

**Updated LNAPL Volume Estimation
for the Greenpoint Petroleum
Remediation Site**

Brooklyn, New York

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List of Abbreviations and Acronyms

amsl	above mean sea level
API	American Petroleum Institute
dyne/cm	dyne per centimeter
EEEP	Ecology and Environment Engineering, P.C.
EPA	(United States) Environmental Protection Agency
ft ³ LNAPL/ft ²	cubic feet of LNAPL per square foot
ft/ft	feet per foot
LDRM	LNAPL Distribution and Recovery Model
LNAPL	lighter-than-water non-aqueous phase liquid
mg/mL	milligrams per milliliter
msl	mean sea level
NYSDEC	New York State Department of Environmental Conservation
PRP	potentially responsible party
RTDF	Remediation Technologies Development Forum
VG-alpha	van Genuchten “a”
VG-beta	van Genuchten “N”

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Introduction and Background

As part of Work Assignment Number D006794, Ecology and Environment Engineering, P.C. (EEEEPC) has been tasked by the New York State Department of Environmental Conservation (NYSDEC), Division of Environmental Remediation, to prepare a current estimate of the volume of petroleum remaining in a subsurface plume at the Greenpoint Petroleum Remediation sites based on existing data and to include a discussion on the applicability and quantity of the available data as well as recommendations on methods for improving the estimate.

In September 1978, the United States Coast Guard discovered an oil spill entering Newtown Creek from the Meeker Avenue area. A study conducted by Geraghty and Miller in 1979 estimated the volume of lighter-than-water non-aqueous phase liquid (LNAPL) in the subsurface at the Greenpoint site to be approximately 16.8 million gallons.

According to NYSDEC records, as of January 2009 approximately 10 million gallons of product had been recovered from the plume areas. Recent investigations estimate the plume currently extends as far north as the ExxonMobil Brooklyn Terminal, as far south as the Brooklyn-Queens Expressway, and to the west to an area located between Monitor Street and Kingsland Avenue. Quarterly well-gauging events are conducted in more than 300 wells in a single day to collect the necessary data to develop site-wide groundwater elevation and free-product (LNAPL) thickness contour maps. However, as stated in the 2007 United States Environmental Protection Agency (EPA) *Newtown Creek/Greenpoint Oil Spill Study* report: “True product thickness is often difficult to determine but is usually less than the apparent thickness measured in the wells. A re-evaluation of remaining plume volume across the entire project area, using corrected product thickness values, is warranted.”

In support of NYSDEC efforts to address LNAPL contamination at the Greenpoint site, this report reviews and discusses the scientific literature on the various LNAPL volume-estimation methodologies that exist (including the 1979 Geraghty and Miller model); estimates the current nominal LNAPL volume using the selected methodology and recent quarterly well-gauging data; discusses input parameters; and discusses the additional information that would be needed to reduce the uncertainty and refine the model. This current report replaces a previous volume estimate report completed by EEEEEPC (July 2009). Using the recommendations in the July 2009 report, EEEEEPC contacted the three potentially responsible

parties (PRPs)—Exxon Mobil, BP, and Chevron/Texaco—in an attempt to obtain additional aquifer and field data for the site. ExxonMobil provided EEEPC with additional data that was used to complete this updated volume estimate.

2

LNAPL Volume-Estimation Approaches

Introduction

Three types of methodologies for estimating the volume of LNAPL in a subsurface spill were identified during the literature review:

- **Simple approach.** This methodology assumes the air/oil and oil/water interfaces observed in monitoring wells are a direct reflection of the top and bottom of the LNAPL layer. This approach also assumes that soil pore spaces in between the interfaces are fully saturated with LNAPL. This was the methodology used by Geraghty and Miller (1979).
- **Pancake model approach.** In this model, described in Ballestero et al. (1994), LNAPL thickness in monitoring wells is not considered a direct reflection of LNAPL in adjacent soil pore spaces because LNAPL is suspended on the capillary fringe. Like the simple approach, this method assumes that LNAPL is in the form of a fully saturated pancake layer on top of the capillary fringe.
- **Variable saturation model approach.** In this model, LNAPL in soil pore space is not considered to be fully saturated but, rather, is a mixture of air, water, and oil. This model reflects what is observed empirically—that LNAPL saturation (percent of pore space taken up by LNAPL) varies with depth and peaks at percent saturations well below 100% (American Petroleum Institute [API] October 2006; Lenhard and Parker 1990; Farr et al. 1990).

2.1 Simple Approach

Geraghty and Miller (1979) used the simple approach to derive an estimate of LNAPL volume at the Greenpoint site. Their estimation methodology assumed that the thickness of LNAPL in observation wells was representative of the thickness of LNAPL in the aquifer and that LNAPL in the aquifer was 100% LNAPL rather than a mixture with water and/or air. Geraghty and Miller (1979) estimated the total volume of LNAPL in the aquifer using the following steps:

- The apparent thickness of LNAPL in various wells throughout the site was measured.

- An average product thickness and porosity of four site areas (delineated by ownership [Kingsland Avenue, Mobil, Amoco, and Meeker Avenue]) was estimated for each site.
- The average measured product thickness in wells in each of the four areas was determined and the value multiplied it by the site area to calculate the volume of saturated sediment.
- The volume of saturated sediment was multiplied by the porosity of the soil (using either 0.2 or 0.3, depending on the area) to get the volume of LNAPL product.

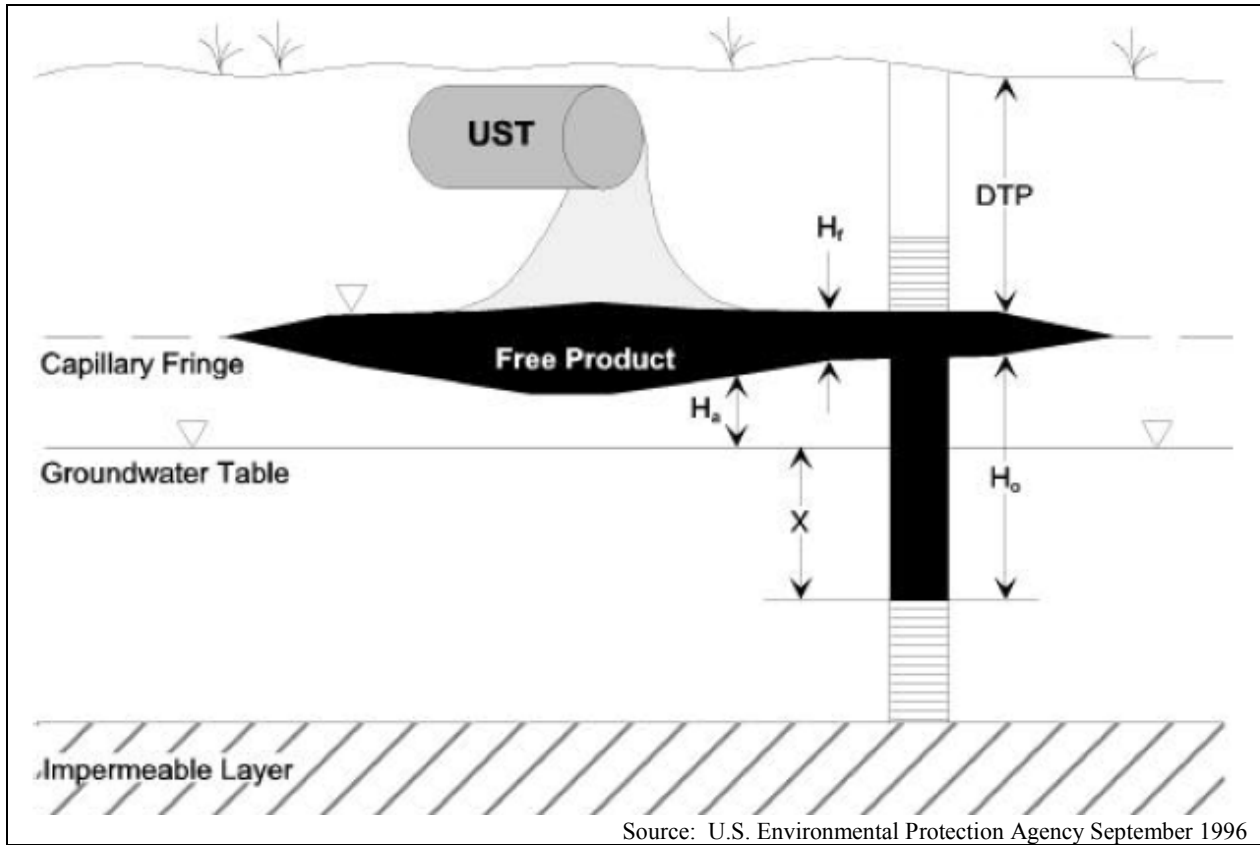
The resulting estimated volume of subsurface LNAPL was 16.8 million gallons.

2.2 Pancake Model Approach

The science of the occurrence of subsurface LNAPL has developed considerably since the Geraghty and Miller 1979 study. An EPA (September 1996) technical guidance manual describing LNAPL estimation methods compared a number of approaches used to estimate actual product thickness. As documented in this 1996 EPA manual, the pancake model approach presented by Ballestero et al. (1994) appeared to be the most successful model available for predicting actual LNAPL thickness in 1996. The Ballestero et al. conceptual model assumes the LNAPL is in the form of a 100% LNAPL pancake sitting on top of the capillary fringe. The model, however, also assumes that LNAPL in the observation wells is not a direct reflection of the LNAPL layer in the subsurface. Ballestero et al. conceptualized the difference between LNAPL thickness observed in a well and actual LNAPL thickness in soil, as follows (see Figure 2-1):

- Where an observation well intercepts the LNAPL layer, LNAPL suspended above the capillary fringe flows down the well to the water table.
- LNAPL accumulates in the well and its weight further depresses the water table in the well, thereby making room for additional LNAPL. Eventually, a balance is established between the amount of LNAPL in the well (H_0+H_f) and the amount of water displaced by LNAPL (H_f).
- The result is that LNAPL thickness observed in a well can be as much as four times greater than actual LNAPL thickness in the surrounding soil.

The Ballestero et al. model takes into account an additional complication in that as the thickness of the free product (LNAPL) sitting on top of the capillary fringe increases, the degree to which it penetrates the capillary fringe increases, thus somewhat decreasing the difference between apparent and actual thicknesses.



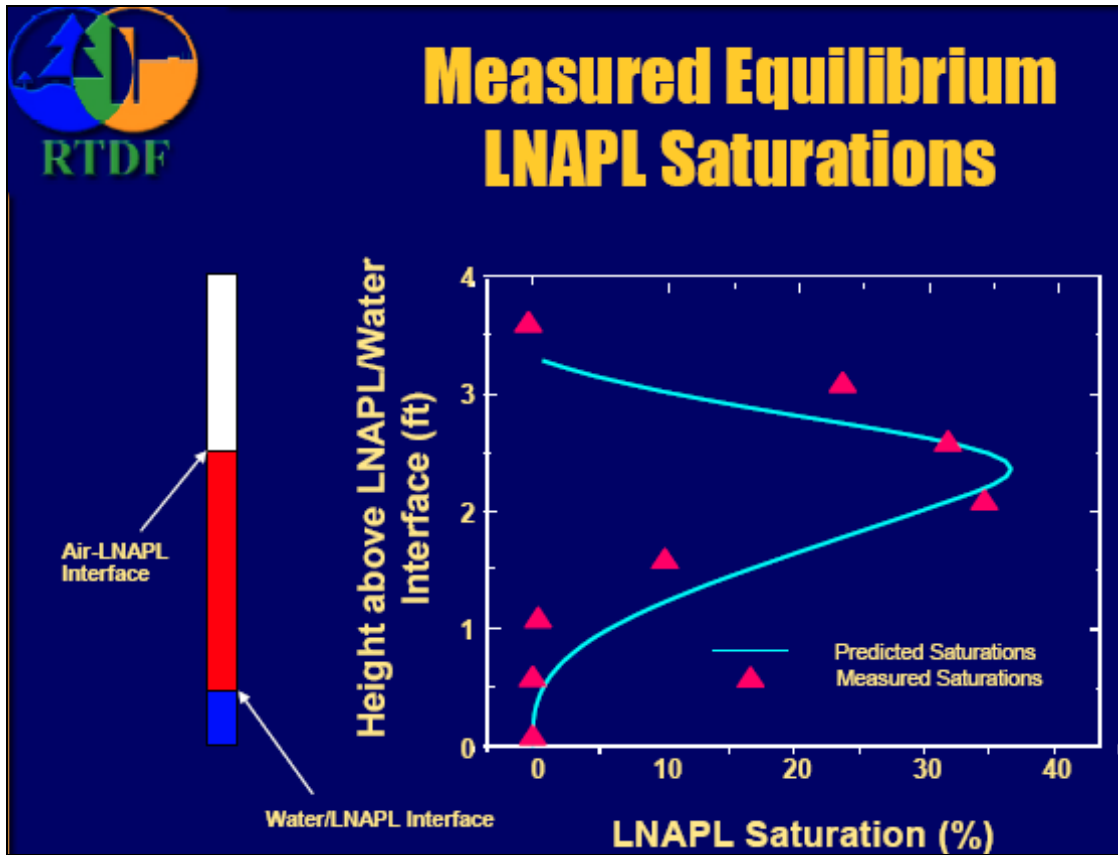
Source: U.S. Environmental Protection Agency September 1996

Figure 2-1 Discrepancy between Free Product Thickness in Well vs. Surrounding Soil

2.3 Variable Saturation Model Approach

While the conceptual model of an oil-saturated pancake on the capillary fringe is somewhat instructive as to why LNAPL thickness should be different between wells and adjacent soil, it is now considered an over-simplification of the occurrence of LNAPL in the subsurface that may result in incorrect volume estimates. Independent research by Farr and McWhorter (1990) and Lenhard and Parker (1990) extended the understanding of LNAPL behavior—developed for oil reservoirs in the 1930s—to environmental applications of hydrocarbon spills and leaks (Remediation Technologies Development Forum [RTDF] 2006). As discussed in Adamski et al. (2005), conceptual models by Lenhard and Parker (1990) and Farr et al. (1990) describe a condition where air, water, and LNAPL all coexist to varying degrees within the vertical soil profile. That is, rather than a 100% saturated oil layer, LNAPL saturation increases with depth to a maximum percentage and then decreases with depth again (see Figure 2-2). NAPL does not fill the soil void space but, rather, occurs in the void space as a mixture with air near the capillary fringe and as a mixture with water near the water table. Soil type and particle size distribution determine maximum LNAPL saturation. Larger grain sizes (e.g., sand, gravel) allow LNAPL to penetrate more pores while smaller grain sizes (e.g., silt, clays) inhibit LNAPL penetration and thus have lower maximum LNAPL saturation. The saturation of LNAPL varies significantly over its observed thickness, and maximum percent saturations are lower than 100%. Remediation Technologies Development Forum (2006) states that of 212 analyses at

BP refining sites (the location of these sites is not presented), 83% of all samples had LNAPL saturations lower than 10%; fine-grained media had typical maximum saturations of 2% to 5%, and coarse-grained media had typical maximum saturations of 10% to 56%.



Source: Remediation Technologies Development Forum 2006.

Figure 2-2 LNAPL Saturation with Depth for a Typical Site

In the variable saturation model, LNAPL saturation varies with depth in the subsurface. The variation in saturation can be predicted by knowing the 1) the properties of the subsurface media, 2) the properties of the LNAPL, and 3) the apparent thickness of LNAPL in the well. Percent saturation with depth can be integrated over the entire depth of the LNAPL to generate a specific volume (volume per unit area), e.g., the cubic feet of LNAPL per square foot ($\text{ft}^3 \text{LNAPL}/\text{ft}^2$) surface area. The resulting units are length (ft^3/ft^2 or feet). Thus, in simplistic terms, the specific volume can be thought of as an equivalent thickness or depth of oil without the presence of a porous media. The thickness of the observed oil layer influences the peak saturation: as observed LNAPL thickness increases, so does maximum LNAPL saturation. Calculations based on the variable saturation model of total volume of LNAPL, its migration potential, and the recoverable volume can be predicted using the LNAPL Distribution and Recovery Model (LDRM) (Charbeneau January 2007). The EPA (2005) reported on use of the LDRM at a BP former refinery in Sugar Creek, Missouri, where it was found to predict the LNAPL recovery volume to within 6% of the actual volume.

3

Selection of Approach

As indicated by the discussion of volume estimation approaches, the Geraghty and Miller (1979) estimate should be viewed as inaccurate and not comparable to estimates of volume using more current techniques. Similarly, the pancake conceptual model of a saturated LNAPL layer floating on the water table or capillary fringe should also be considered inaccurate. Rather, LNAPL exists over a range of saturation, typically well below 100% saturation, between the area above the capillary fringe extending down to the water table as illustrated by the Variable Saturation Model Approach. The LDRM incorporates this approach, so it was selected to calculate the LNAPL volume in the Greenpoint area.

It should be noted that derivation of the equations in the LDRM is predicated on the assumption of vertical equilibrium conditions. Specifically, the water table should not vary significantly. Tidal water-level fluctuations in Newtown Creek have been observed to impact water table elevations in observation wells adjacent to Newtown Creek. A tidal survey was completed at the Apollo Street site as part of the remedial investigation. The results of this study indicated that wells located 200 feet or more inland from Newtown Creek typically showed less than 1 foot of tidal influence on groundwater levels compared with wells directly adjacent to the creek, which show tidal influences similar to the fluctuations in Newtown Creek itself (3.0 to 5.9 feet in observation wells vs. 3.6 to 6.0 feet in Newtown Creek). As a result, model predictions in the vicinity of Newtown Creek will be less accurate. While more complex models run in continuous simulation mode to take into account the impacts of tidal fluctuations could provide a more accurate volume estimate, the level of detail was beyond the scope of this volume-estimation effort. If a more complex model is used in the future (e.g., for evaluating alternative remedial efforts) volume estimates could be reconsidered using such a model at that time. Given the current scope and availability of data, however, the LDRM is considered the most appropriate model.

4

Methodology

The LDRM is designed to be applied at a single observation well. For this application, the LDRM was used to calculate the specific volume (essentially an equivalent depth or thickness of pure product without the presence of subsurface soils) of LNAPL *at each observation well* having sufficient data. The model's results vary with each observation well and thus are used to define contours of the LNAPL specific volume (thickness). The specific volume contours are then processed in AutoCAD to generate an estimate of the total volume of subsurface LNAPL. Data were available for a substantial number of observation wells—the boundaries of the spill area are largely defined by observation wells with no apparent LNAPL. (The one exception is the northern boundary of the spill area.) A set of three model runs was performed in order to generate nominal, minimum, and maximum specific volume estimates at each observation well. In cases where site-specific data was too limited to assign values to each model input parameter, the model defaults were used for those parameters to develop a nominal volume estimate. The model was then re-run using the minimum and maximum values in the range of plausible values for each uncertain input parameter in order to generate minimum and maximum specific volume estimates at each well (see Appendix A, Sensitivity Analysis and Model Predictive Uncertainty Range). These specific volume estimates were then used to generate minimum and maximum LNAPL volume estimates.

Of the specific LNAPL volume calculated for each well, only a portion of this total LNAPL volume can be recovered by draining oil to a pumped well or trench. The amount of oil remaining in the soil is at residual saturation and is considered immobile in that it will not move in response to a LNAPL head gradient. While additional LNAPL could ultimately be recovered through the use of more active technologies, such as the application of surfactants, “recoverable” LNAPL is typically reserved for the amount of LNAPL at greater than residual saturation. The LDRM also calculates the portion of the specific volume at each well that is expected to be recoverable. In the course of running the LDRM for nominal, minimum, and maximum volume estimates, the recoverable specific volume at each observation well was also recorded. It should also be noted that while LNAPL must necessarily be mobile for it to be considered recoverable, not all mobile LNAPL will necessarily be recovered. If, during the course of recovery, mobile LNAPL flows into soils that are below residual LNAPL saturation, some LNAPL would become trapped in those soils and become non-recoverable.

5

Input Parameter Values

5.1 Input Parameter Value Selection

The process used to derive values for each input parameter is presented in this section.

5.1.1 Maximum Observed LNAPL Thickness

Maximum observed LNAPL thickness is one of the most important observation well-specific data required to run the model. The model assumes that the well screen straddles the water table, so where well data indicated that the well screen does not straddle the water table or well data was insufficient to confirm this requirement, the well was excluded from the analysis. Of the 305 wells evaluated:

- Seventy-eight wells (26%) had well screens that did not straddle the ground-water surface and were excluded from the analysis. Because subsurface LNAPL resides above the water table, screening the well below the ground-water table (typical for groundwater-contaminant monitoring) would preclude LNAPL entry into the well.
- Thirty-three wells (11%) did not have available borehole records and thus could not be evaluated for proper location of the well screen.
- Five wells (2%) had no associated measurement of groundwater elevation with respect to a datum or mean sea level (msl) and thus the known elevation of the well screen could not be evaluated.
- Seven wells (2%) were excluded from the analysis where the location (northing/easting) of a well was not known.
- Six additional wells (2%) were excluded from analysis because they either had no measured product thickness data or were located outside the most recently calculated isopleths of the extent of mobile free-product at the Greenpoint site. Figure 5-1 shows the isopleths calculated from May and August 2008 gauging data.

In summary, 176 of the 305 wells were used in the analysis.

Observed LNAPL thickness was measured at increments of 0.01 foot using an electronic oil/water-level indicator with graduated cable. The oil/water level indi-

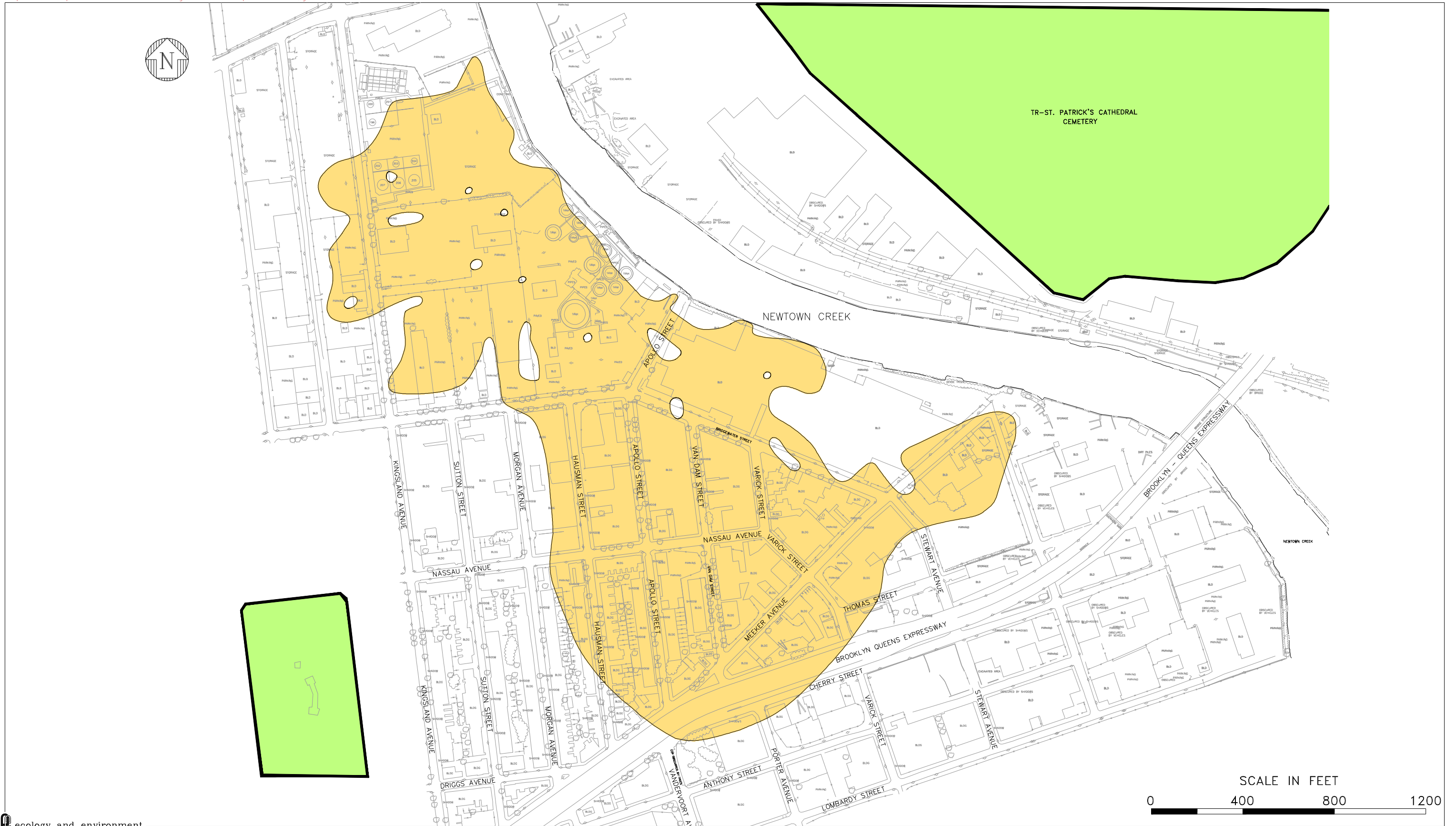
cator allows the user to record the depth to the air/oil interface and oil/water interface. Observation dates of February 2007 and March 2008 were selected because they both represent periods where groundwater pumping (with LNAPL recovery) had been in operation for several months or more and the groundwater cones of depression and oil profiles could reasonably be expected to be established. Groundwater pumping was halted in early March 2007 (U.S. Environmental Protection Agency September 12, 2007) and resumed in the summer of 2007. Observed LNAPL thickness values were taken from the *Quarterly Progress Report (1st Quarter, 2007) ExxonMobil Off-Site Greenpoint Remediation Project* (Remedial Engineering, P.C. 2007) and the *Quarterly Progress Report (1st Quarter), Off-Site Free-Product Recovery System* (Remedial Engineering, P.C. 2008) reports.

Observed LNAPL thickness data from the period when the ExxonMobil treatment system was shut down (May 2007) was compared with the above periods (February 2007 and March 2008) to assess the degree to which the period selected might impact the volume estimate. Forty-three of the approximately 176 measured wells were found to have differences of 50% or greater between May 2007 values and the average of the February 2007 and March 2008 values. As would be expected, a portion of these wells showed a significant increase during the shutdown period while a portion of the wells showed a significant decrease. Observation wells in the vicinity of the remedial wells tend to show an increase in observed thickness in response to water table drawdown and inflow of LNAPL from surrounding areas. Observation wells farther from remedial wells tend to show a decrease in observed LNAPL thickness in response to the draining of LNAPL towards remedial wells. Observed LNAPL thickness at remedial wells tends to show a decrease because the level of LNAPL in the remedial well is low via LNAPL extraction. While the overall pattern of observed LNAPL thickness changes in response to LNAPL remedial pumping, the overall volume estimate would not be expected to change, depending on the period selected (other than in response to removal of free-product during remediation).

Because the model requires the maximum observed LNAPL thickness at each well, the greater of the two readings (from February 2007 and March 2008), was used. The LNAPL thickness data from the February 2007 and March 2008 periods were also compared with more recent data collected in July 2009 to confirm that the selected values were still representative of the site. In cases where the February 2007/March 2008 product thickness value was lower than the July 2009 value by 3 feet or more, the July 2009 value was used. Three feet was assumed to be large enough to differentiate a significant difference in thickness measurement from any expected variation in the product thickness over time. In all other cases, the greater of the February 2007 and March 2008 values were used.

5.1.2 Ground Surface and Water Table Elevations

Ground surface elevation only becomes a factor in determining the LNAPL volume when the water table or LNAPL layer exceeds the ground surface and water or LNAPL is present on top of the soil. At the Greenpoint site, since both the



ecology and environment
LEGEND

- PRODUCT THICKNESS CONTOUR
- PRODUCT THICKNESS IS > 0
- GRASSED AREAS

NOTES:

1. SITE BACKGROUND TAKEN FROM DRAWING MC3072502.dwg PROVIDED BY ROUX ASSOCIATES INC., DATED JANUARY 20, 2005.
2. APPROXIMATE LOCATION OF FREE PRODUCT PLUME BASED ON INTERPRETATION OF DATA PRESENTED IN SECOND AND THIRD QUARTER 2008 PROGRESS REPORTS FOR THE FORMER EXXON MOBIL BROOKLYN TERMINAL, BROOKLYN, NEW YORK.

SCALE IN FEET
 0 400 800 1200

FIGURE 5-1 CURRENT EXTENT OF MOBILE FREE PRODUCT PLUME BASED ON MAY AND AUGUST 2008 WELL GAUGING DATA GREENPOINT

LNAPL and groundwater table layers are both below the ground surface, this is not an issue. Ground surface elevations at the Greenpoint site typically range from 10 to 40 feet above mean sea level (amsl), while groundwater elevations typically range from 0 to 5 feet amsl. Thus a nominal value of 25 feet amsl for the ground surface elevation and 2 feet amsl for the water table elevation was used for all observation wells in the model.

5.1.3 Vertical Hydraulic Gradient

Vertical hydraulic gradient is the difference in hydraulic head as observed between a monitoring well pair. An overall water vertical gradient value was calculated for a number of well pairs with available coincident shallow and deeper groundwater head measurements (see Table 5-1).

While one well pair (CMW-29S/D) does appear to have a consistent and potentially significant negative gradient (average of 0.07 feet per foot [ft/ft] downward), there does not appear to be any consistent temporal or spatial pattern to the vertical gradient data. For example, of the two fall vertical gradient measurement periods, one has a very slight positive value (0.0085 in November 2006) and the other has a slight negative value (-0.0155 in November 2007). The overall average vertical gradient value is less than 1% (-0.0038 ft/ft). Because such a small vertical gradient produces essentially the same result as a vertical gradient of zero, for simplicity, a vertical gradient of 0.000 was used for each well modeled using the LDRM.

5.1.4 LNAPL Density and Viscosity

LNAPL density was available for most observation wells with LNAPL thickness measurements, reported as specific gravity (density = specific gravity x 1.00 milligrams per milliliter [mg/mL] [i.e., density of water]) (Remedial Engineering, P.C. 2007; 2008). EEEPC observed that specific gravity values at the Greenpoint site tend to be very similar to the specific gravity values of nearby wells. As a result, where LNAPL density had not been previously measured or assigned for a particular well, EEEPC assigned a value based on the value of the closest observation well with an existing LNAPL density value. Assigned LNAPL density values are noted in Appendix B.

The LNAPL viscosity used in this application was the default value. The LNAPL viscosity has no impact on the calculation of specific volume. LNAPL viscosity is used, however, in other calculations performed by the LDRM relating to LNAPL migration and recovery.

5.1.5 Hydraulic Conductivity

The LDRM model does not use hydraulic conductivity in calculating specific volume but does use these data in calculating other model outputs relating to LNAPL migration and recovery. As such, an assumed value of 15 feet per day, which is within the typical range of hydraulic conductivity values for sand, was assigned.

Table 5-1 Vertical Hydraulic Gradient Measured at Well Pairs

Well ID	11/6/2006			11/28/2007			3/7/2008			Average	
	Water Elevation (ft amsl)	Elevation of Center of the Well Screen	Gradient (ft/ft)	Water Elevation (ft amsl)	Elevation of Center of the Well Screen	Gradient (ft/ft)	Water Elevation (ft amsl)	Elevation of Center of the Well Screen	Gradient (ft/ft)		
CMW-19S	1.84	4.86	-0.0068	2.46	4.86	-0.0478	1.80	4.86	-0.0163	-0.0236	
CMW-19D	1.67	-20.23		1.26	-20.23		1.39	-20.23			
CMW-23S	3.64	-5.01	-0.0016	1.14	-5.01	0.0128	1.20	-5.01	0.0088	0.0067	
CMW-23D	3.60	-29.99		1.46	-29.99		1.42	-29.99			
CMW-24S	1.90	-3.16	0.0000	1.35	-3.16	0.0004	1.22	-3.16	0.0008	0.0004	
CMW-24D	1.90	-28.17		1.36	-28.17		1.24	-28.17			
CMW-25S	2.42	-1.95	0.0118	1.75	-1.95	0.0026	1.84	-1.95	0.0000	0.0048	
CMW-25D	2.60	-17.22		1.79	-17.22		1.84	-17.22			
CMW-29S	2.84	3.29	-0.0465	2.78	3.29	-0.0903	2.49	3.29	-0.0619	-0.0662	
CMW-29D	2.12	-12.21		1.38	-12.21		1.53	-12.21			
CMW-34S	1.98	7.02	-0.0042	1.31	7.02	-0.0019	0.18	7.02	0.0630	0.0190	
CMW-34D	1.89	-14.40		1.27	-14.40		1.53	-14.40			
CMW-36S	1.79	2.22	-0.0019	1.31	2.22	-0.0005	NM	2.22	NM	-0.0012	
CMW-36D	1.75	-19.08		1.30	-19.08		NM	-19.08			
CMW-41S	-2.20	-3.21	0.1171	0.84	-3.21	0.0004	2.10	-3.21	-0.0293	0.0294	
CMW-41D	0.44	-25.75		0.85	-25.75		1.44	-25.75			
Average			0.0085	Average			-0.0155	Average			-0.0050
										-0.0038	
										Overall Average	

Key:

amsl = Above mean sea level.

ft/ft = Feet per foot.

5.1.6 Surface Tensions

Values for the surface tension parameters were taken from measurements reported in the *Supplemental Investigation of the Off-Site Free Product Plume* (Roux Associates January 24, 2003). Because the model is sensitive to the surface tension values, the range of reported values for these parameters was considered in the sensitivity analysis and development of the range of uncertainty in the model's prediction. The range of values reported in Roux is as follows:

- **Air/Water Surface Tension.** 63.0 to 70.0 dyne per centimeter (dyne/cm)
- **Air/LNAPL Surface Tension.** 22.9 to 23.3 dyne/cm
- **LNAPL/Water Surface Tension.** 9.8 to 13.8 dyne/cm

Roux reported surface tension parameter values from samples taken from MW-15, MW-33, and a composite from remedial wells RW-A, RW-C, RW-D, and RW-E. Nominal values for the surface tension parameters were estimated by taking a weighted average of the above samples (i.e., by weighting the remedial wells composite sample at four-sixths of the total).

5.1.7 Capillary Pressure Curve Parameters

The capillary pressure curve parameters include Van Genuchten "N" (VG-beta), Van Genuchten "a" (VG-alpha), and irreducible water saturation. The Van Genuchten capillary pressure curve model relates water saturation to capillary pressure head. In the van Genuchten model, the "a" and "N" parameters characterize soil texture. Smaller values of "a" correspond to smaller pore sizes while smaller values of "N" correspond to wider ranges in pore sizes. Irreducible water saturation is the minimum percent saturation that will remain at an ever-increasing capillary pressure.

Originally, the VG-beta and irreducible water saturations were estimated using the API parameters database (American Petroleum Institute October 2006) for poorly graded sand (SP) and poorly graded sand with silt (SM), while VG-alpha values were based on measured field data. However, 26 measurements for VG-alpha from 21 unique locations were available from the additional aquifer and field data for the site provided by ExxonMobil. Measurements from boreholes and monitoring wells that could not be located or were outside of the most recently calculated isopleths of the extent of mobile free product at the Greenpoint site were not included in the average or range of values (see Figure 5-1). Additionally, any measurements that fell outside two standard deviations of the mean were excluded. Overall the VG-alpha values ranged from 0.13 to 0.64 and were within the literature values for the soil types observed on the site:

- VG-alpha values for soil type SP ranged from 0.0951 to 1.57 per foot with an average value of 0.564.

- VG-alpha values for soil type SP-SM ranged from 0.093 to 1.69 with an average of 0.625.

VG alpha values were plotted on a site map at locations where they were sampled. This revealed that the new data were clustered around the northern section of the Greenpoint site, i.e., the Exxon Mobil property, and on the southern section of the Greenpoint site, i.e., the Paragon property. No data were available for the central section of the Greenpoint site, i.e., the BP property. The limits of the three sections were divided based on property lines.

The VG-alpha data for both the data from the northern and southern sections showed a decrease in the range between minimum and maximum VG-alpha parameters by approximately 30%. Because no new data were available for the central section, continuity was assumed. The assumption of continuity was chosen over the use of literature values for the central section because the data for the other sections are based on field measurements and are expected to better represent site conditions than literature values. The minimum, maximum, and nominal values for VG-alpha for the northern and southern sections were averaged to get the respective values for the central section. Table 5-2 summarizes the input values for VG-alpha used in the minimum, nominal, and maximum LDRM calculations.

Table 5-2 Location-Specific LDRM Input Parameter Values

LDRM Data Inputs	Minimum	Nominal	Maximum
Porosity			
Northern	0.3	0.36	0.42
Central	0.31	0.37	0.43
Southern	0.32	0.38	0.44
van Genuchten "a" (VG-alpha) (1/ft)			
Northern	0.15	0.25	0.46
Central	0.14	0.3	0.54
Southern	0.13	0.35	0.61

Note: Data from the northern and southern sections are based on analysis of measured parameters. The values for the central section were averages of the northern and southern section values because a continuity of parameters was assumed.

Key:

ft = Feet.
 LDRM = LNAPL distribution and recovery model.
 mg/mL = Milligrams per milliliter.

5.1.8 Porosity

Originally, two measured values of porosity (0.38 and 0.44) based on “undisturbed samples from two core holes in the main spill area” were available from Geraghty and Miller (1979) and five porosity measurements were reported by ExxonMobil (Roux Associates, Inc. May 24, 1991). However, 58 porosity measurements from 28 unique locations were provided in the additional aquifer and field data from ExxonMobil. Similar to VG-alpha, measurements from boreholes and monitoring wells that could not be located or that were outside the most re-

cently calculated isopleths of the extent of mobile free product at the Greenpoint site or that fell outside two standard deviations of the mean were excluded from the average and range of values. Porosity measurements were taken at multiple depths in some boreholes and monitoring wells. The same clusters of wells in the northern and southern sections were used for estimating the average porosity values. The mean porosity values were 0.36 and 0.38 for the northern and southern sections. The average porosity for the central section was assumed to be 0.37 based on continuity.

Table 5-2 summarizes the range of porosity values used in the minimum, nominal, and maximum LDRM calculations. With the additional data from ExxonMobil, the original porosity range was reduced by approximately 30%.

5.1.9 Residual LNAPL f-factor

Residual LNAPL has been found to be proportional to initial LNAPL saturation. That is, the higher the saturation for LNAPL initially present in the soil, the higher the amount of LNAPL that remains once LNAPL is drained or pumped from the subsurface. The relationship between residual LNAPL and initial LNAPL saturation is defined by the residual LNAPL f-factor. For this estimate, we used the value recommended in the LDRM User Manual.

5.2 Summary of Input Parameter Values

All the input parameter values used in the current LDRM calculations are shown in Table 5-3. Parameters with variable values were determined either by well or location on the Greenpoint site. The model was run once to get a nominal estimate of the volume and then twice more using minimum and maximum input values to define the model predictive range. The parameters that were adjusted to determine the minimum and maximum volume estimates included surface tensions, porosity, and VG-alpha.

Input parameter values determined based on location in the Greenpoint Site were also varied to determine the model's predictive range.

Table 5-3 LDRM Input Parameter Values

LDRM Data Inputs	Value	Notes	Sensitivity ¹
Maximum observed LNAPL thickness ² (ft)	Variable	For each well, selected maximum of February 2007 and March 2008 observed thickness values, except where past trend indicated a difference of more than 3 feet. If the value needed to be higher than both the February 2007 and March 2008 data, the July 2009 data were used (the most recent); otherwise, the lower of the February 2007/March 2008 data were used (see Appendix B).	Sensitive
Ground Surface Elevation (ft amsl)	25	Ranges from 10 to 40 feet; 25 feet is rough estimate of average.	None
Water Table Elevation (ft amsl)	2	Range is from 0 to 5 feet; 2 feet is rough estimate of average.	None
Water Vertical Gradient (ft/ft)	0	Based on observations at shallow/deep well pairs (see Table 5-1).	Sensitive
LNAPL Density (mg/mL)	Variable	Range of density values observed on site is 0.78 to 0.94 (see Appendix B). Values assigned to wells with no observed value based on most proximate well.	Sensitive
LNAPL Viscosity (cp)	2	LDRM default.	None
Air/Water Surface Tension (dyne/cm)	68.5 ³	Weighted average of measured values reported in Roux (January 24, 2003).	Sensitive
Air/LNAPL Surface Tension (dyne/cm)	23.0 ³	Weighted average of measured values reported in Roux (January 24, 2003).	Sensitive
LNAPL/Water Surface Tension (dyne/cm)	11.5 ³	Weighted average of measured values reported in Roux (January 24, 2003).	Sensitive
Porosity ²	Variable	Separate ranges based on spatial distribution (see Table 5-2).	Sensitive
Hydraulic Conductivity (ft/day)	15	Assumed based on typical values for sand.	None
van Genuchten "N" (VG-beta)	2.7	Average of average values for SP and SP-SM soils (API Parameter Database).	Some
van Genuchten "a" (VG-alpha) (1/ft) ²	Variable	Separate ranges based on spatial distribution (see Table 5-2).	Sensitive
Irreducible Water Saturation	0.20	Average of average values for SP and SP-SM soils (API Parameter Database).	Some
Residual LNAPL f-factor	0.3	Median of observed; value recommended by LDRM user manual. Range observed is 0.2 to 0.5.	Some

Note:

¹ Sensitivity of LNAPL volume estimation to changes in parameter value. Where parameter sensitivity is "None," parameter value has no influence on LDRM prediction of specific volume but may influence LDRM predictions for other calculations (e.g., recovery rate).

² Value has been changed from initial parameter.

³ Nominal value (see Section 5.1.6 above for range of values).

Key:

amsl = Above mean sea level.
 API = American Petroleum Institute.
 cp = Centipoise.
 ft = Feet.

LDRM = LNAPL distribution and recovery model.
 LNAPL = Light, non-aqueous phase liquid.
 mg/mL = Milligrams per milliliter.
 SM = Poorly graded sand with silt.
 SP = Poorly graded sand.

6

Results

The LDRM was run to calculate the LNAPL specific volume and recoverable LNAPL volume at each observation well with sufficient data. Nominal, minimum, and maximum LNAPL volumes were estimated for the site. Derivation of the minimum and maximum results is discussed in detail in the Sensitivity Analysis and Model Predictive Uncertainty Range (see Appendix A). Nominal, minimum, and maximum model results for each observation well are shown in Appendix B. Sufficient data were available to calculate the LNAPL-specific volume for 176 wells. Statistics relating to the calculated nominal specific volume values are:

- **Average:** 0.30 (ft³ LNAPL/ft²)
- **Median:** 0.005 (ft³ LNAPL/ft²)
- **Range:** 0.0 feet to 5.8 (ft³ LNAPL/ft²)
- **Number of values less than 0.1 feet:** 131
- **Number of values 0.1 to 1.0 feet:** 30
- **Number of values greater than 1.0 feet:** 15

Specific volumes calculated at the wells were used to generate a free-product (LNAPL) volume estimate by integrating the specific volume values over the site area. The AutoCAD composite volume calculation function was used to estimate the volume of LNAPL by integrating the specific volume values at each well across the LNAPL plume area (see Figure 6-1). An estimate of total recoverable LNAPL volume was also generated by integrating the recoverable LNAPL volume values at each well across the LNAPL plume area. The model results for the nominal case are:

- **Current Total LNAPL Volume:** 9,800,000 gallons
- **Current Recoverable LNAPL Volume:** 6,900,000 gallons

In an attempt to quantify this uncertainty of the model, it was run two additional times, once using all the minimum input parameters and the other using all the maximum input parameters. The result for the minimum total LNAPL volume is

6,200,000 gallons, with 3,900,000 recoverable. The modeled result for the maximum total LNAPL volume is 13,400,000 gallons, with 9,300,000 recoverable. Based on this method, the model predictive range suggests an uncertainty of 36% of the total nominal value.

These volumes can be interpreted in light of current LNAPL recovery rates as well as the total LNAPL volume recovered to date. According to product recovery numbers reported by the responsible parties to NYSDEC, approximately 417,000 gallons of LNAPL was recovered (about 34,750 gallons per month) in 2008; the total LNAPL volumes recovered as of December 31, 2008 were:

■ Exxon On-Site	
Annual 2008 Report ¹	1,738,749 gallons
■ Exxon Off-Site	
Annual 2008 Report ²	4,296,310 gallons
■ Paragon	
Annual 2008 Progress Report ³	32,040 gallons
■ BP	
Annual 2008 Report ⁴	3,375,172 gallons
■ Meeker Avenue Task Force	Approx. 170,000 gallons
■ Total	9.6 million gallons

In 2009, an additional 881,000 gallons of LNAPL was recovered (about 73,400 gallons per month), which increased the total amount of LNAPL recovered to approximately 10.5 million gallons.

To determine a rough estimate of the total original spill volume, the total LNAPL recovered to date can be added to the estimated remaining LNAPL volume. Since the data used to estimate the remaining plume volume is from 2007 and 2008, the 2008 total recovered LNAPL volume of 9,610,000 gallons should be used for the original spill volume estimate. Based on this method, 9.6 million gallons removed to date added to 9.8 million gallons remaining produces an original spill volume estimate of 19.4 million gallons. However, this estimate is associated with the same uncertainties and assumptions as the LDRM model and model input parameters. As such, using this method means the original volume could range from as little as 15.8 million gallons (using the minimum input parameters estimate of 6,200,000 gallons) to as much as 23.0 million gallons (using the maximum input parameters estimate of 13,400,000 gallons).

¹ Remedial Engineering, P.C. 2009a.

² Remedial Engineering, P.C. 2009b.

³ Science Applications International Corporation 2009.

⁴ Delta Consultants 2009.

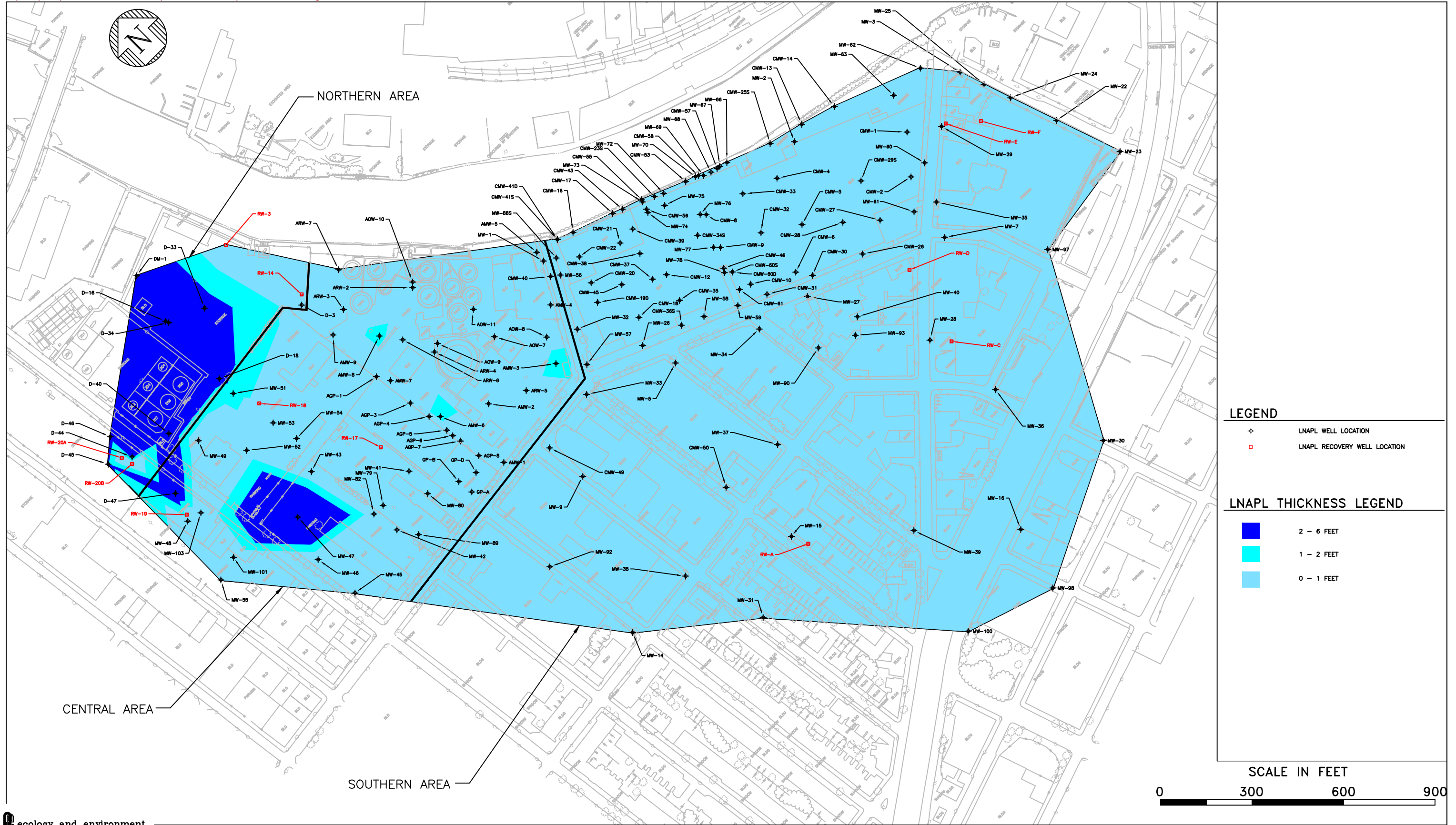


Figure 6-1 ESTIMATED LNAPL SPECIFIC VOLUME AND SITE BOUNDARIES GREENPOINT NEW YORK, NEW YORK

7

Conclusions

7.1 Overview

The LDRM model was selected for use in estimating the volume of LNAPL at the Greenpoint Petroleum Remediation site because it incorporates recent advances in the knowledge of the science of subsurface LNAPL. The volume of petroleum product estimated within the boundary where free product (LNAPL) is detected at the Greenpoint Petroleum Remediation site is 9,800,000 gallons, with 6,900,000 gallons estimated as recoverable (see Table 7-1). This estimate was developed using existing 2007 and 2008 data and, as such, is an estimate of the volume of petroleum product remaining at the end of 2008. These estimates are also associated with an amount of uncertainty due to uncertainty in the model input parameters. To quantify this uncertainty, the model was run two additional times, once using all the minimum input parameters (which estimated 6,200,000 gallons remain) and another using all the maximum input parameters (which estimated 13,400,000 gallons remain), which suggests an uncertainty of approximately 36%. According to product recovery numbers reported to NYSDEC by the responsible parties, approximately 9,600,000 gallons of free product were recovered as of January 1st, 2009.

Table 7-1 Estimated Volume of Petroleum Product as of December 31, 2008

Estimated Original Spill Volume	DEC Reported Volume of Product Recovered	Estimated Remaining Volume	Estimated Remaining Recoverable Volume	Estimated Remaining Unrecoverable Volume
19,400,000	9,600,000	9,800,000	6,900,000	2,900,000

7.2 Model Improvement Recommendations Based on the LNAPL Volume Estimate and Sensitivity Analysis

Additional model-sensitive data could reduce the uncertainty in values for these input parameters and thus reduce the uncertainties in the volume estimate. The VG-alpha and porosity data provided by ExxonMobil improved the volume estimate and reduced the estimate's uncertainty from approximately 50% to 36%. However, the ExxonMobil additional information did not include data for the central part of the site, and an average of the northern and southern sections values was assumed in order to obtain the values of VG-alpha and porosity. Therefore, it is recommended that additional model-sensitive data (such as VG-alpha and po-

rosity) be provided or collected for the central area, which may further improve the volume estimate and reduce the range of uncertainty.

Alternatively, or in addition to additional data, a Monte-Carlo simulation could be run for each specific volume calculation. Parameter probability distributions would replace specific values (nominal, minimum, maximum) assigned to each parameter. Monte-Carlo software (e.g., Excel add-on) would iteratively run the model calculation, sampling from probability distributions for each parameter and generating an output in the form of a probability distribution. Percentile values (e.g., 10th percentile, 50th percentile, 90th percentile) specific volume probability distributions for each well would then be used to generate 10th, 50th, and 90th percentile probability estimates of the LNAPL volume. In this way, the likelihood associated with the range of plausible volume predictions could also be presented.

Boring logs for some monitoring wells in the northern area of the site indicate a 2- to 3-foot-thick layer of clay. Because the primary porosity in clays is from extremely small pore spaces, the capillary pressure in the bulk of clay soils is higher than in all other soil types. This high capillary pressure is sufficiently high to prevent the intrusion of LNAPL into primary pore spaces. Macro-pores, or the cracks and fissures in clay composing clay's secondary porosity, however, are large enough and have capillary pressure low enough that LNAPL is able to flow through them. But because this secondary porosity composes a small fraction of the total porosity of clay, the actual volume of LNAPL in a layer of clay with observed LNAPL is significantly less than the volume of LNAPL in other soil types, such as sand (Remediation Technologies Development Forum 2006). The LDRM was applied using a uniform soil type (poorly graded sand and poorly graded sand with silt) for all wells, such that if a soil type has a significant component of clay, the model will overpredict specific volume. However, the extent of overprediction is limited to wells where the clay was observed in the borings and applies only to the thickness of the clay. Thus, given LNAPL flow through secondary porosity, a clay layer could result in a maximum of 2 to 3 feet of additional capillary rise and, thus, some fraction of that in predicted actual thickness. Given sufficient field measurements, up to three different soil layers could be modeled using the LDRM, and clay layers, where present, could be fully represented and better estimates of actual specific volume would result.

The modeled estimates close to Newtown Creek should be interpreted with caution because the LDRM assumes vertical equilibrium, but many of the wells adjacent to Newtown Creek show large fluctuations in the water table due to tidal effects. An additional amount of uncertainty is associated with the portion of the LNAPL volume affected by tides but is likely well within the range of uncertainty in the volume estimates presented here.

Additionally, while the remaining boundaries of the site appear to be well-defined by observation wells with no apparent LNAPL, the northern boundary of the free-product plume is not. Identifying the current northern boundary of the plume

would require additional observations at existing wells in the area. If LNAPL is present in these northern wells, the volume estimate would increase.

Another possibility would be to use the data from the 1979 Geraghty and Miller study to derive an estimate using the LDRM model. Such an analysis would present a better estimate of the LNAPL volume at that time period (i.e., prior to remedial efforts) and could be used to evaluate progress in removing LNAPL volume. Because additional observation wells have been drilled and data have been collected at these new wells since then, it would be necessary to ensure that a realistic spill impact area is considered.

8

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A

Sensitivity Analysis and Model Predictive Uncertainty Range

A screening-level sensitivity analysis was conducted after the previous LNAPL volume estimate had been made to evaluate which parameter values influenced the model results the most. VG-alpha, porosity, and some product thickness inputs used in the model have been modified since this original sensitivity analysis was performed; however, the method for determining the range of uncertainty and the model's sensitivity to certain parameters has remained the same. EEEPC identified the water vertical gradient, the three surface tension parameters, VG-alpha, and porosity as sensitive parameters. Vertical gradient has been measured at the site and found to be near zero, with no clear upward or downward gradient and no apparent trend across the site. As discussed in Section 5, representative porosity measurements were available from four site locations, and surface tension parameter measurements were available from two monitoring wells and a composite of four remedial wells. VG-alpha data was not available at the site. In addition, over the ranges of their reported values, porosity, VG-alpha, and the surface tension parameters can significantly influence the model results. As a result, porosity, VG-alpha, and the three surface tension parameters were identified as critical to the model results and the uncertainty of the volume estimation.

A range of uncertainty, bounding the nominal LNAPL volume estimate, was generated. High and low volume estimates were generated by using values for sensitive parameters, within the reasonable range of their literature values that cause the model results to be highest or lowest. Table A-1 lists the five sensitive parameters that were adjusted in developing the uncertainty bounds on the volume estimate. Minimum and maximum van Genuchten alpha values were based on the range of values reported in the API parameter database for soil types SP and SP-SM (based on the plot shown in Figure A-1, values above 0.0325 1/cm [0.99 1/ft] were considered outliers and not part of the valid range). The range of values for porosity was based on the range of measured values from Geraghty and Miller (1979) and Roux (May 24, 1991). The range of porosity values measured on-site falls well within the range reported in the API database for soil types SP and SP-SM (as shown in Figure A-1). The range of surface tension values were based on the range reported in Roux (January 24, 2003). Based on the plots in Figure A-2a through 2c, air/LNAPL surface tension values outside the range of 22 to 32 dyne/cm appear to be outliers (yellow boxes in Figure A-1 through A-2c indicate expected values, discounting outliers). Similarly, considering the correla-

A Sensitivity Analysis and Model Predictive Uncertainty Range

tion between values for air/water surface tension and LNAPL/water surface tension, values for these parameters are expected to be within the ranges of 50 to 74 dyne/cm and 10 to 25 dyne/cm, respectively. The range of values of the surface tension parameters are also within the range reported in the API database for SP and SP-SM soils.

Table A-1 Nominal, Minimum, and Maximum Values for Sensitive Parameters that are not Available or Well-Defined at the Greenpoint Site

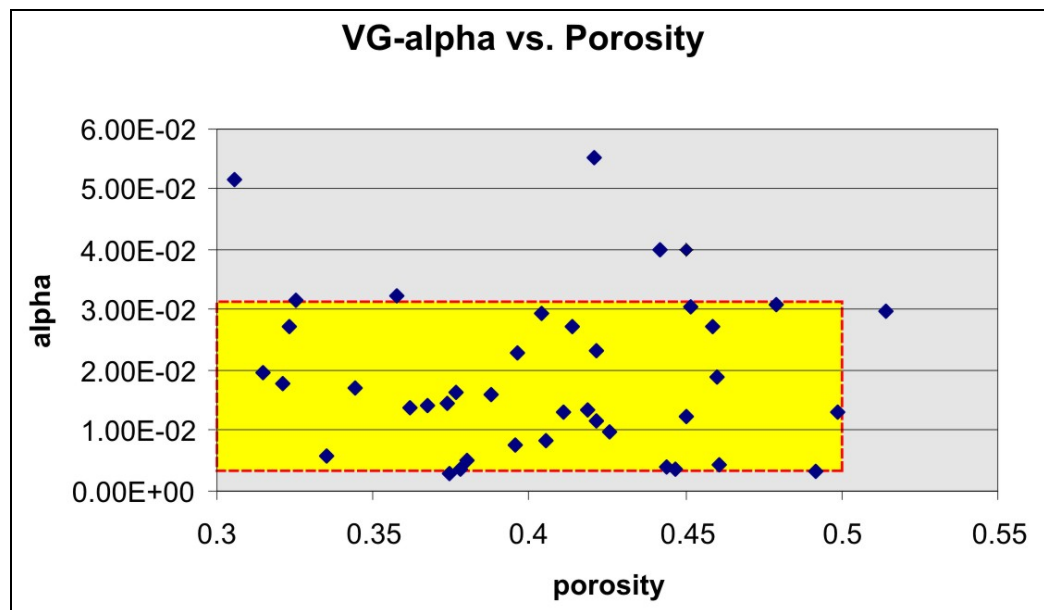
Model Parameter	Nominal	Minimum	Maximum
Air/Water Surface Tension (dyne/cm)	68.5	63.0	70.0
Air/LNAPL Surface Tension (dyne/cm)	23.0	22.9	23.3
LNAPL/Water Surface Tension (dyne/cm)	11.5	9.8	13.8
Porosity	0.42	0.38	0.45
van Genuchten alpha (1/ft)	0.59	0.093	0.99

Key:

1/ft = One per foot.

Dyne/cm = Dyne per centimeter.

LNAPL = Light non-aqueous phase liquid.



Note: Expected values are highlighted in yellow (discounting outliers).

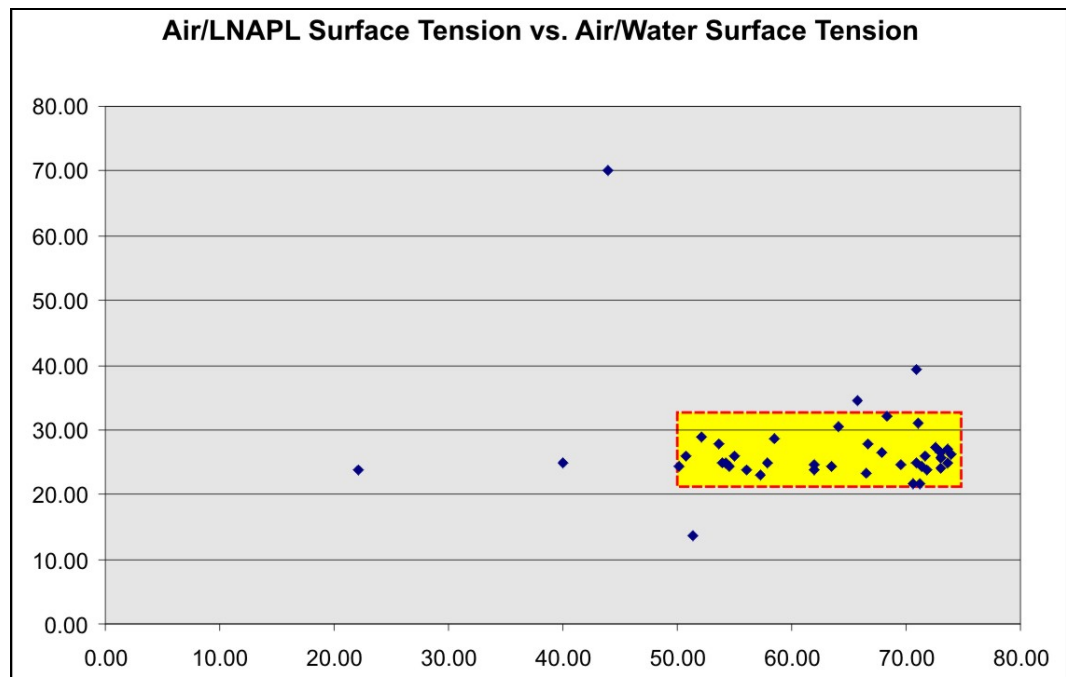
Figure A-1 Plot of VG-alpha vs. Porosity for SP and SP-SM Soil Types in the API Parameter Database

The soil parameters were tested for correlation. A plot of porosity versus VG-alpha (see Figure A-1) using values for SP and SP-SM soils in the API parameter database shows no correlation between these two parameters. As a result, any combination of these two parameters, over their range of reported values, can be used together. To generate the range of model predictive uncertainty associated with uncertainty in the values of these parameters, values for these parameters are selected so their combination produces minimum and maximum model results. Since a higher porosity and a higher VG-alpha value result in a higher specific volume result, the maximum values of porosity and VG-alpha are used together in

A Sensitivity Analysis and Model Predictive Uncertainty Range

generating the maximum model result. Similarly, the minimum values of these two parameters are used together to generate a minimum model result.

Surface tension parameters were also tested for correlation. Surface tension parameter values for SP and SP-SM soils, as measured by other researchers at a variety of LNAPL sites, were extracted from the API parameter database and graphed (see Figures A-2a through A-2c). Only air/water surface tension and LNAPL/water surface tension values appear to be correlated. Site measurements for these parameters appear to be consistent with the positive correlation shown in the plot. It should be noted that while a decrease in air/water surface tension results in a decrease in model-calculated specific volume, a decrease in LNAPL/water surface tension results in an increase in calculated specific volume. While simultaneous use of the minimum air/water surface tension parameter value with the maximum LNAPL/water surface tension parameter value would result in the lowest specific volume, such a combination is not likely to occur due to the correlation of these parameters. As a result, minimum and maximum values of each parameter are used together in model runs used to define minimum and maximum specific volumes.

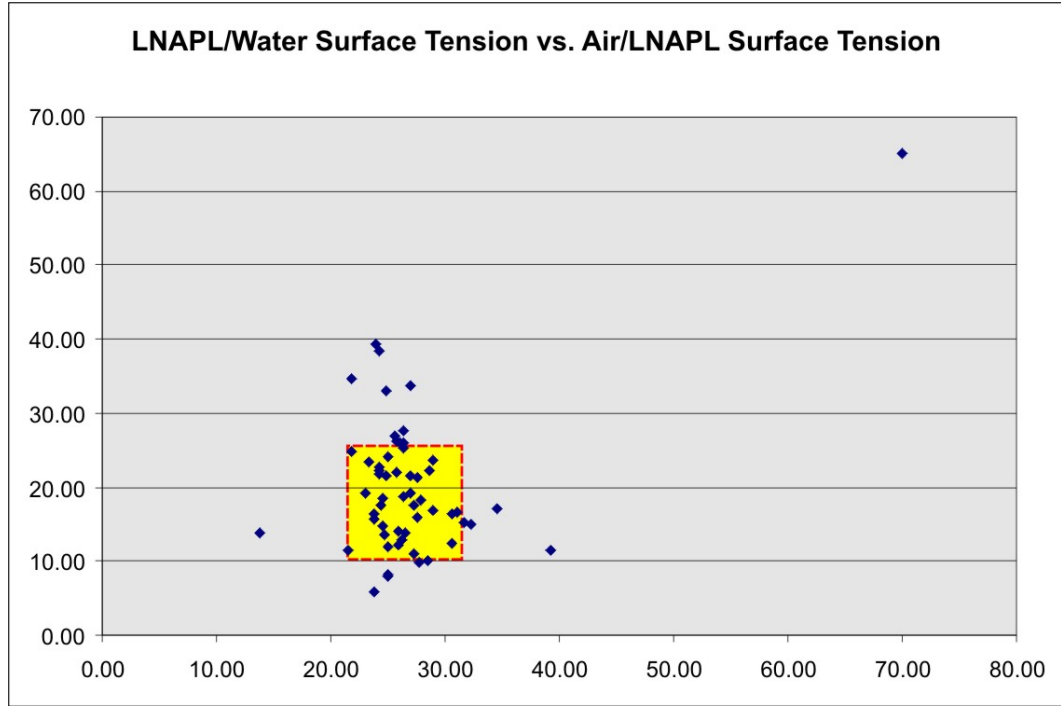


Data Source: API Parameter Database

Note: Expected values are highlighted in yellow (discounting outliers).

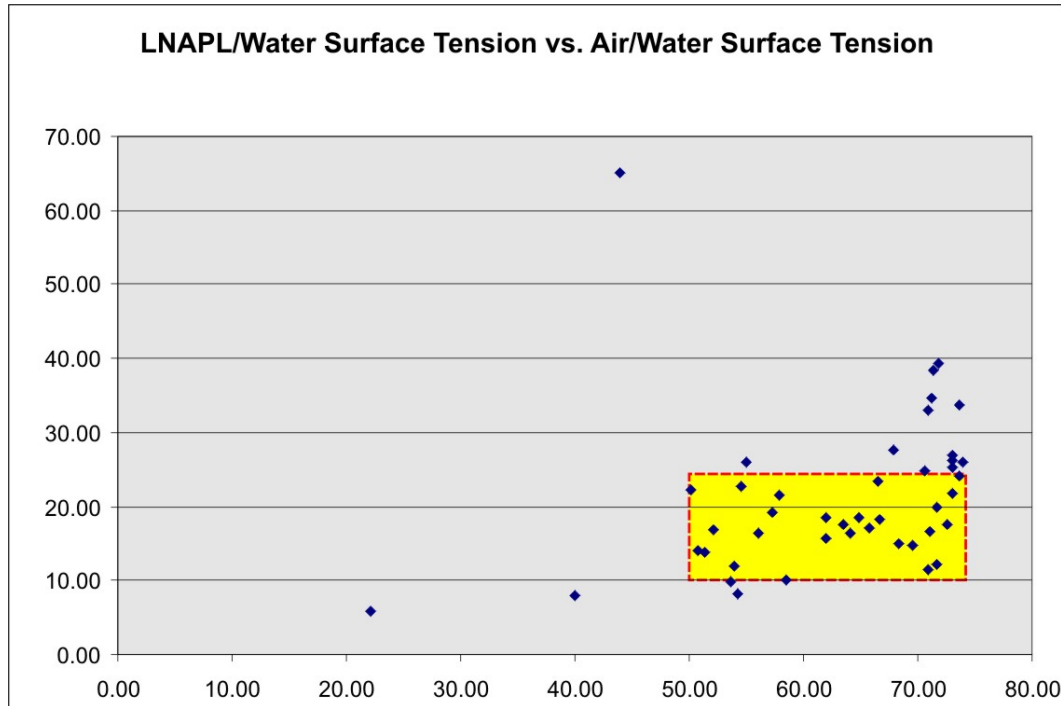
Figure A-2a Test for Correlation of Surface Tension Parameters Based on Measurements at Numerous LNAPL Sites

A Sensitivity Analysis and Model Predictive Uncertainty Range



Data Source: API Parameter Database
 Note: Expected values are highlighted in yellow (discounting outliers).

Figure A-2b Test for Correlation of Surface Tension Parameters Based on Measurements at Numerous LNAPL Sites



Data Source: API Parameter Database
 Note: Expected values are highlighted in yellow (discounting outliers).

Figure A-2c Test for Correlation of Surface Tension Parameters Based on Measurements at Numerous LNAPL Sites

A Sensitivity Analysis and Model Predictive Uncertainty Range

The uncertainty range associated with the nominal volume estimate was generated by running the model for the combination of parameter values that produces the extreme high and low actual LNAPL thicknesses.

The range of different model input parameter values results in a large range of plausible LNAPL volume estimates: from 4,700,000 to 16,000,000 gallons (i.e., a ratio of maximum to minimum volume estimates of 3.4). The range of plausible recoverable LNAPL volume estimates is from 3,300,000 to 11,000,000 gallons. The uncertainty in the volume estimates indicated by these ranges is due to the variability in site measurements of porosity and surface tension parameters and the lack of site-specific knowledge of the VG-alpha soil parameter. The low end of the uncertainty range for the recoverable volume should be considered in light of actual current free product (LNAPL) recovery rates. According to product recovery numbers reported by the responsible parties, approximately 417,000 gallons or 34,750 gallons per month of LNAPL was recovered in 2008, while 881,000 gallons or 73,400 gallons per month of LNAPL was recovered in 2009.

As a final sensitivity analysis, the LDRM model was run for apparent thickness volumes recorded during the period the pump was shut down in May 2007. The results indicate a nominal plume volume of 11,000,000 gallons and a recoverable volume of 7,600,000 gallons. The total volume estimated for May 2007 is approximately 25% less than the nominal volume estimate based on the February 2007 and March 2008 observation dates, when the LNAPL recovery wells were functioning. The reason for the discrepancy is likely the use of the maximum of the two observed thickness values (at each well) for the February 2007/March 2008 observations versus use of single observed thickness values (at each well) for the May 2007 observation. Thus the nominal estimate is likely somewhat conservative due to the use of the maximum values from two observation periods.

B

Observation Well-Specific Inputs and Model Results

B.1 Northern Section of the Greenpoint Site
Table B-1 Observation Well-Specific Inputs and Model Results for the Northern Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
D-16	0.85	23.12	3.0207	4.1514	5.4074
D-18	0.79	12.56	1.8438	2.367	2.976
D-3	0.86	6.96	0.2628	0.5042	0.8482
D-33	0.85	16.68	1.8086	2.6058	3.5195
D-34	0.8	18.53	2.9428	3.7845	4.7012
D-40	0.84	17.95	2.2017	3.0581	4.0251
D-44	0.83	14.48	1.6941	2.3652	3.135
D-45	0.85	14.63	1.4477	2.1357	2.9371
D-46	0.83	15.66	1.9175	2.6482	3.4797
DM-1	0.89	24.62	2.4272	3.6535	5.0603
RW-14	0.86	4.19	0.0614	0.1456	0.2998
RW-20A	0.83	0.56	0.0001	0.0003	0.001
RW-20B	0.83	0	0	0	0
RW-3	0.86	0.11	0	0	0

Key:

- ft³/ft² = Cubic feet per square foot.
- LNAPL = Light non-aqueous phase liquid.
- mg/mL = Milligrams per milliliter.

B.2 Central Section of the Greenpoint Site
Table B-2 Observation Well-Specific Inputs and Model Results for the Central Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
AGP-1	0.9	2.34	0.0019	0.0121	0.0354
AGP-3	0.85	0.85	0.0003	0.0015	0.0042
AGP-4	0.82	0	0	0	0
AGP-5	0.82	0	0	0	0
AGP-6	0.82	0	0	0	0
AGP-7	0.82	0	0	0	0
AGP-8	0.82	0	0	0	0
AMW-1	0.8	1.55	0.0116	0.0419	0.0801
AMW-2	0.81	1.86	0.0157	0.0575	0.1097
AMW-3	0.8	10.25	1.2442	1.8760	2.3761
AMW-4	0.8	0	0	0	0
AMW-5	0.8	0.67	0.0006	0.0026	0.0061
AMW-6	0.82	9.7	0.0001	1.5522	2.0476
AMW-7	0.9	6.87	0.0852	0.3355	0.6358
AMW-8 ¹	0.89	12.42	0.5835	1.3659	2.0455
AMW-9	0.88	4.88	0.051	0.2072	0.4024
AOW-10	0.92	9.01	0.1054	0.4302	0.8293
AOW-11	0.89	3.43	0.011	0.0592	0.1433
AOW-7	0.8	0.14	0	0	0
AOW-8	0.8	2.3	0.0421	0.1224	0.2045
AOW-9	0.87	2.66	0.0086	0.0444	0.1056
ARW-2	0.89	0.85	0.0001	0.0004	0.0014
ARW-3	0.88	4.89	0.0513	0.2083	0.4042
ARW-4	0.87	0.97	0.0002	0.0013	0.004
ARW-5	0.87	0.87	0.0001	0.0009	0.0027
ARW-6	0.87	0.76	0.0001	0.0005	0.0016
D-47	0.79	15	2.3665	3.2409	3.9501
DM-1	0.89	24.62	2.3824	4.0999	5.4799
GP-A	0.8	0.25	0	0.0001	0.0002
GP-B	0.8	0.81	0.0012	0.005	0.0116
GP-D	0.8	1.12	0.0037	0.0152	0.0322
MW-1	0.8	0	0	0	0
MW-101	0.83	0	0	0	0
MW-103	0.79	0	0	0	0
MW-41	0.8	0	0	0	0
MW-42	0.89	8.1	0.1876	0.586	0.9885
MW-43	0.94	0.81	0	0	0.0002
MW-45	0.8	1.85	0.0211	0.0693	0.1246

B Observation Well-Specific Inputs and Model Results

Table B-2 Observation Well-Specific Inputs and Model Results for the Central Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
MW-46	0.8	0	0	0	0
MW-47	--	0.03	4.4039	5.7951	6.9976
MW-48	0.8	4.7	0.2826	0.5516	0.7705
MW-49	0.86	1.03	0.0004	0.0022	0.0064
MW-51	0.86	10.29	0.6252	1.2927	1.8456
MW-52	0.88	5.75	0.0865	0.3132	0.5687
MW-53	0.88	0	0	0	0
MW-54	0.88	0.45	0	0.0001	0.0002
MW-55	0.83	0.35	0	0.0001	0.0003
MW-79	0.89	6.75	0.1083	0.3872	0.6974
MW-80	0.85	0	0	0	0
MW-82	0.8	3.7	0.1598	0.3515	0.5153
MW-89	0.8	0	0	0	0
RW-17	0.86	1.84	0.0031	0.0171	0.044
RW-18	0.88	7.72	0.2086	0.6090	0.9975
RW-19	0.79	0.44	0.0002	0.0008	0.0018

Notes:

¹ Modified to higher value from July 2009.

Key:

- ft³/ft² = Cubic feet per square foot.
- LNAPL = Light non-aqueous phase liquid.
- mg/mL = Milligrams per milliliter.

B.3 Southern Section of the Greenpoint Site
Table B-3 Observation Well-Specific Inputs and Model Results for the Southern Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
CMW-1	0.79	0	0	0	0
CMW-10	0.8	1.1	0.003	0.0207	0.0396
CMW-12	0.8	0.83	0.0011	0.0082	0.0168
CMW-13	0.89	0	0	0	0
CMW-14	0.79	0	0	0	0
CMW-16	0.82	0	0	0	0
CMW-17	0.82	0	0	0	0
CMW-18	0.8	2.6	0.0543	0.2049	0.3051
CMW-19D	0.8	0	0	0	0
CMW-2	0.79	1.75	0.0212	0.0952	0.1495
CMW-20	0.8	2.34	0.0392	0.162	0.2477
CMW-21	0.8	0.54	0.0002	0.0018	0.004
CMW-22	0.8	0	0	0	0
CMW-23S	0.84	0.74	0.0002	0.0018	0.0046
CMW-25S	0.86	0	0	0	0
CMW-26	0.8	0	0	0	0
CMW-27	0.8	0.01	0	0	0
CMW-28	0.8	0	0	0	0
CMW-29 S	0.79	0	0	0	0
CMW-30	0.8	0.93	0.0016	0.012	0.024
CMW-31	0.8	0	0	0	0
CMW-32	0.8	0	0	0	0
CMW-33	0.86	0.35	0	0.0001	0.0002
CMW-34S	0.84	0	0	0	0
CMW-35	0.8	1.59	0.0109	0.0615	0.1051
CMW-36S	0.8	2.42	0.0436	0.1748	0.265
CMW-37	0.8	2.23	0.0337	0.145	0.2245
CMW-38	0.8	1.6	0.0112	0.0625	0.1067
CMW-39	0.82	3.17	0.0577	0.2415	0.3719
CMW-4	0.86	0	0	0	0
CMW-40	0.82	3.73	0.94	0.3403	0.5032
CMW-41D	0.82	0	0	0	0
CMW-41S	0.82	0	0	0	0
CMW-43	0.82	0.31	0	0.0001	0.0003
CMW-45	0.82	1.25	0.0024	0.0192	0.0398
CMW-46	0.8	0	0	0	0

B Observation Well-Specific Inputs and Model Results

Table B-3 Observation Well-Specific Inputs and Model Results for the Southern Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
CMW-49	0.8	1.35	0.0062	0.0386	0.0695
CMW-5	0.8	0	0	0	0
CMW-50	0.78	1.52	0.0189	0.0802	0.1234
CMW-53	0.86	0.01	0	0	0
CMW-55	0.82	0.06	0	0	0
CMW-56	0.82	0	0	0	0
CMW-57	0.85	2.57	0.0121	0.0877	0.1674
CMW-58	0.86	2.79	0.0119	0.0902	0.1764
CMW-6	0.8	1.15	0.0035	0.0238	0.0449
CMW-60D	0.8	0	0	0	0
CMW-60S	0.8	0	0	0	0
CMW-61	0.8	1.36	0.0064	0.0395	0.0709
CMW-8	0.84	1.73	0.004	0.0336	0.0702
CMW-9	0.8	0	0	0	0
MW-100	0.8	1.56	0.0103	0.0583	0.1003
MW-14	0.79	0	0	0	0
MW-15	0.79	2.05	0.0351	0.1391	0.2097
MW-16	0.81	0.32	0	0.0002	0.0005
MW-2	0.89	0	0	0	0
MW-22	0.8	0.05	0	0	0
MW-23	0.8	0	0	0	0
MW-24	0.8	0.35	0	0.0004	0.0008
MW-25	0.8	1.94	0.0214	0.1035	0.1667
MW-26	0.8	0	0	0	0
MW-27	0.8	0	0	0	0
MW-28	0.79	1.51	0.0129	0.0651	0.1065
MW-29	0.79	1.15	0.005	0.0301	0.0533
MW-3	0.8	1.56	0.0103	0.0583	0.1003
MW-30	0.8	0	0	0	0
MW-31	0.79	1.45	0.0113	0.0584	0.0966
MW-32	0.79	0.15	0	0	0
MW-33	0.79	2.05	0.0351	0.1391	0.2097
MW-34	0.8	1.63	0.0119	0.0658	0.1116
MW-35	0.79	0	0	0	0
MW-36	0.8	1.59	0.0109	0.0615	0.1051
MW-37	0.78	1.63	0.0237	0.0953	0.1443
MW-38	0.78	2.5	0.0847	0.2449	0.3384
MW-39	0.79	1.08	0.004	0.0249	0.0449
MW-40	0.8	1.16	0.0036	0.0244	0.046

B Observation Well-Specific Inputs and Model Results
Table B-3 Observation Well-Specific Inputs and Model Results for the Southern Section

Well Number	LNAPL Density (mg/mL)	Free-Product Recovery Used In Model (ft)	LNAPL Specific Volume		
			(ft ³ /ft ²) Minimum	(ft ³ /ft ²) Nominal	(ft ³ /ft ²) Maximum
MW-5	0.81	0.9	0.001	0.0083	0.0177
MW-56	0.8	3.55	0.1317	0.3848	0.5366
MW-57	0.8	2.09	0.0274	0.1243	0.1959
MW-58	0.8	1.47	0.0083	0.0494	0.0865
MW-59	0.8	1	0.0021	0.0153	0.0299
MW-60	0.79	2.21	0.0443	0.165	0.2442
MW-61	0.79	0	0	0	0
MW-62	0.8	0	0	0	0
MW-63	0.79	0	0	0	0
MW-66	0.85	0	0	0	0
MW-67	0.85	2.9	0.0184	0.1219	0.2223
MW-68	0.85	0.22	0	0	0
MW-69	0.86	2.85	0.0128	0.0958	0.1857
MW-7	0.79	0.29	0	0.0003	0.0006
MW-70	0.86	1.27	0.0007	0.0071	0.018
MW-72	0.82	0.34	0	0.0002	0.0005
MW-73	0.82	0.88	0.0007	0.0059	0.0133
MW-74	0.82	1.65	0.0064	0.0453	0.086
MW-75	0.84	0.04	0	0	0
MW-76	0.84	0.45	0	0.0003	0.0008
MW-77	0.8	1.35	0.0062	0.0386	0.0695
MW-78	0.8	1.66	0.0127	0.0691	0.1166
MW-88S	0.8	0	0	0	0
MW-9	0.8	0.7	0.0006	0.0046	0.0097
MW-90	0.79	1.52	0.0132	0.0662	0.1082
MW-92	0.79	0	0	0	0
MW-93	0.79	0.17	0	0	0.0001
MW-97	0.79	0	0	0	0
MW-98	0.8	0	0	0	0
RW-A	0.79	3.28	0.1352	0.3685	0.5039
RW-C	0.79	2.92	0.0992	0.2951	0.4119
RW-D	0.8	3.45	0.1220	0.3645	0.5109
RW-E	0.8	1.01	0.0022	0.0158	0.0308
RW-F	0.81	0.28	0	0.0001	0.0003

Key:

ft³/ft² = Cubic feet per square foot.
 LNAPL = Light non-aqueous phase liquid.
 mg/mL = Milligrams per milliliter.