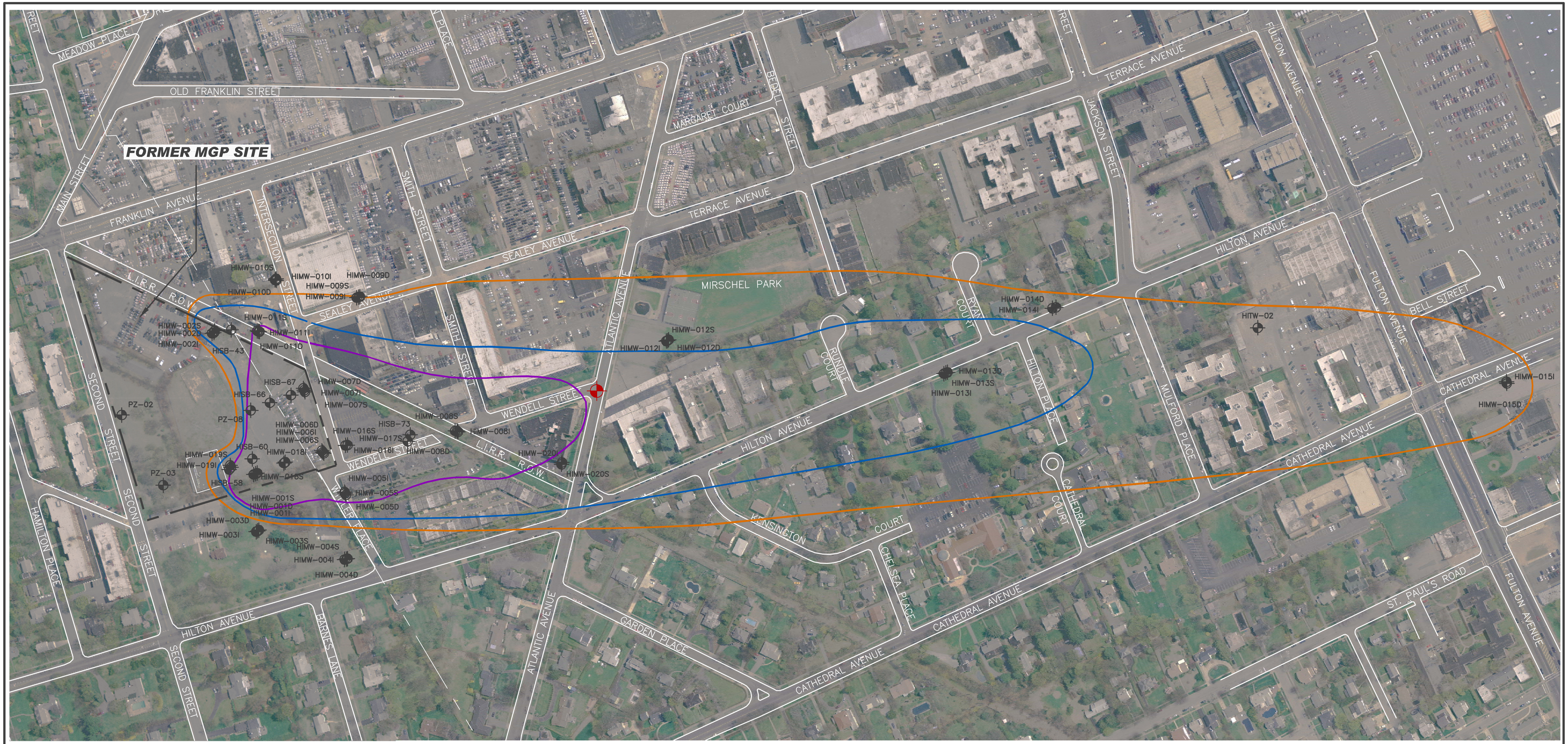
CLIENT: NATIONAL GRID

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

TITLE: SITE PLAN

FIGURE NO.: 1–2

P:\acad-project\Keyspan-Hempstead-NY\dwg\GwModel.dwg, GWMR_1-2_SitePlan, 9/1/2010 1:28:00 PM



N

LEGEND

▬ ▪ ▪ ▬	NATIONAL GRID PROPERTY BOUNDARY
⊕	MONITORING WELL
⊕	SIMULATED MONITORING WELL LOCATION
▬	ESTIMATED EXTENT OF GROUNDWATER PLUME AS DEFINED BY TOTAL BTEX AND/OR TOTAL PAH CONCENTRATIONS EQUAL TO, OR GREATER, THAN 5,000 MICROGRAMS PER LITER (UG/L)
▬	ESTIMATED EXTENT OF GROUNDWATER PLUME AS DEFINED BY TOTAL BTEX AND/OR TOTAL PAH CONCENTRATIONS EQUAL TO, OR GREATER, THAN 1,000 UG/L
▬	ESTIMATED EXTENT OF GROUNDWATER PLUME AS DEFINED BY TOTAL BTEX AND/OR TOTAL PAH CONCENTRATIONS EQUAL TO, OR GREATER, THAN 100 UG/L

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0 300 600
SCALE IN FEET

PROJECT NO:	11176098		
DESIGN:	FS	SCALE:	1" = 300'
APPROVED:	GJB	DATE:	AUG 2010
DRAWN:	FS	FILE NO:	GwModel

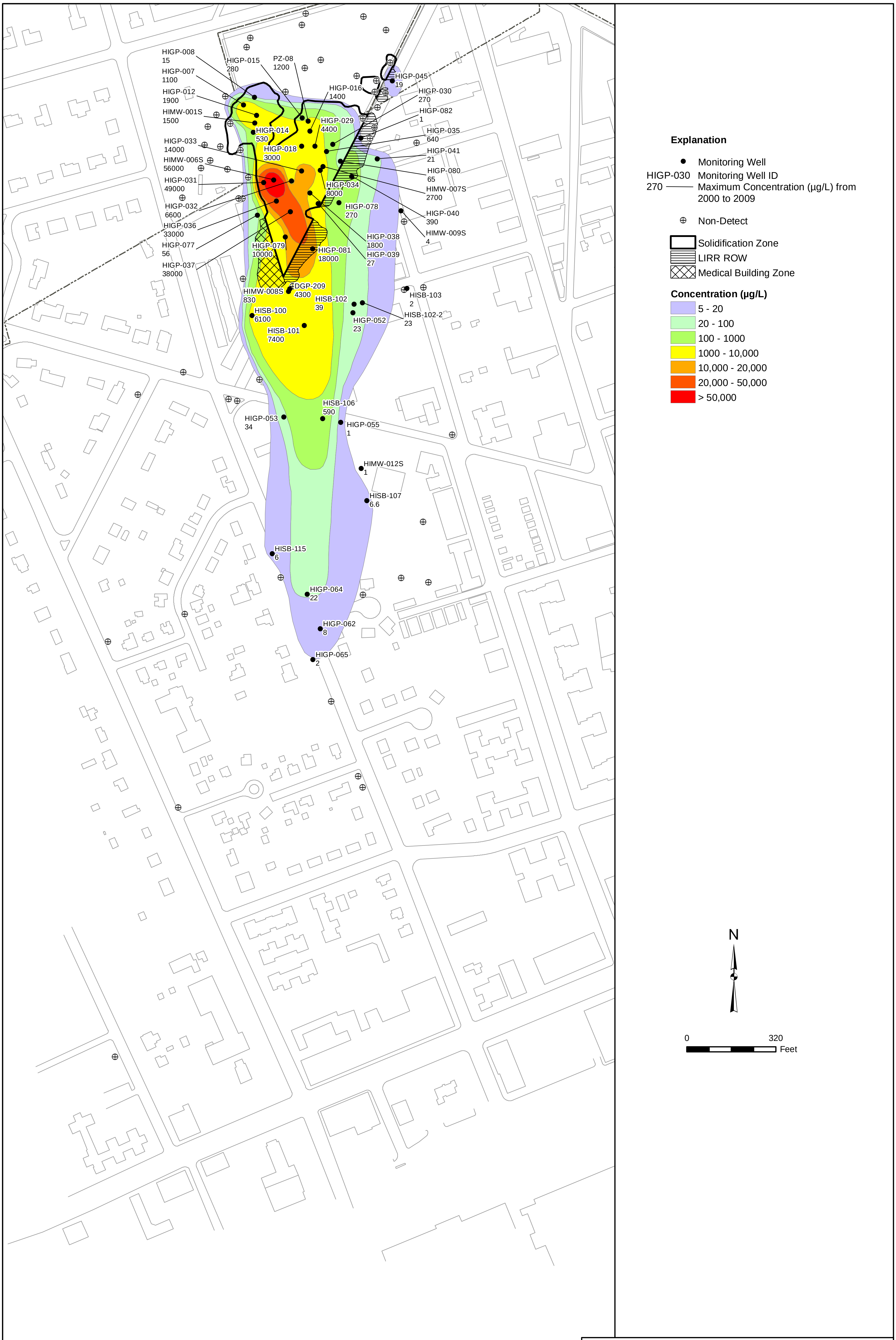
CLIENT:
NATIONAL GRID

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

TITLE:
DISSOLVED-PHASE BTEX
AND PAH PLUME IN
GROUNDWATER

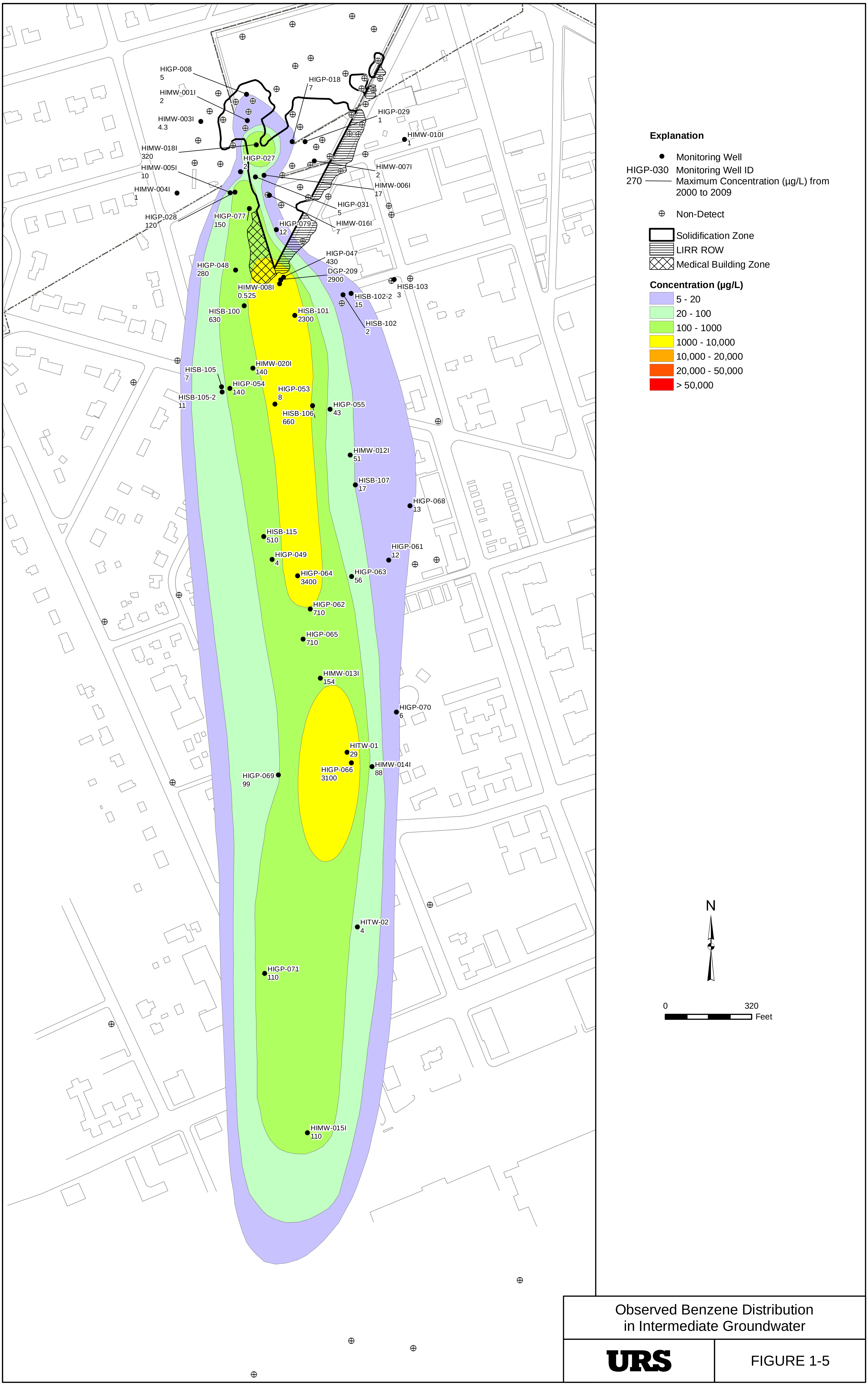
FIGURE NO.:
1-3

P:\acad-project\Keyspan-Hempstead-NY\dwg\GwModel.dwg, GWMR_1-3_Plume, 9/1/2010 1:39:32 PM



Observed Benzene Distribution
in Shallow Groundwater

FIGURE 1-4



Observed Benzene Distribution
in Intermediate Groundwater

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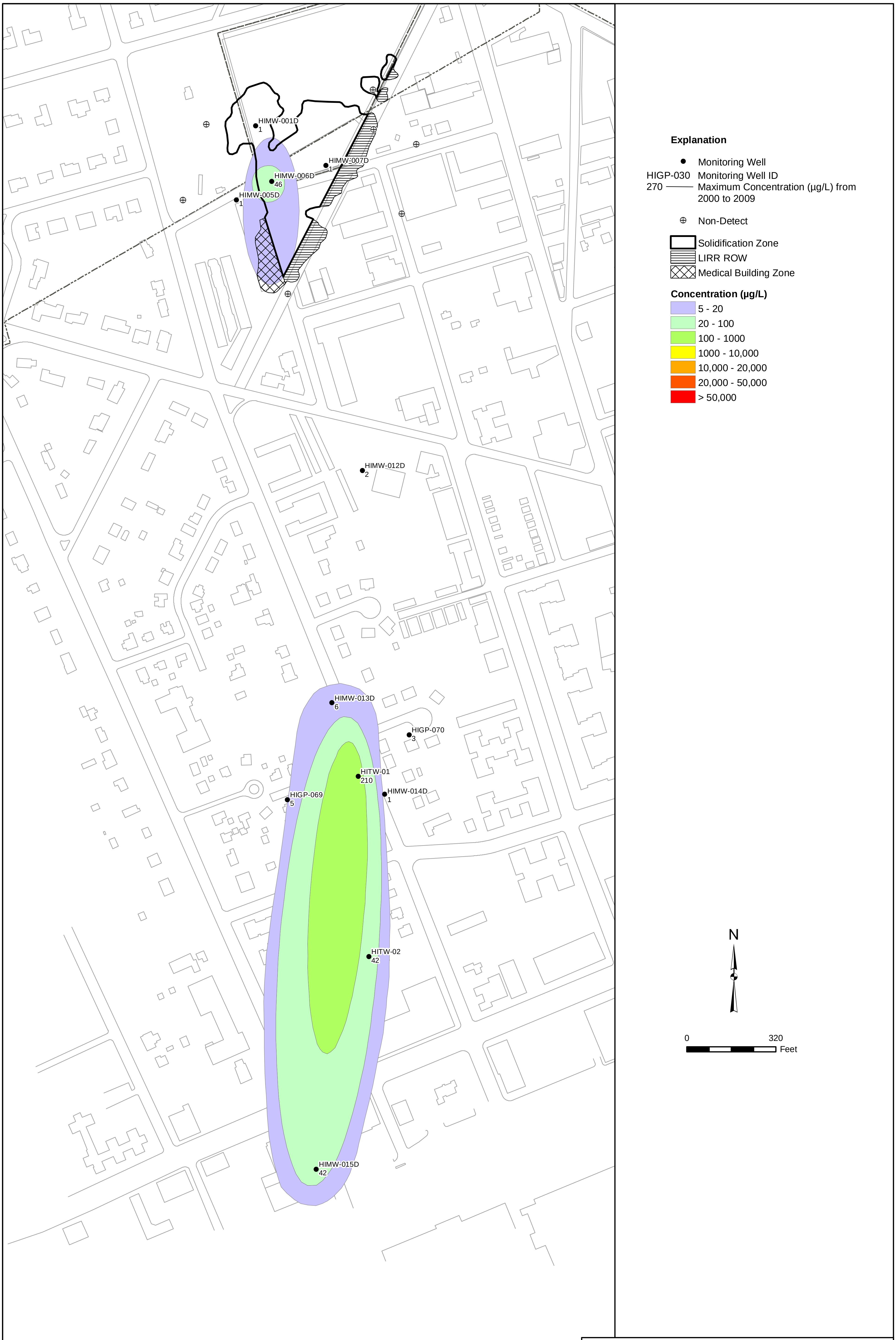
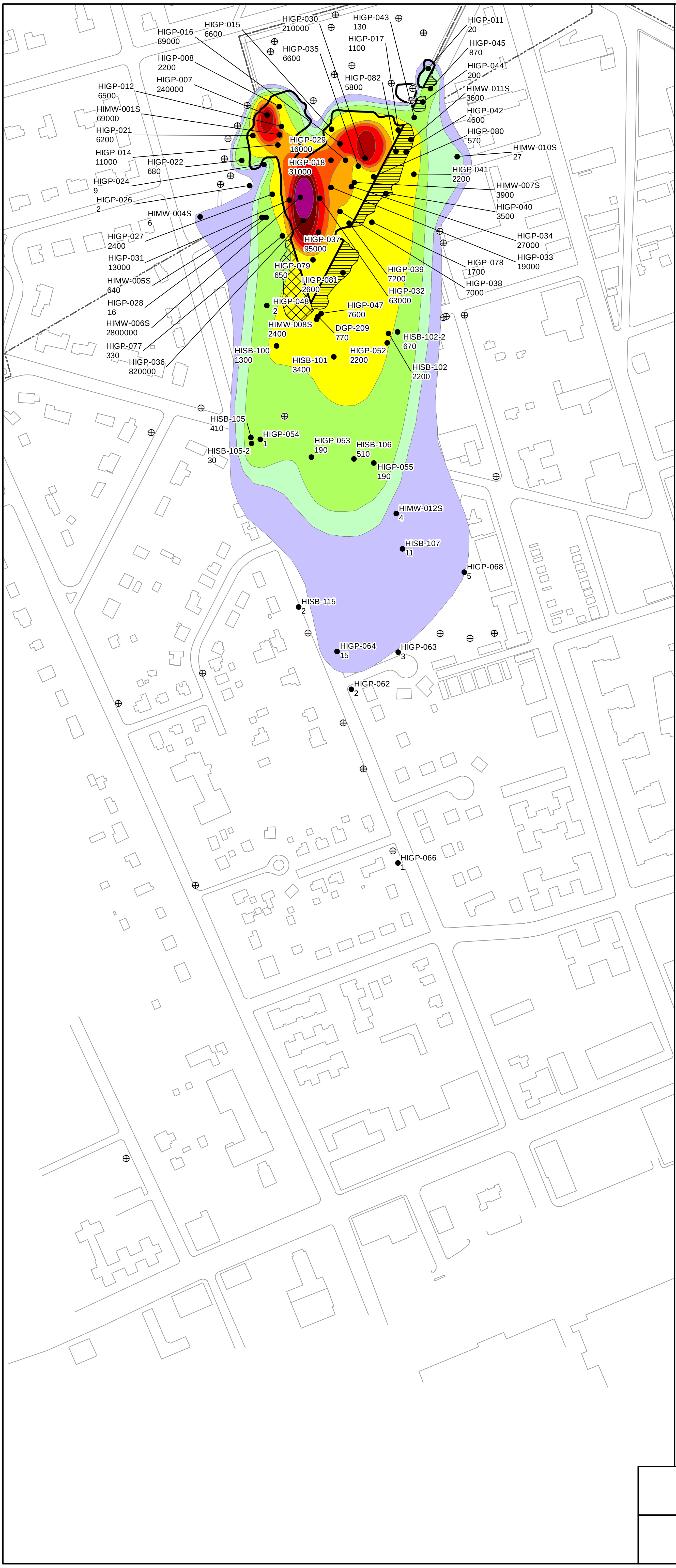
FIGURE 1-5



Observed Benzene Distribution in Deep Groundwater

URS

FIGURE 1-6



Explanation

● Monitoring Well

HIGP-030 Monitoring Well ID
270 —— Maximum Concentration (µg/L) from 2000 to 2009

⊕ Non-Detect

▭ Solidification Zone
▤ LIRR ROW
▩ Medical Building Zone

Concentration (µg/L)

🟪 5 - 20
🟩 20 - 100
🟩 100 - 1000
🟨 1000 - 10,000
🟧 10,000 - 20,000
🟧 20,000 - 50,000
🟥 50,000 - 100,000
🟥 100,000 - 500,000
🟫 500,000 - 1,000,000
🟪 > 1,000,000

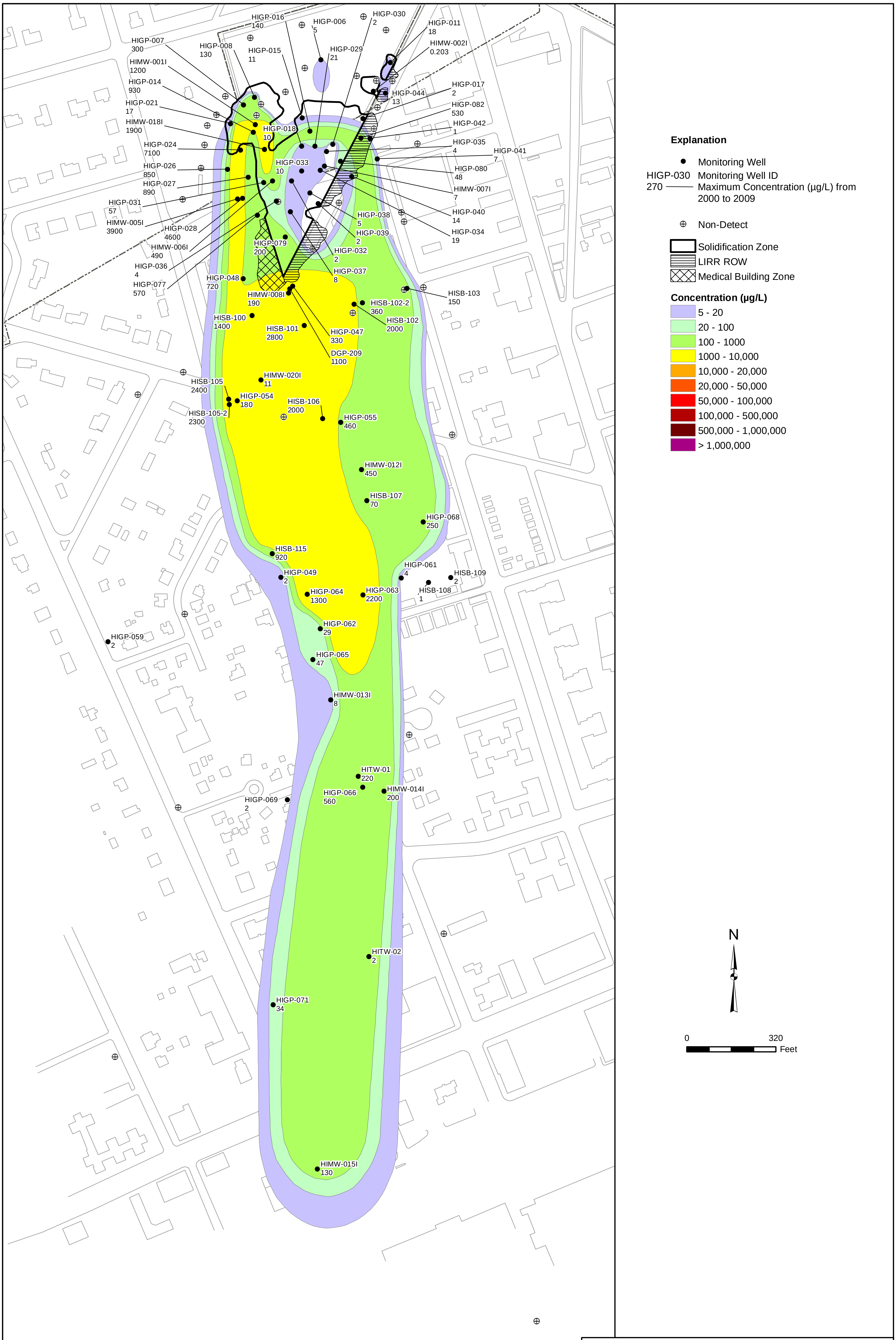
N

0 320
Feet

Observed Naphthalene Distribution in Shallow Groundwater

URS

FIGURE 1-7



Observed Naphthalene Distribution in Intermediate Groundwater

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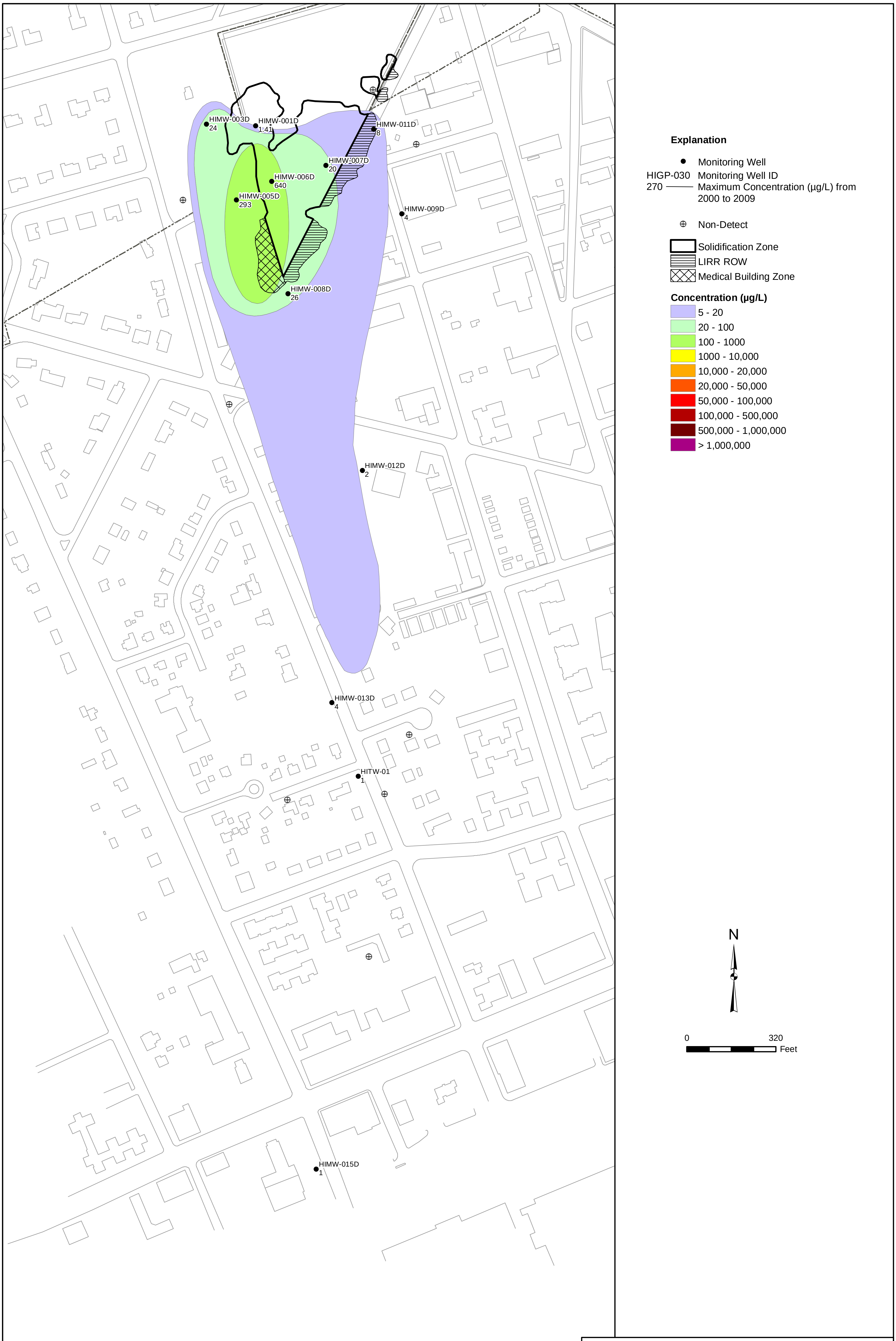
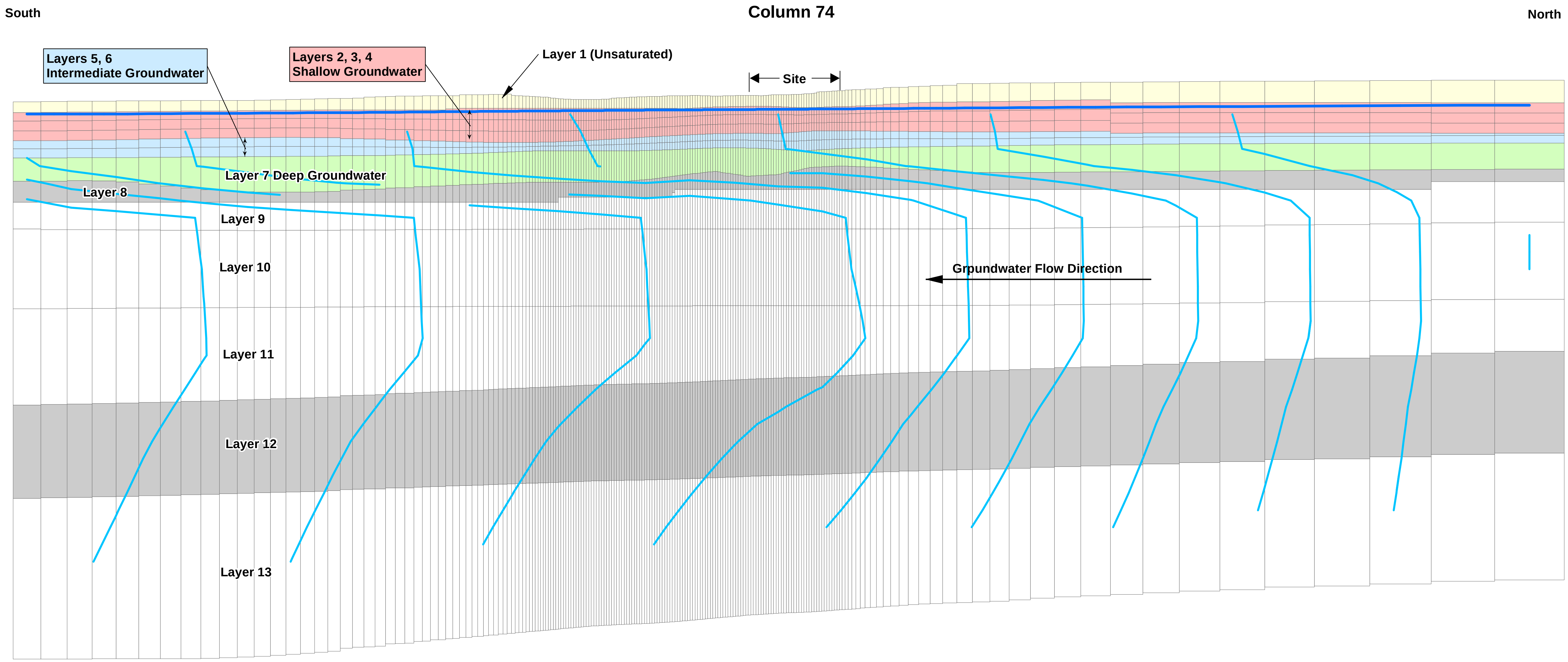
FIGURE 1-8



Observed Naphthalene Distribution in Deep Groundwater

URS

FIGURE 1-9



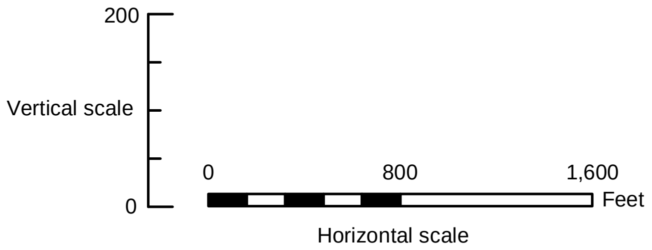
Layers 1, 2, 3 and 4 - Fill/topsoil and Glacial Outwash
Layers 1, 2, 3, and 4 are considered as shallow zone, corresponding to shallow monitoring wells

Layers 5 and 6 - Upper subunit of Upper Magothy
Layers 5 and 6 are considered as intermediate zone, corresponding to intermediate monitoring wells

Layer 7 - Lower portion of upper subunit of Upper Magothy
Layer 7 is considered as deep zone, corresponding to deep monitoring wells

Layer 8 - Lower subunit of Upper Magothy
Layer 8 is a low permeability layer, which acts as a confining layer at the bottom of Upper Magothy

Layers 9, 10, and 11 - Lower Magothy
Layer 12 - Raritan Clay
Layer 13 - Lloyd Aquifer



Legend

— Hydraulic Head
— Water Table

Typical Flow Model Domain Cross-Section

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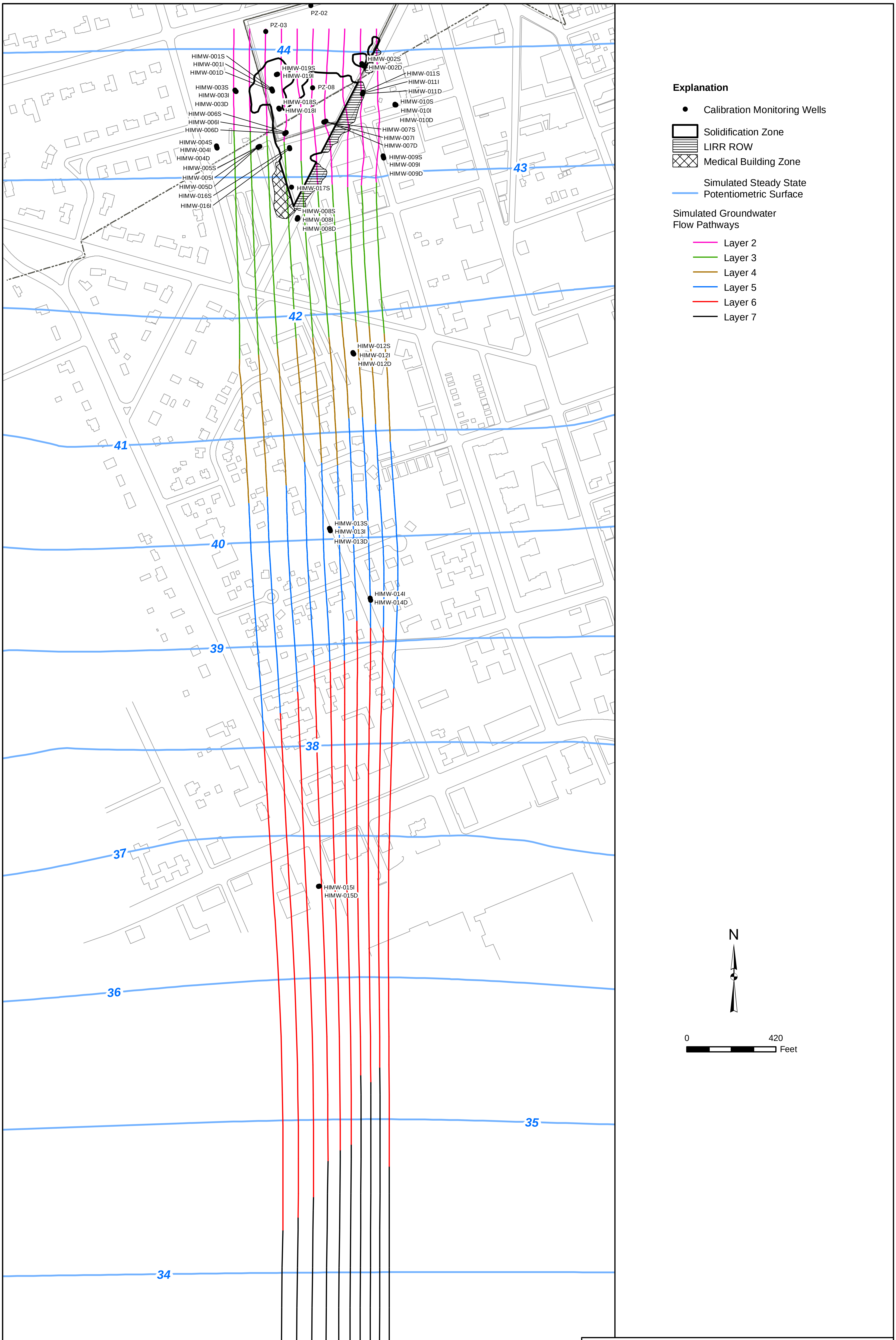
FIGURE 3-1

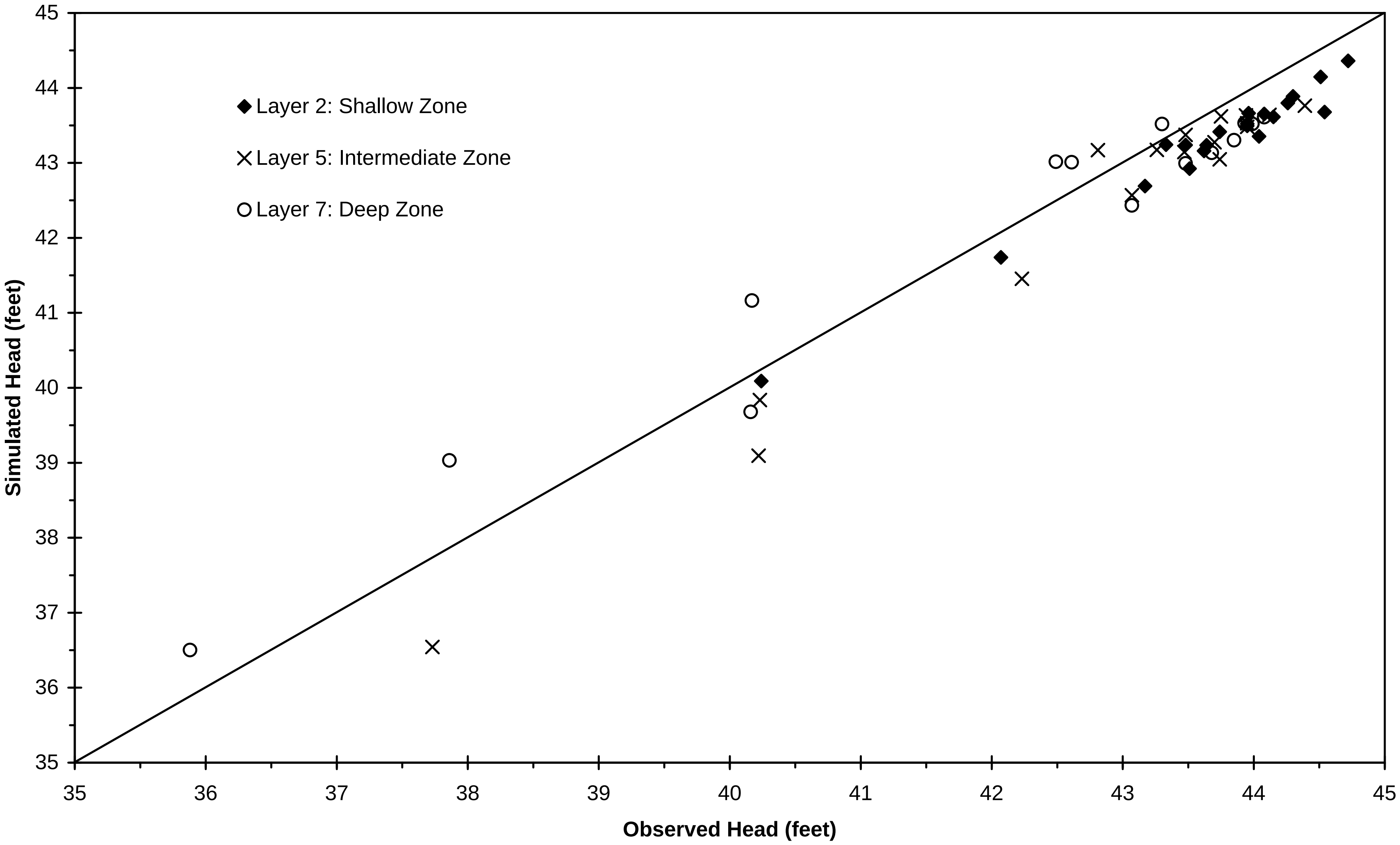


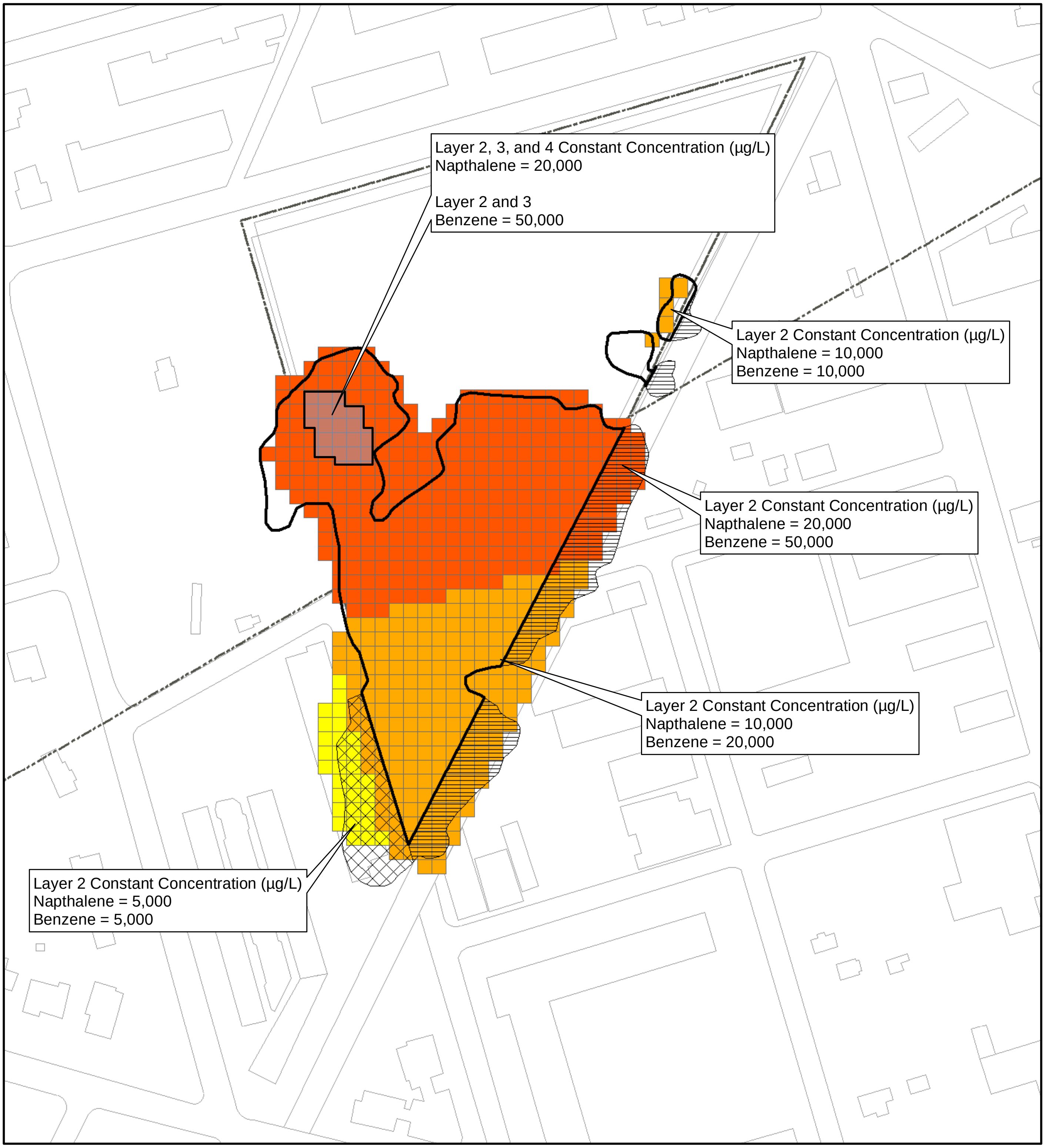
Calibrated Steady-State Flow Model Groundwater
Surface Potentiometric Head Distribution and
Simulated Groundwater Flow Pathways

URS

FIGURE 4-1

Figure 4-2. Comparison of Observed and Calibrated Hydraulic Heads

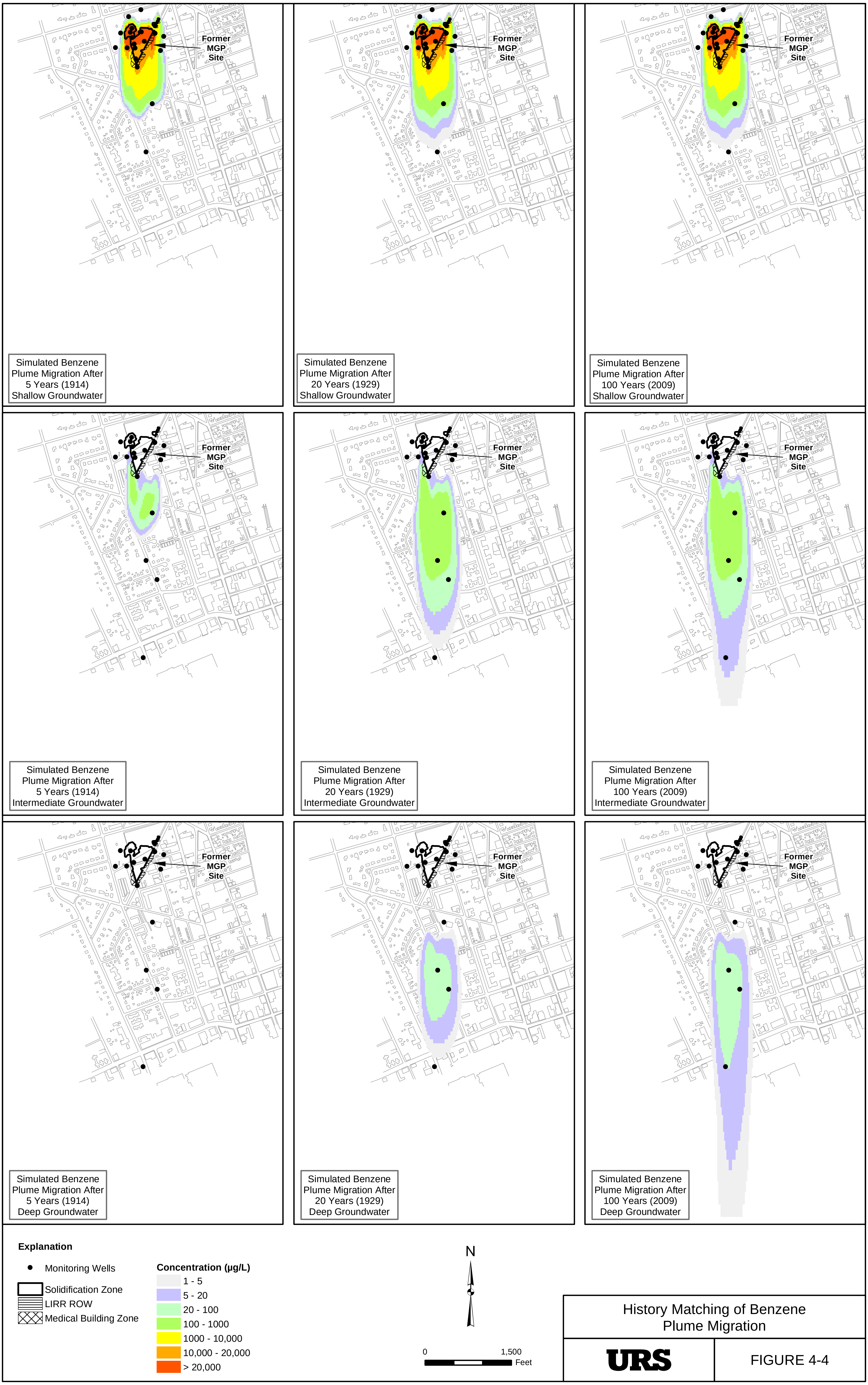




Transport Model Constant Concentration Boundaries

URS

FIGURE 4-3



History Matching of Benzene Plume Migration

URS

FIGURE 4-4

Simulated Naphthalene Plume Migration After 5 Years (1914) Shallow Groundwater

Simulated Naphthalene Plume Migration After 20 Years (1929) Shallow Groundwater

Simulated Naphthalene Plume Migration After 100 Years (2009) Shallow Groundwater

Simulated Naphthalene Plume Migration After 5 Years (1914) Intermediate Groundwater

Simulated Naphthalene Plume Migration After 20 Years (1929) Intermediate Groundwater

Simulated Naphthalene Plume Migration After 100 Years (2009) Intermediate Groundwater

Simulated Naphthalene Plume Migration After 5 Years (1914) Deep Groundwater

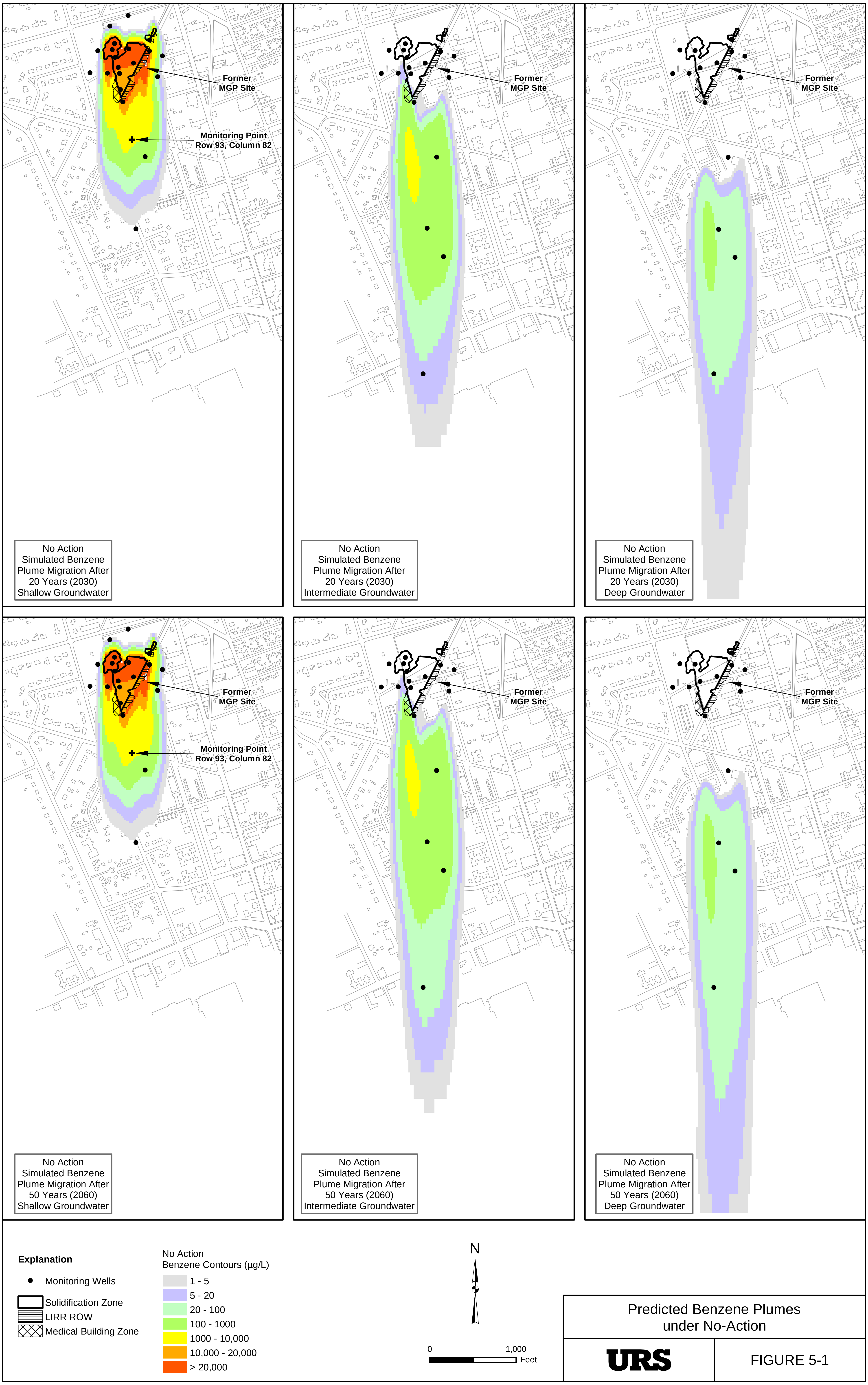
Simulated Naphthalene Plume Migration After 20 Years (1929) Deep Groundwater

Simulated Naphthalene Plume Migration After 100 Years (2009) Deep Groundwater

History Matching of Naphthalene Plume Migration

URS

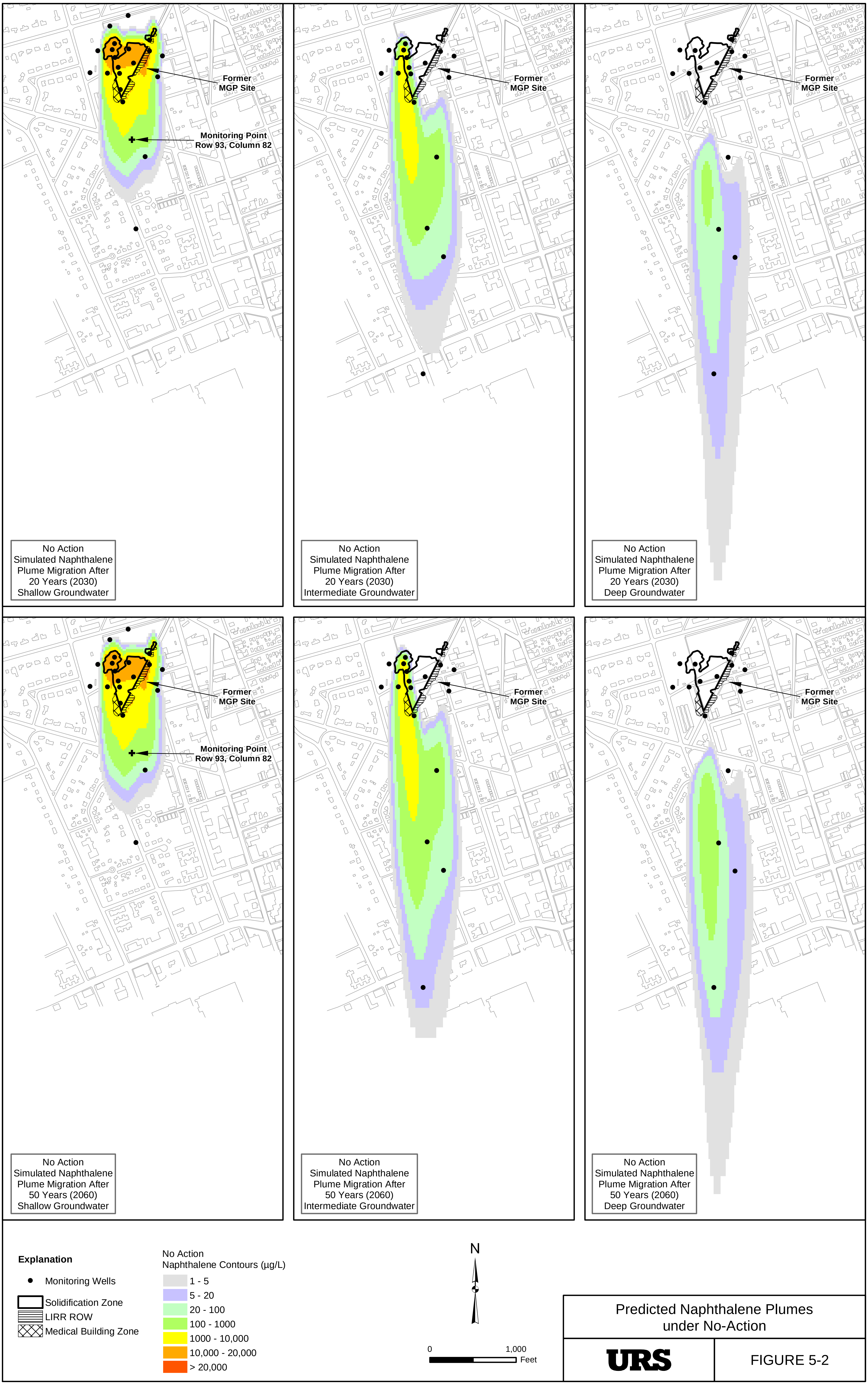
FIGURE 4-5



Predicted Benzene Plumes under No-Action

URS

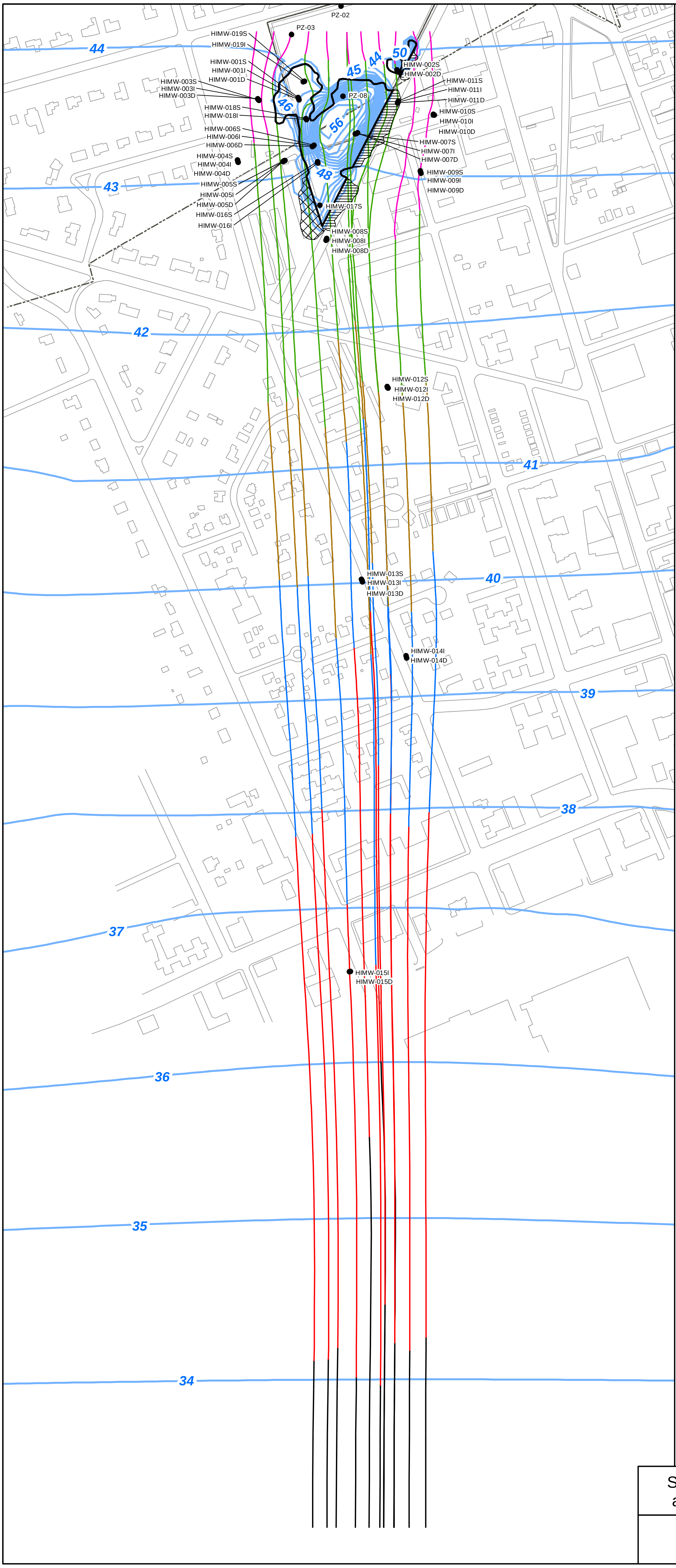
FIGURE 5-1



Predicted Naphthalene Plumes under No-Action

URS

FIGURE 5-2



Explanation

● Calibration Monitoring Wells

▭ Solidification Zone

▤ LIRR ROW

▦ Medical Building Zone

Simulated Steady State Potentiometric Surface

Simulated Groundwater Flow Pathways

- Layer 2
- Layer 3
- Layer 4
- Layer 5
- Layer 6
- Layer 7

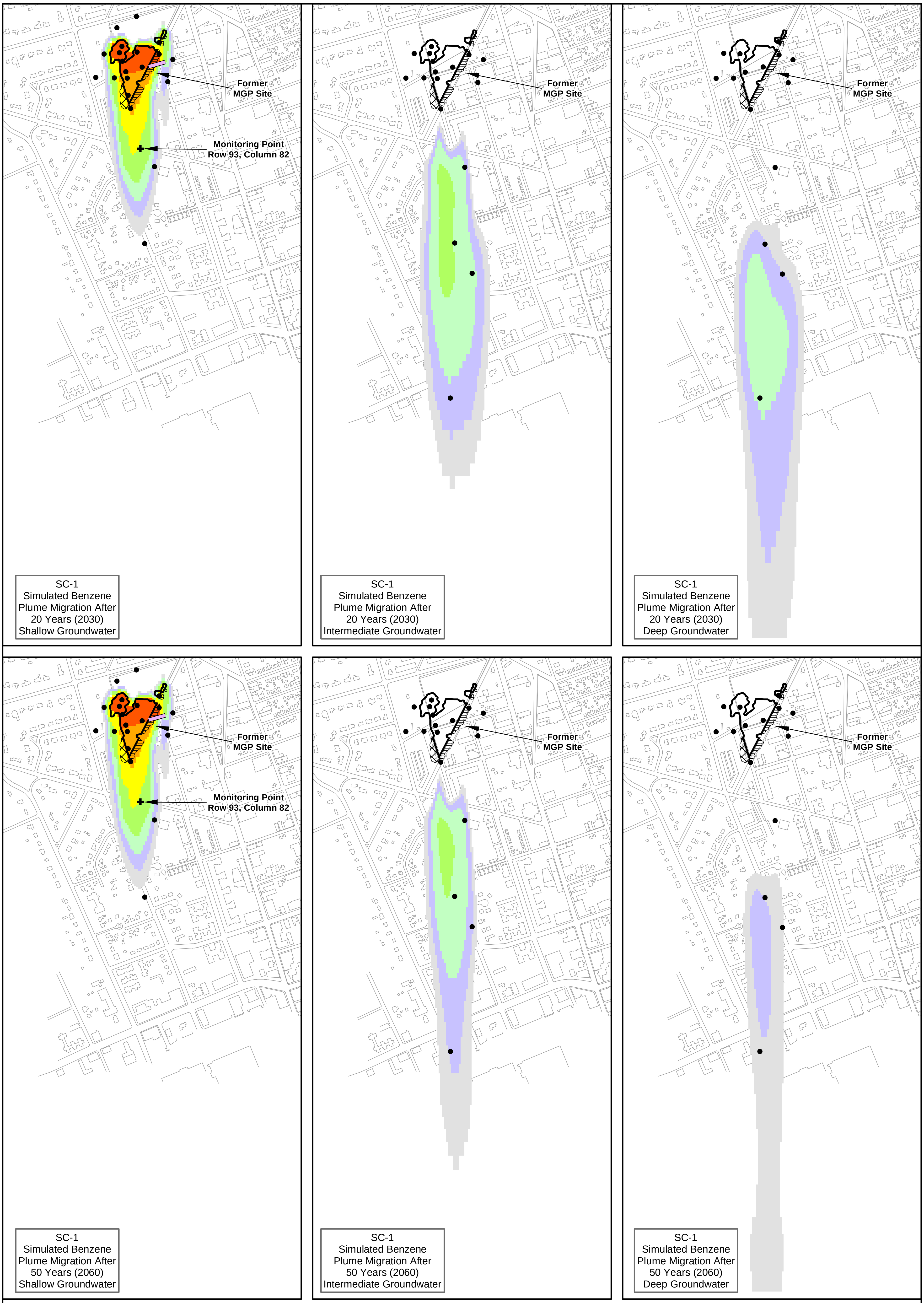
N

0 420 Feet

SC-1 Predicted Groundwater Mounding and Flow Pathways with Solidification

URS

FIGURE 5-3



Explanation

- ● Monitoring Wells
- ▭ Solidification Zone
- ☰ LIRR ROW
- ▨ Medical Building Zone
- ═ Proposed Oxygen Injection Lines

SC-1: Solidification of Source Zone excluding Medical Building and LIRR ROW, and NE Oxygen Injection
Benzene Contours (µg/L)

- ⬜ 1 - 5
- 🟪 5 - 20
- 🟩 20 - 100
- 🟩 100 - 1000
- 🟨 1000 - 10,000
- 🟧 10,000 - 20,000
- 🟥 > 20,000

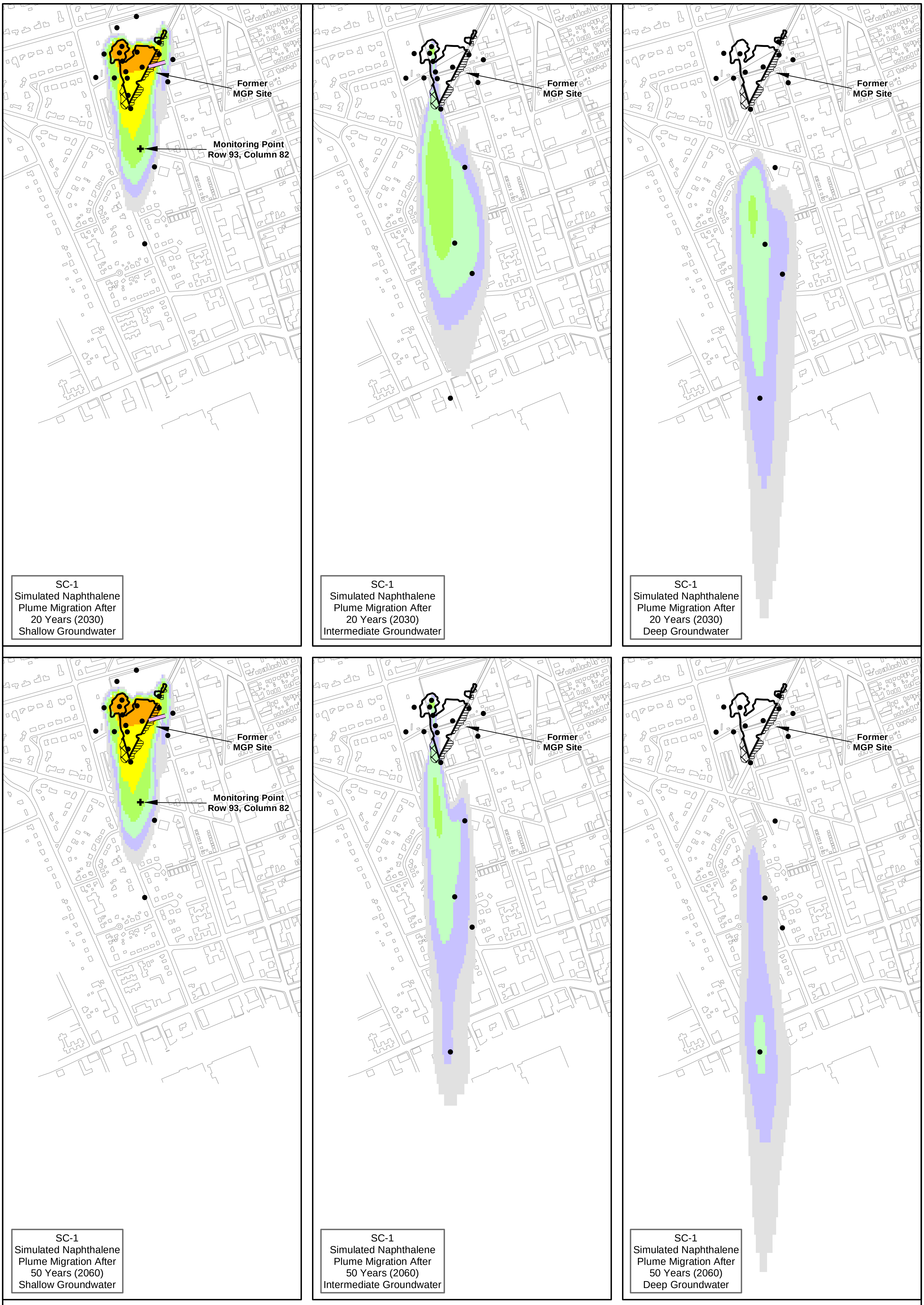
N

0 1,000
Feet

SC-1 Predicted Benzene Plume

URS

FIGURE 5-4



Explanation

● Monitoring Wells

▭ Solidification Zone

▤ LIRR ROW

▩ Medical Building Zone

— Proposed Oxygen Injection Lines

SC-1: Solidification of Source Zone excluding Medical Building and LIRR ROW, and NE Oxygen Injection
Naphthalene Contours (µg/L)

- ⬜ 1 - 5
- 🟪 5 - 20
- 🟩 20 - 100
- 🟩 100 - 1000
- 🟨 1000 - 10,000
- 🟧 10,000 - 20,000
- 🟥 > 20,000

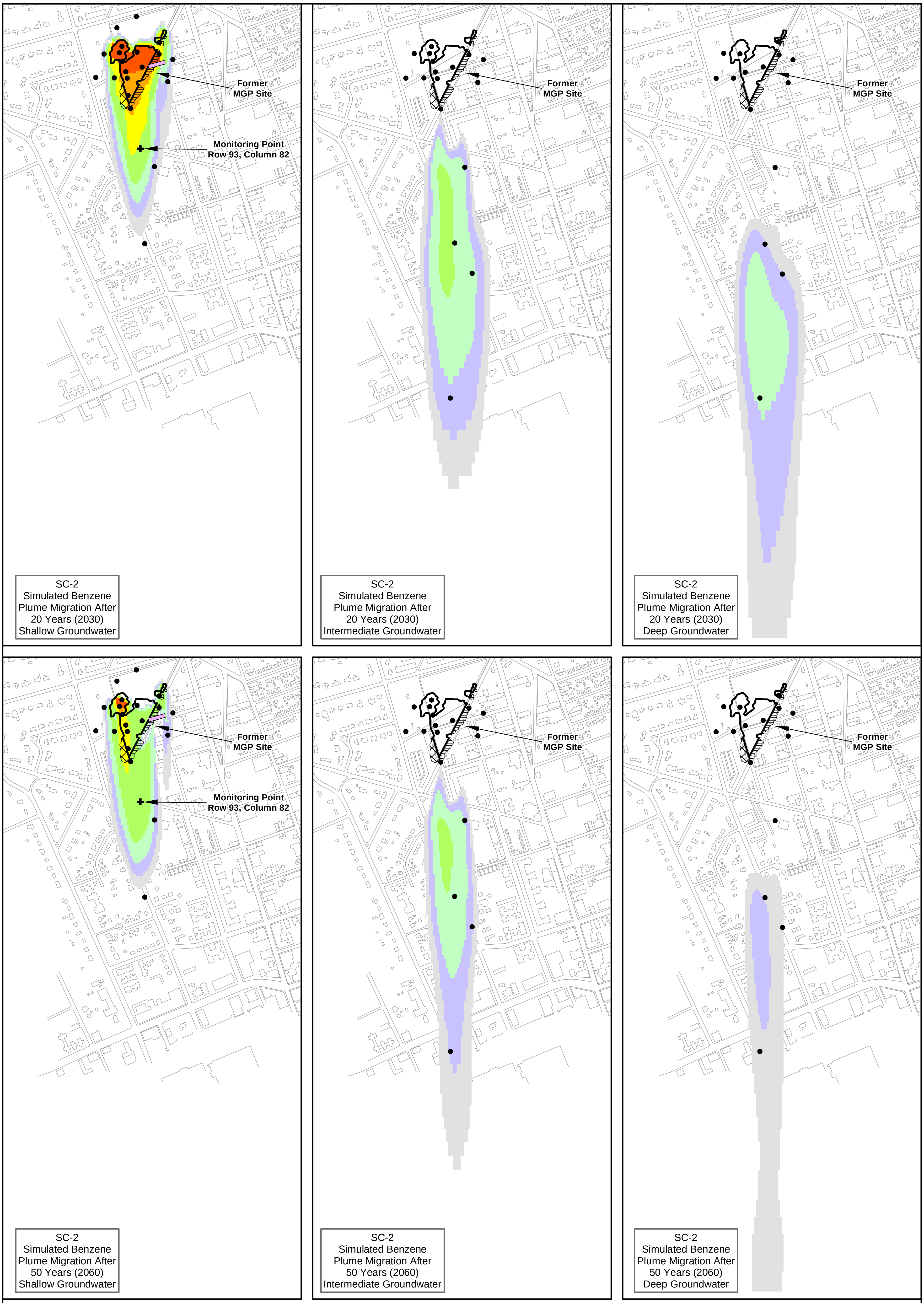
N

0 1,000 Feet

SC-1 Predicted Naphthalene Plume

URS

FIGURE 5-5



SC-2
Simulated Benzene
Plume Migration After
20 Years (2030)
Shallow Groundwater

SC-2
Simulated Benzene
Plume Migration After
20 Years (2030)
Intermediate Groundwater

SC-2
Simulated Benzene
Plume Migration After
20 Years (2030)
Deep Groundwater

SC-2
Simulated Benzene
Plume Migration After
50 Years (2060)
Shallow Groundwater

SC-2
Simulated Benzene
Plume Migration After
50 Years (2060)
Intermediate Groundwater

SC-2
Simulated Benzene
Plume Migration After
50 Years (2060)
Deep Groundwater

Explanation

- ● Monitoring Wells
- ☐ Solidification Zone
- ▤ LIRR ROW
- ▩ Medical Building Zone
- ═ Proposed Oxygen Injection Lines

SC-2: Solidification of Source Zone
including Medical Building but not LIRR ROW,
and NE Oxygen Injection
Benzene Contours (µg/L)

- ⬜ 1 - 5
- 🟪 5 - 20
- 🟩 20 - 100
- 🟩 100 - 1000
- 🟨 1000 - 10,000
- 🟧 10,000 - 20,000
- 🟥 > 20,000

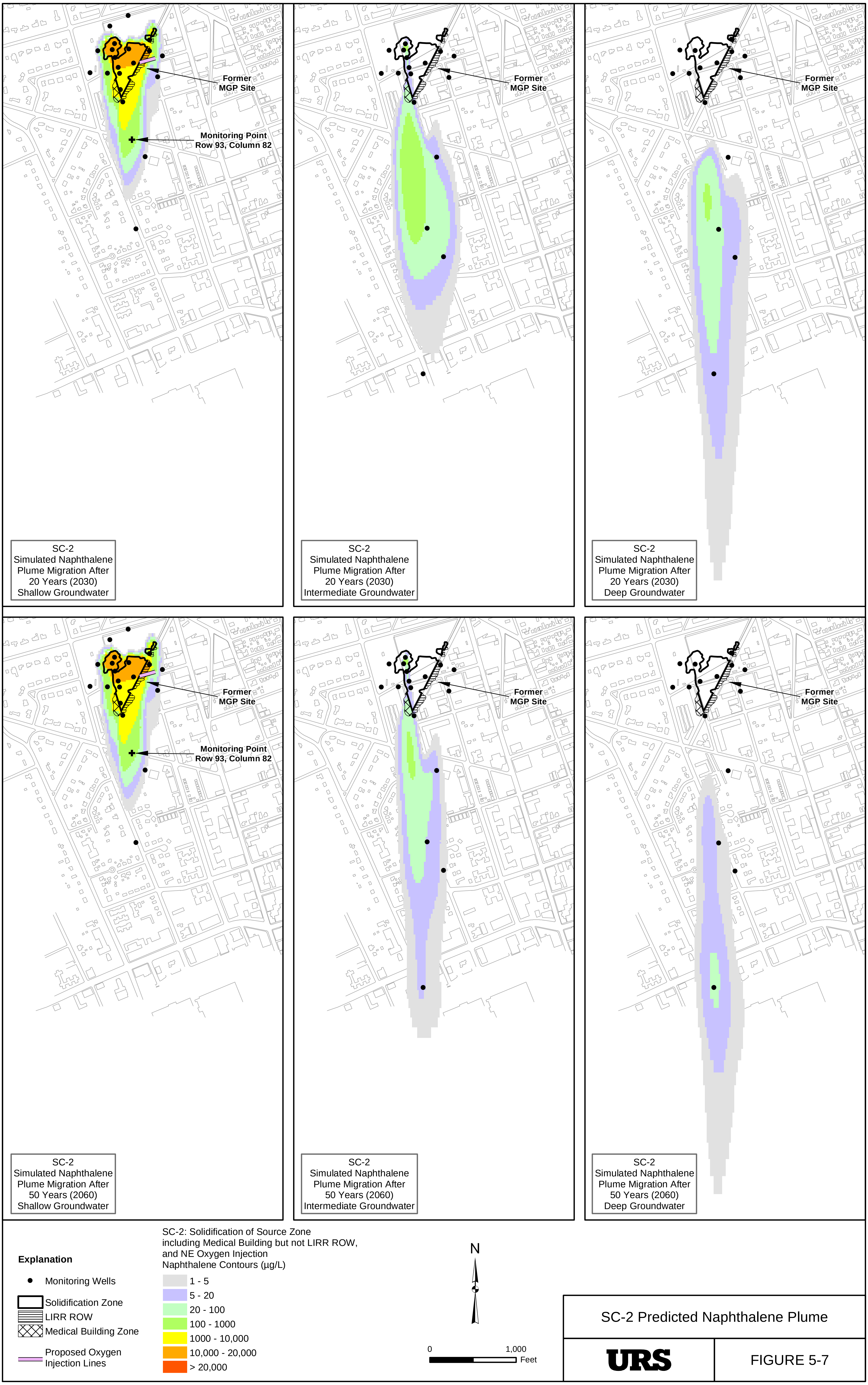
N

0 1,000
Feet

SC-2 Predicted Benzene Plume

URS

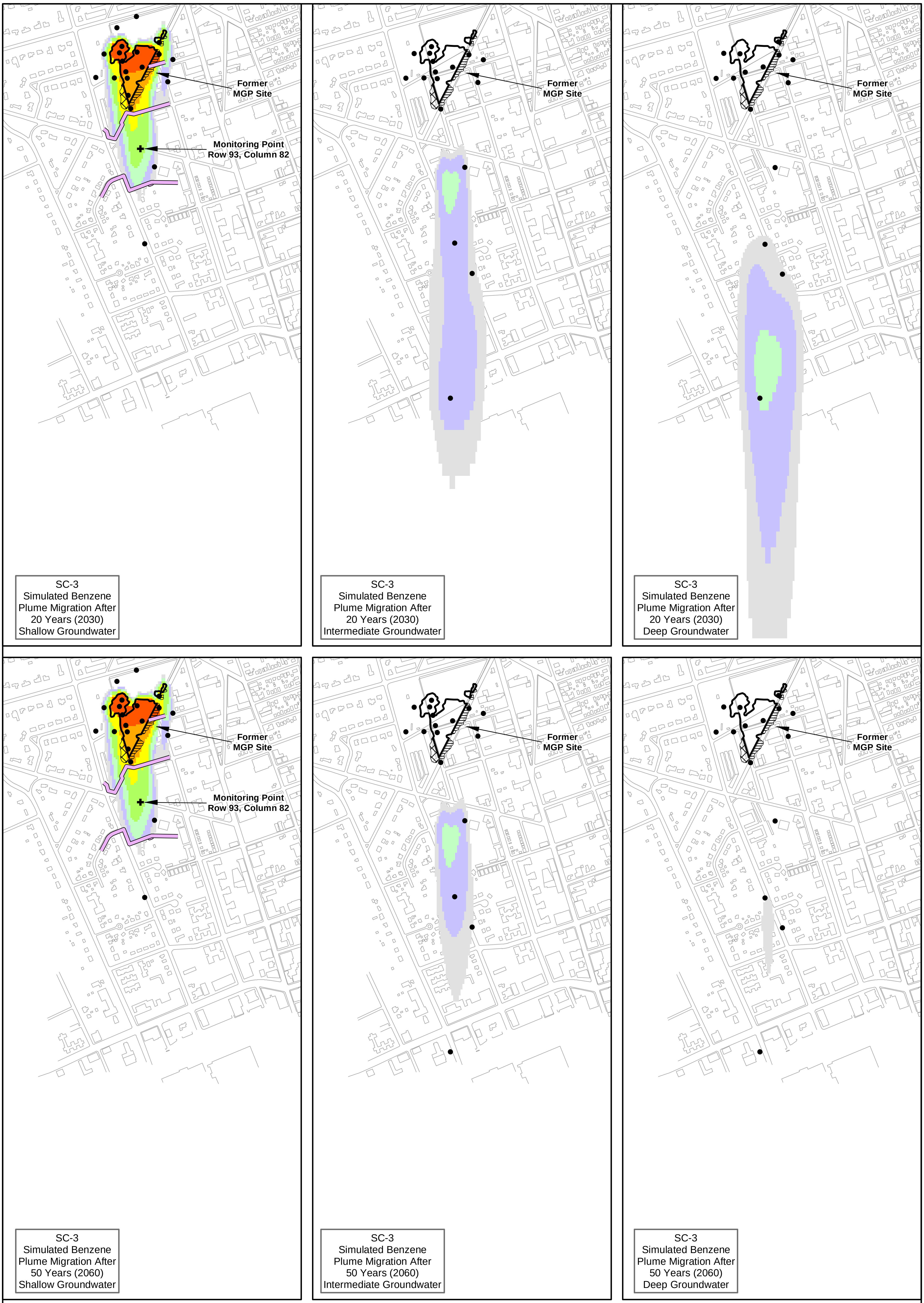
FIGURE 5-6



SC-2 Predicted Naphthalene Plume

URS

FIGURE 5-7



Explanation

- ● Monitoring Wells
- ☐ Solidification Zone
- ▤ LIRR ROW
- ▩ Medical Building Zone
- Proposed Oxygen Injection Lines

SC-3: Solidification of Source Zone excluding Medical Building and LIRR ROW, and Multiple Oxygen Injection Lines
Benzene Contours (µg/L)

- 1 - 5
- 5 - 20
- 20 - 100
- 100 - 1000
- 1000 - 10,000
- 10,000 - 20,000
- > 20,000

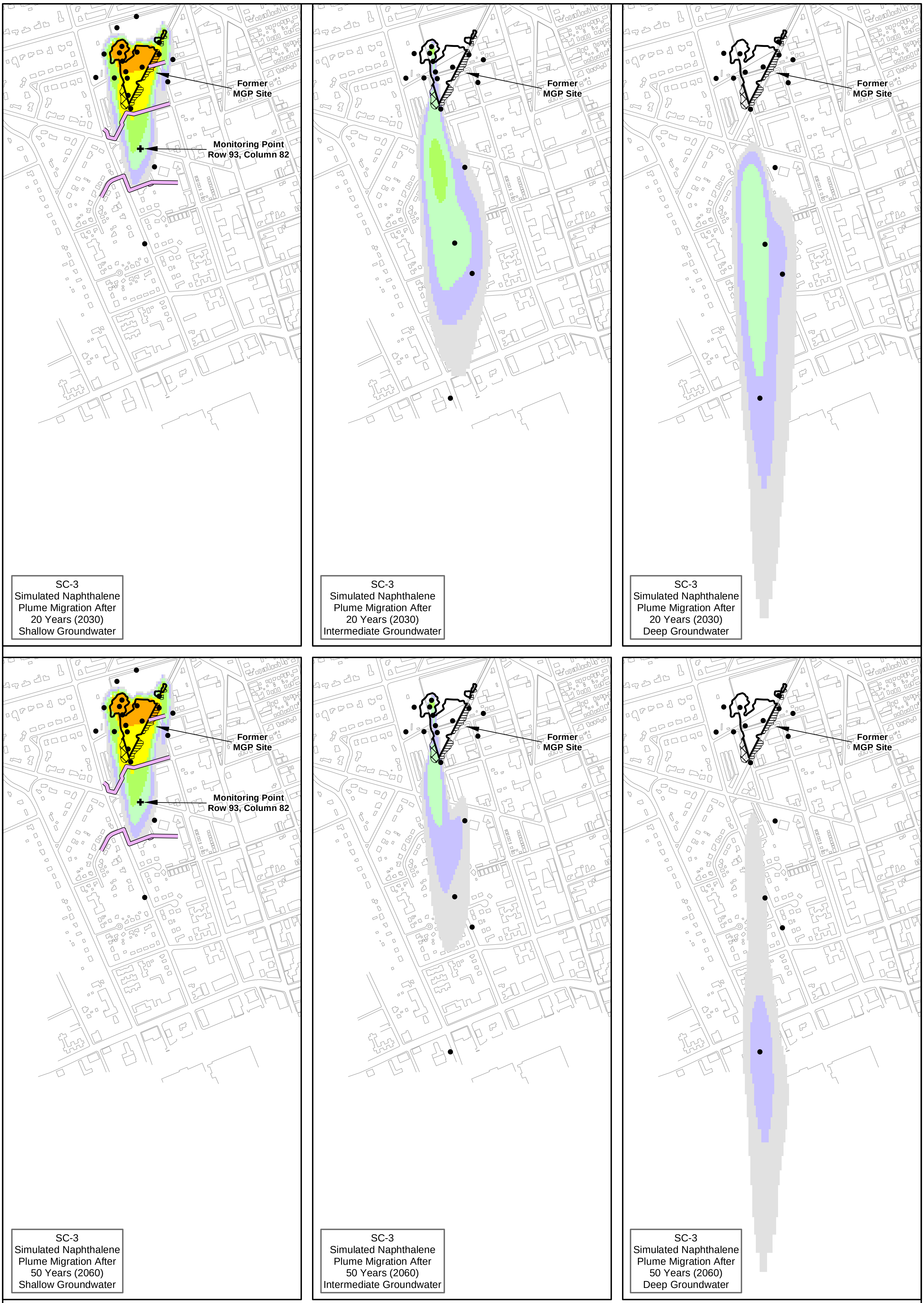
N

0 1,000 Feet

SC-3 Predicted Benzene Plume

URS

FIGURE 5-8



Explanation

- ● Monitoring Wells
- ☐ Solidification Zone
- ▤ LIRR ROW
- ▩ Medical Building Zone
- ═ Proposed Oxygen Injection Lines

SC-3: Solidification of Source Zone
excluding Medical Building and LIRR ROW,
and Multiple Oxygen Injection Lines
Naphthalene Contours (µg/L)

- ⬜ 1 - 5
- 🟪 5 - 20
- 🟩 20 - 100
- 🟩 100 - 1000
- 🟨 1000 - 10,000
- 🟧 10,000 - 20,000
- 🟥 > 20,000

N

0 1,000 Feet

SC-3 Predicted Naphthalene Plume

URS

FIGURE 5-9

Figure 5-10. Comparison of Remedial Alternatives at Selected Location (Layer 2) for Benzene

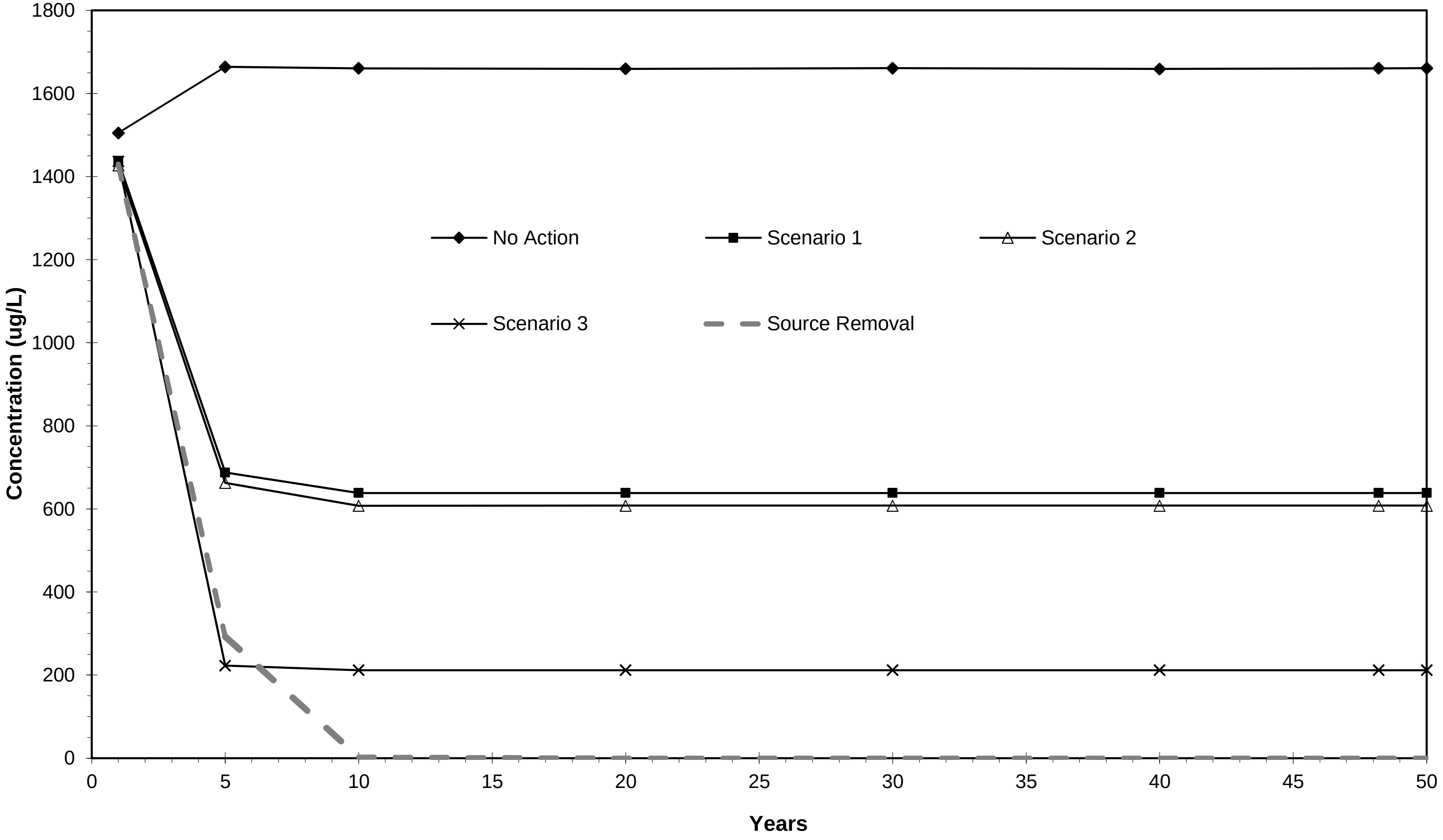
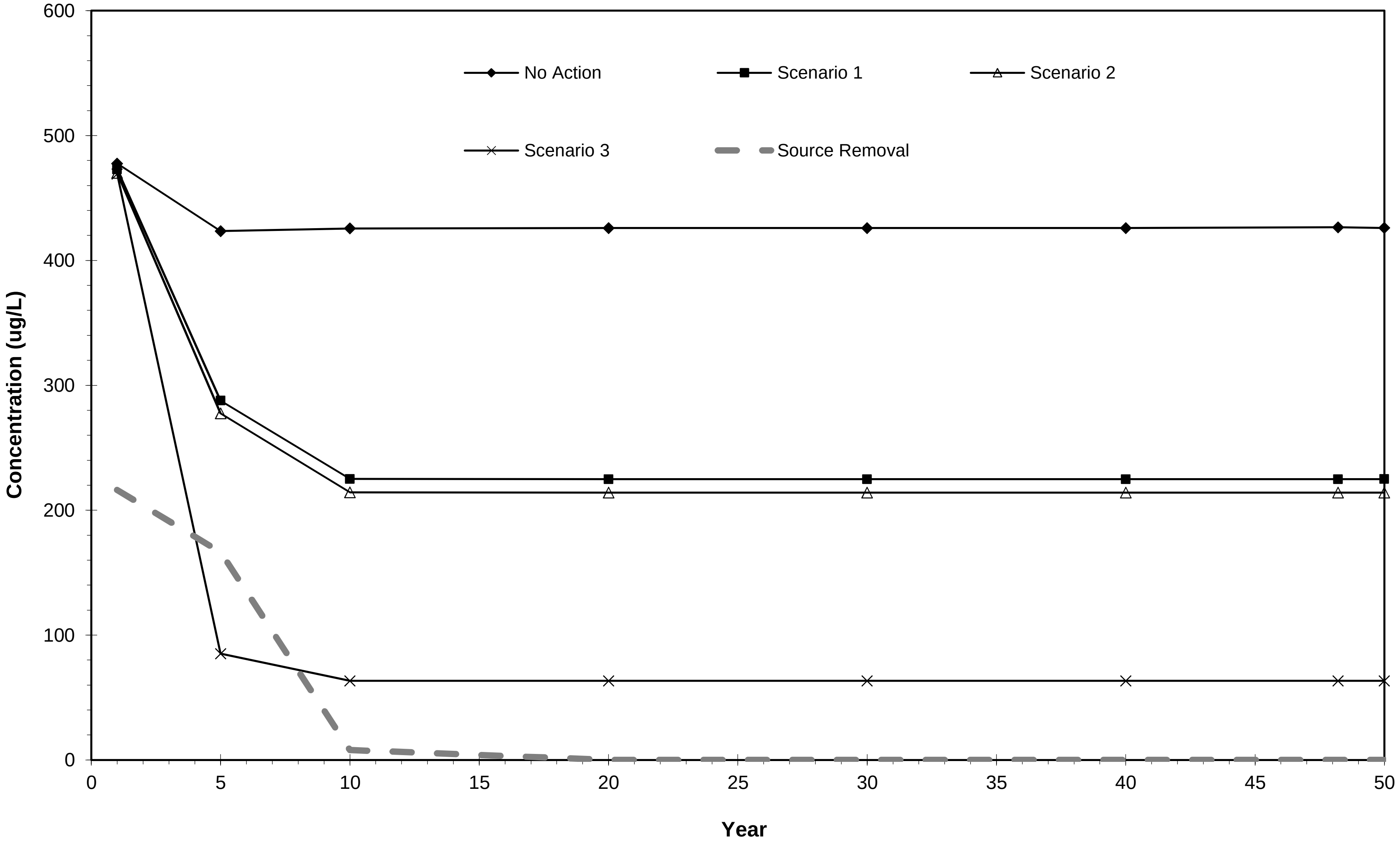


Figure 5-11. Comparison of Remedial Alternatives at Selected Location (Layer 2) for Naphthalene



TABLES

Table 1-1
Hydraulic Conductivities of Long Island Aquifers
Hempstead Intersection Street Former Manufactured Gas Plant Site
Hempstead, New York

Stratigraphic Unit	**Typical Published Value for Horizontal Hydraulic Conductivity** (ft/day)	**Typical Published Value for Vertical Hydraulic Conductivity** (ft/day)	**Slug Test Range of Average Hydraulic Conductivity Estimates** (ft/day)
Upper Glacial	200 - 270	20 - 27	45.4 - 204.1
Upper subunit of Upper Magothy	50	1.4	43.5 - 172.6
Lower subunit of Upper Magothy	NA	NA	0.06*
Raritan Clay	0.01	0.001	NA
Lloyd Aquifer	40	NA	NA

Notes:

NA = Not available/not applicable

ft/day = feet per day

* = Vertical hydraulic conductivity value based on shelby tube sample results presented in Remedial Investigation Report (0.00058 ft/day). Horizontal hydraulic conductivity assumed to equal 100 times vertical conductivity

Table 1-2
Physical and Chemical Properties of Benzene and Naphthalene
Hempstead Intersection Street Former Manufactured Gas Plant Site
Hempstead, New York

	Solubility* (mg/L)	**Specific Density***	**Henry's Constant*** (atm-m3/mol)	**log Kow***	**log Koc***	**Groundwater Biodegradation****
Benzene	1.75E+03	0.868	5.40E-03	2.12	1.94	10 days to 24 months
Naphthalene	3.00E+01	1.145	4.60E-04	3.36	3.11	1 day to 258 days

Reference:

*: Knox, et al. 1993.
**: Howard, et al. 1991.

Table 3-1
Water Supply Wells
Hempstead Intersection Street Former Manufactured Gas Plant Site
Hempstead, New York

Well	X (ft)	Y (ft)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Pumping Rate (gpm)
N-00079	2105346	178456	-278	-368	83
N-00080	2105345	178659	-368	-418	1090
N-00082	2105341	179871	-330	-482	292
N-00083	2105341	179671	-303	-343	153
N-04425	2105343	179165	-265	-305	674
N-07298	2105341	179471	-334	-384	400
N-10033	2101452	179140	-364	-466	234
N-10034	2101398	179033	-395	-476	476
				Total	**3402**

Notes:

ft = feet

gpm = gallons per minute

Table 4-1
Comparison of Observed and Simulated Hydraulic Heads
Hempstead Intersection Street Former Manufactured Gas Plant Site
Hempstead, New York

Well	X	Y	Model Layer	Observed Head (ft)	Simulated Head (ft)	Residual (ft)
HIMW-001D	2101659.27	179087.40	7	43.93	43.53	0.40
HIMW-001I	2101657.75	179091.65	5	43.94	43.63	0.31
HIMW-001S	2101655.19	179097.50	2	44.54	43.68	0.86
HIMW-002D	2102080.91	179216.71	7	45.2	43.88	1.32
HIMW-002S	2102088.13	179208.93	2	44.3	43.89	0.41
HIMW-003D	2101483.28	179092.85	7	43.3	43.52	-0.22
HIMW-003I	2101486.06	179088.55	5	43.75	43.62	0.13
HIMW-003S	2101488.13	179084.50	2	43.96	43.66	0.30
HIMW-004D	2101398.83	178819.52	7	42.49	43.02	-0.53
HIMW-004I	2101397.52	178822.51	5	43.26	43.17	0.09
HIMW-004S	2101396.26	178828.46	2	43.33	43.24	0.09
HIMW-005D	2101590.56	178821.25	7	42.61	43.01	-0.40
HIMW-005I	2101595.16	178824.04	5	42.81	43.17	-0.36
HIMW-005S	2101598.60	178825.70	2	43.48	43.24	0.24
HIMW-006D	2101716.31	178886.49	7	43.68	43.14	0.54
HIMW-006I	2101719.13	178889.23	5	43.7	43.28	0.42
HIMW-006S	2101723.62	178892.22	2	44.04	43.35	0.69
HIMW-007D	2101911.72	178944.73	7	43.85	43.30	0.55
HIMW-007I	2101906.06	178942.40	5	43.48	43.37	0.11
HIMW-007S	2101901.22	178940.66	2	43.74	43.42	0.32
HIMW-008D	2101775.09	178482.70	7	43.07	42.43	0.64
HIMW-008I	2101777.66	178485.62	5	43.07	42.57	0.50
HIMW-008S	2101777.73	178490.69	2	43.17	42.69	0.48
HIMW-009D	2102184.47	178771.05	7	43.48	42.99	0.49
HIMW-009I	2102183.31	178775.55	5	43.74	43.05	0.69
HIMW-009S	2102181.75	178780.87	2	43.62	43.16	0.46
HIMW-010D	2102237.28	179021.62	7	43.99	43.52	0.47
HIMW-010I	2102241.51	179022.33	5	43.95	43.53	0.42
HIMW-010S	2102238.09	179025.06	2	43.95	43.49	0.46
HIMW-011D	2102083.78	179074.51	7	44.08	43.61	0.47
HIMW-011I	2102084.63	179077.33	5	44.12	43.64	0.48
HIMW-011S	2102086.09	179080.74	2	44.15	43.61	0.54
HIMW-012D	2102042.40	177845.86	7	40.17	41.16	-0.99
HIMW-012I	2102040.00	177849.09	5	42.23	41.45	0.78
HIMW-012S	2102038.17	177853.25	2	42.07	41.74	0.33
HIMW-013D	2101932.89	177009.78	7	40.16	39.68	0.48
HIMW-013I	2101928.81	177020.96	5	40.23	39.84	0.39
HIMW-013S	2101930.86	177015.56	2	40.24	40.09	0.15
HIMW-014D	2102123.25	176681.97	7	37.86	39.03	-1.17
HIMW-014I	2102120.52	176692.45	5	40.22	39.09	1.13
HIMW-015D	2101876.48	175331.19	7	35.88	36.50	-0.62
HIMW-015I	2101881.00	175332.22	5	37.73	36.54	1.19
HIMW-016I	2101739.82	178814.78	5	43.47	43.15	0.32
HIMW-016S	2101738.59	178820.71	2	43.64	43.23	0.41
HIMW-017S	2101748.56	178633.91	2	43.51	42.92	0.59
HIMW-018I	2101690.98	179002.42	5	43.95	43.48	0.47
HIMW-018S	2101688.26	179006.63	2	43.95	43.52	0.43
HIMW-019I	2101677.65	179165.57	5	44.39	43.76	0.63
HIMW-019S	2101683.42	179168.17	2	44.26	43.80	0.46
PZ-02	2101839.21	179491.24	2	44.72	44.36	0.36
PZ-03	2101627.04	179369.74	2	44.51	44.15	0.36
PZ-08	2101848.08	179103.90	2	44.08	43.65	0.43

SUMMARY OF CALIBRATION STATISTICS	
Residual Mean	0.34
Res. Std. Dev.	0.46
Sum of Squares	16.84
Abs. Res. Mean	0.50
Min. Residual	-1.17
Max. Residual	1.32
Range in Target Values	9.32
Std. Dev./Range	0.05

Notes:
(ft) = feet

Table 4-2
Estimated Fate and Transport Model Parameters
Hempstead Intersection Street Former Manufactured Gas Plant Site
Hempstead, New York

Parameter	Compound	Model Layers	Estimated Value	Source
Soil Bulk Density		Entire Model	2.52 kg/L	Site data
Soil-Water Distribution Coefficient (Kd)	Benzene	Shallow	0.1 L/kg	Calibration
		Intermediate/Deep	0.25 L/kg	Calibration
	Naphthalene	Shallow	0.2 L/kg	Calibration
		Intermediate/Deep	0.5 L/kg	Calibration
Biodegradation Half-life	Benzene	Shallow	182 days	Calibration
		Intermediate/Deep	640 days	Calibration
	Naphthalene	Shallow	137 days	Calibration
		Intermediate/Deep	548 days	Calibration
Longitudial Dispersivity		Entire Model	10 ft	Calibration
Transvers Dispersivity		Entire Model	1 ft	Calibration
Vertical Dispersivity		Source Area	0.5 ft	Calibration
		Plume Area	0.01 ft	Calibration
Effective Porisity		Layers 1 to 7 and 9	0.2	Assumed
		Layer 8	0.1	Assumed