LNAPL MOBILITY EVALUATION

AREA OF INDUSTRIAL REDEVELOPMENT

Pontiac North Campus
Pontiac, Michigan

General Motors Corporation
Pontiac, Michigan

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ENCORE
Environmental Corporate Remediation ©

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LIST OF ACRONYMS

2-D	2-Dimensional
3-D	3-Dimensional
AIR	Area of Industrial Redevelopment
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
cm	Centimeters
cm^3	Cubic centimeters
cp	Centipoise
CPT	Cone penetration test
EEC	ENCORE Environmental Consortium
ENCORE	Environmental Corporate Remediation Company, Inc.
FPMP	Free product mobility package
ft	Feet
ft^2	Square feet
ft^3	Cubic feet
g	Grams
GM	General Motors Corporation
LIF	Laser induced fluorescence
LNAPL	Light non-aqueous phase liquid
PTS	PTS Laboratories
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
s	Second
U.S. EPA	United States Environmental Protection Agency
USPS	United States Postal Service
UV	Ultra violet
VOC	Volatile organic compounds

LIST OF PARAMETERS/SYMBOLS

α	van Genuchten α
α_{ow}	Capillary Pressure Head Parameter – Oil/Water (ft^{-1})
α_{ao}	Capillary Pressure Head Parameter – Air/Oil (ft^{-1})
b_o	LNAPL Thickness (ft)
ϕ	Total Soil Porosity
ϕ_{eff}	Effective Porosity
g	Gravitational Constant (kg m/s^2)
i	Reference Point Along Vertical LNAPL Saturation Profile
i_w	Water Hydraulic Gradient (assumed equal to oil gradient)
k	Soil Permeability (cm^2)
k_{ro}	LNAPL Relative Permeability
k_{ro-b}	LNAPL Relative Permeability from Burdine Equation
k_{ro-m}	LNAPL Relative Permeability from Mualem Equation
K_w	Hydraulic Conductivity Water (cm/s or ft/day)
K_o	LNAPL Conductivity (cm/s or ft/day)
λ	Pore Size Distribution Index
μ_o	LNAPL Viscosity (cp)
μ_w	Water Viscosity (cp)
M	Model Fitting Parameter
M_o	LNAPL Mobility (cm/s)
n	Number of Equally Spaced Points Along Z-Axis
N	van Genuchten N
ρ_o	LNAPL Density (g/cm^3)
ρ_w	Water Density (g/cm^3)
q_o	LNAPL Specific Discharge (cm/s or ft/day)
σ_{aw}	Air-Water Interfacial Tension (dynes/cm)

σ_{ow}	Oil-Water Interfacial Tension (dynes/cm)
σ_{ao}	Air-Oil Interfacial Tension (dynes/cm)
S_o	LNAPL Saturation
S_{or}	LNAPL Residual Saturation
S_{ors}	LNAPL Residual Saturation – Saturated Zone
S_{orv}	LNAPL Residual Saturation – Vadose Zone
S_t	Total (LNAPL plus Water) Saturation
S_w	Water Saturation
S_{wr}	Water Residual (Irreducible) Saturation
T_o	LNAPL Transmissivity (cm^2/s or ft^2/day)
V_o	LNAPL Specific Volume (ft^3/ft^2)
υ_o	LNAPL Velocity (cm/s)
z	Reference Elevation on the Vertical LNAPL Saturation Profile (ft)
z_{ao}	Air-Oil Elevation (ft)
z_{aw}	Air-Water Elevation (ft)
z_{ow}	Oil-Water Elevation (ft)
$z_{\max}$	Maximum Elevation of LNAPL (above residual saturation) in Smear Zone (ft)

1.0 INTRODUCTION

Light non-aqueous phase liquid (LNAPL) was discovered in the southwest portion of the General Motors Corporation (GM) Pontiac North Campus site (Site) in Pontiac, Michigan during implementation of a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI). More specifically, the LNAPL was discovered in an area of the Site that is presently undergoing industrial redevelopment. The area of industrial redevelopment (AIR) is approximately 75 acres in size. The United States Postal Service (USPS), in cooperation with GM and Environmental Corporate Remediation Company, Inc. (ENCORE), a wholly owned subsidiary of GM, is in the process of constructing an 850,000 square foot USPS distribution facility in the AIR. The Site location and the location of the AIR, with respect to the Site, are shown in Figures 1.1 and 1.2, respectively.

The LNAPL in the AIR has been categorized into the following designated areas based on the historically inferred LNAPL locations and/or physical/chemical characteristics: LNAPL Areas 1, 2, 3, 7, 9, 10 and 11. LNAPL Area 3 is partially situated beneath the proposed USPS building footprint. Consequently, GM/ENCORE and the USPS, during negotiations for the redevelopment of the property, agreed that ENCORE would aggressively remediate LNAPL Area 3. The objective was for ENCORE to recover as much LNAPL as practicable prior to the commencement of building construction activities. The LNAPL investigation and remediation efforts in LNAPL Area 3 have been reported to the United States Environmental Protection Agency (U.S. EPA) in a series of reports and memos issued over the past five years. This report focuses on the remaining LNAPL Areas 1, 2, 7, 9, 10 and 11 in the AIR. In particular, this report presents an evaluation of the mobility and stability of LNAPL within the AIR, excluding LNAPL Area 3.

LNAPL mobility and overall plume stability were evaluated using several lines of evidence including:

- Site history in the AIR (i.e. probable LNAPL release date(s), inferred time in the subsurface);
- Historical monitoring data (including in-well or apparent LNAPL thicknesses); and
- Current monitoring and test data (presented in this report) both in the interior portions and outer fringes of the LNAPL areas.

Although LNAPL recoverability was not the focus of this report, aggressive LNAPL recovery was conducted in Areas 9 and 10 in early 2005. LNAPL recovery was conducted using high vacuum multi-phase extraction (MPE) techniques. The LNAPL recovery results in Areas 9 and 10 were also used as an additional line of evidence for evaluating LNAPL mobility and plume stability.

This Report is organized as follows:

- Section 1.0 – Introduction;
- Section 2.0 – Background;
- Section 3.0 – General Discussion on LNAPL Behavior in the Subsurface;
- Section 4.0 – LNAPL Mobility Evaluation Methodology;
- Section 5.0 – LNAPL Mobility Evaluation Results;
- Section 6.0 – LNAPL Mobility Evaluation Discussion;
- Section 7.0 – LNAPL Recoverability;
- Section 8.0 – Conclusions and Recommendations; and
- Section 9.0 – References.

2.0 BACKGROUND

LNAPL Areas 1, 2, 3, 7, 9, 10 and 11 were discovered during subsurface investigation activities at the Site associated with the RFI, which commenced in 2001. The LNAPL areas, with the exception of the northern portion of LNAPL Area 2, are located within the AIR. The approximate locations of the LNAPL areas are identified in Figure 2.1.

The LNAPL in the AIR is believed to have resulted from a historical release(s) during past manufacturing operations. The AIR was previously occupied by a foundry, a final vehicle assembly plant, and an engine manufacturing plant. These buildings were decommissioned and demolished between 1995 and 1997. Consequently, it is believed that there has not been an active source release of LNAPL in the AIR for at least 10 years, and quite possibly much longer.

To assess the need for LNAPL remediation in the AIR, the ENCORE Environmental Consortium (EEC) evaluated LNAPL mobility and plume stability in the AIR LNAPL areas other than LNAPL Area 3. The evaluation was not conducted in LNAPL Area 3 since GM/ENCORE and USPS had already implemented aggressive LNAPL recovery measures in this area. The remediation efforts in LNAPL Area 3 are presented in the respective Interim Measures Report (ENCORE, 2006). This Report presents the results of the LNAPL mobility and plume stability evaluation.

For the purpose of this evaluation, the different LNAPL areas were grouped as follows: Area 1/2/7, Area 9/10, and Area 11. These three areas represent unique pairings of soil and LNAPL types based on historical site investigation data. For example, historical Site investigation data indicates that the predominant soil type and the LNAPL type (based on qualitative descriptions coupled with product fingerprint data) encountered across LNAPL Areas 1, 2, and 7 are consistent. Therefore, these areas are combined as Area 1/2/7 for the purpose of this evaluation.

3.0 GENERAL DISCUSSION ON LNAPL BEHAVIOR IN THE SUBSURFACE

This section presents some of the basic LNAPL concepts that describe the occurrence and behavior of LNAPL in the subsurface. Specifically, this section addresses LNAPL behavior at the water table and includes the vertical impacted zone typically referred to as the smear zone. The behavior of LNAPL in the vadose zone (above the smear zone) is not addressed here.

3.1 GENERAL LNAPL MOBILITY / STABILITY DISCUSSION

The mobility of LNAPL generally relates to its ability to move within and throughout an LNAPL plume. LNAPL mobility can be highly influenced by a fluctuating water table. This is due to the fact that, in general, LNAPL does not 'float' on the water table like a pancake, but rather coexists with air and groundwater at varying saturations within the impacted soil zone, both above and below the water table. The mobility of LNAPL is dependent on a variety of LNAPL properties (density, viscosity, interfacial tension) and soil properties (grain size) and is often characterized in terms of LNAPL saturation and residual saturation. LNAPL saturation is defined as the percent of the pore space that is occupied by LNAPL. Residual saturation is defined as the quantity or concentration (expressed as a percentage of the occupied total soil porosity) of LNAPL below which LNAPL will not flow under normal hydraulic conditions. Residual saturation represents the amount of LNAPL trapped by capillary forces within the pore network that is hydraulically unable to move (Beckett, 2005). As LNAPL saturation approaches or decreases to residual, the relative permeability of the LNAPL approaches zero, and the hydraulic conductivity of the LNAPL approaches zero. Hence, LNAPL, when present at concentrations at or below residual, is considered to be immobile.

Recent research suggests that LNAPL residual saturation is a function of initial LNAPL saturation (Johnston, C.D. and Adamski, M., 2005). The greater the initial saturation at any point in an LNAPL plume, the greater the residual saturation at that point. LNAPL saturation distribution for a given soil is predominantly determined by the grain size of the soil (U.S. EPA, 2005a). For any soil formation/LNAPL combination, a maximum residual saturation exists that is equivalent to that established during an LNAPL-water drainage and imbibition test, where the drainage phase proceeds to the irreducible water saturation.

Seasonal water table fluctuations have a direct impact on the mobility of LNAPL. A rising and falling water table creates a 'smear zone' where mobile, continuous LNAPL becomes spread vertically and discontinuous as water (considered the wetting fluid in a soil matrix) and LNAPL (non-wetting fluid) compete for pore space. Assuming a continuous source is not present, this interaction between water and LNAPL can effectively trap LNAPL as discontinuous, immobile droplets within the soil matrix (American Petroleum Institute (API), 2004). Consequently, during seasonal high water tables, LNAPL in the smear zone becomes submerged or trapped beneath the water table and, due to a higher residual saturation in the saturated zone, loses much of its ability to flow through the soil matrix and/or into a monitoring well. This explains the common apparent disappearance of LNAPL in wells at various sites during seasonal high water tables. Conversely, during seasonal low water tables, LNAPL becomes exposed in the unsaturated zone and, due to a lower residual saturation in the unsaturated zone, gains the ability to drain under gravity and flow in the soil and/or into a monitoring well. This explains the reappearance of LNAPL in wells during seasonal low water tables. Hence, the rising and lowering of the water table has a direct influence on the inherent mobility of LNAPL <u>within an LNAPL plume</u>.

LNAPL <u>stability</u> relates to the ability or inability of a plume to expand or move over time. If a plume is growing or moving over time, the plume is typically referred to as unstable, whereas if the plume remains essentially the same size and in the same location over time, the plume is referred to as stable. Generally speaking, 85 to 95% of all historical LNAPL plumes, where the source of the release has been terminated, are stable (Higinbotham, 2006; Beckett, 2005). LNAPL plumes are spatially self-limiting unless continually supplied from an on-going release, thus distinguishing LNAPLs from dissolved and vapor plumes that may migrate significant distances (API, 2004). Typically, once the release of free product stops, LNAPL in the water table region will eventually cease to move as the resistive forces in the saturated soils balance the driving forces in the LNAPL pool (Huntley and Beckett, 2001). The endpoint of this movement is when the LNAPL reaches field residual saturation, a condition where effective hydraulic conductivity of the LNAPL is zero (Huntley and Beckett, 2001). Often times, the following factors combine to produce a stable plume that is not spreading or migrating (U.S. EPA, 2005a):

- LNAPL fluid properties;
- LNAPL relative permeability;
- Conductivity of the porous media;
- Hydraulic gradient;
- Pore throat displacement entry pressure; and
- Fluctuating water table.

For an entire plume, LNAPL is often found to be mobile near the center of the plume, where LNAPL saturation exceeds residual saturation, and immobile at the outer plume fringes where saturation decreases to residual. Hence, parts of the plume exhibit some inherent mobility, whereas the overall plume is stable.

3.2 LNAPL MOBILITY / STABILITY EVALUATIONS

There are various lines of evidence used to evaluate the mobility and stability of an LNAPL plume. These lines of evidence, in order of preference and reliability, are:

- Historical LNAPL spatial distribution data;
- Site-specific LNAPL mobility evaluations; and
- LNAPL modeling simulations.

These lines of evidence are discussed in the following subsections.

3.2.1 HISTORICAL LNAPL SPATIAL DISTRIBUTION DATA

The most preferred line of evidence for evaluating plume stability is historical data regarding the spatial distribution of the plume. When an LNAPL release first occurs, the LNAPL, upon reaching the water table, displaces an amount of water proportional to the driving head behind the release. The LNAPL, being a non-wetting fluid, requires pressure to force it through the soil pores to the extent required to displace the existing pore water. The capillary pressure that must be overcome for a non-wetting LNAPL to enter water-saturated media is called the displacement entry pressure (Mercer and Cohen, 1990). As the release continues, the LNAPL typically expands in a radial direction (despite the groundwater flow direction) until there is insufficient backpressure to continue to displace water. The LNAPL plume becomes stable when there is insufficient backpressure (or head) to continue plume expansion.

Historical LNAPL spatial distribution data are typically based on “in-well” or “apparent” LNAPL thicknesses. Historical LNAPL data are especially useful when the data covers an extended period whereby in-well thicknesses can be assessed during both high water table and low water table conditions. Depending on the site conditions, high and low water tables may be assessed seasonally within a 12-month timeframe or may require a period of years for proper evaluation. Generally speaking, if the position, orientation and size of the LNAPL plume remains similar during low water table conditions over extended periods of time, the LNAPL plume is considered to be stable.

3.2.2 SITE-SPECIFIC LNAPL MOBILITY EVALUATIONS

LNAPL saturated soil cores from areas most impacted within an LNAPL plume may be sent for laboratory analysis of key LNAPL mobility parameters including: LNAPL saturation, residual saturation, and relative permeability. Such evaluations could include some and/or all of the following:

- Photographs of LNAPL saturated undisturbed soil cores in both natural light and ultraviolet light;
- Grain size analysis of soils in the anticipated LNAPL saturated zones;
- Laboratory saturation analyses to determine Site-specific saturations and residual saturations across the plume; and
- LNAPL fluid property testing for: density, viscosity, surface tension, and interfacial tension.

A comparison of saturation versus residual saturation values across an LNAPL plume can be used to assess the mobility of the plume.

3.2.3 LNAPL MODELING SIMULATIONS

There are various LNAPL models, including the API Interactive LNAPL Guide, that may be used to evaluate LNAPL mobility. The models contained in the API Interactive LNAPL Guide are based on a number of assumptions including: the fluids (LNAPL and water) are in vertical equilibrium and the soil conditions are relatively homogeneous. These conditions are required for in-well or apparent LNAPL thicknesses to be considered representative of the spatial (vertical) distribution of LNAPL in the formation. Situations where these conditions are not met include sites with (Johnson and Ling, 2005):

- Water table fluctuations;
- Confined conditions;
- Sump wells in a perched setting;
- On-going LNAPL release; and
- Heterogeneous conditions.

Although in a real world setting, there are often times when vertical equilibrium of liquids and homogeneous soil conditions do not exist, LNAPL models may still be used in some situations to generate qualitative information about LNAPL behavior. The degree to which model results are quantitatively valid and defensible will be based on actual site conditions and the accuracy of the LNAPL conceptual site model.

3.3 LNAPL MOBILITY CALCULATIONS

As described in the API Interactive LNAPL Guide (API, 2004), inherent oil mobility was defined by Parker (1996) and others as the ratio of free oil transmissivity to specific oil volume at a given location. These two parameters can be measured with core analyses or with baildown test analyses. The oil transmissivity is the product of the oil conductivity and the thickness of the free oil zone. The specific volume is the product of oil saturation, total porosity, and the thickness of the free oil zone. The inherent oil mobility is expressed as:

$$M_o = \frac{T_o}{V_o} \tag{1.1}$$

Where:

M_o = inherent oil mobility (ft/day)
V_o = specific oil volume per unit area (ft^3/ft^2)
T_o = oil transmissivity (ft^2/day)

The specific oil volume is a function of the oil saturation along the vertical profile and is expressed as:

$$V_o = \int_{z_1}^{z_2} \phi S_o dz \tag{1.2}$$

Where:

ϕ = total porosity (dimensionless)
S_o = oil saturation (dimensionless)
z = vertical thickness of oil impacts where z_1 is typically considered to be the oil-water interface elevation and z_2 is considered to be the maximum elevation of oil in the vadose zone above the air-oil interface (ft)

Oil saturation is a function of capillary pressure (the difference between the pressure in the non-wetting phase and the pressure in the wetting phase) and varies across the vertical impacted zone in a non-linear manner as shown in Figure 3.1. Hence, Equation 1.2 cannot be evaluated analytically. However, a simplified expression of the specific oil volume averaged across the vertical LNAPL saturation profile can be expressed as (API, 2004):

$$\overline{V_o} = b_o \phi \overline{S_o} \tag{1.3}$$

Where:

$\overline{V_o}$ = mean oil specific volume averaged across the saturation profile (ft^3/ft^2)
b_o = vertical extent of LNAPL impacts, or apparent LNAPL thickness (ft)
$\overline{S_o}$ = mean oil saturation averaged across the saturation profile (dimensionless)

The oil transmissivity is expressed as:

$$T_o = \frac{\rho_o}{\rho_w} \frac{\mu_w}{\mu_o} \int_{z_1}^{z_2} k_{ro} K_w dz \tag{1.4}$$

Where:

ρ_o = oil density (g/cm^3)
ρ_w = water density (g/cm^3)
μ_o = oil viscosity (cp)
μ_w = water viscosity (cp)
k_{ro} = oil relative permeability (dimensionless)
K_w = water hydraulic conductivity (cm/s)

Oil relative permeability is a function of oil saturation and varies across the vertical impacted zone in a non-linear manner as shown in Figure 3.1. Hence, Equation 1.4 cannot be evaluated analytically. However, a simplified expression of the free oil transmissivity averaged across the vertical LNAPL saturation profile can be expressed as (API, 2004):

$$\overline{T_o} = b_o \overline{K_o} \tag{1.5}$$

Where:

$\overline{T_o}$ = mean oil transmissivity averaged across the saturation profile (ft^2/day)
$\overline{K_o}$ = mean oil conductivity averaged across the saturation profile (ft/day)

Substituting Equations 1.3 and 1.5 into Equation 1.1 results in a simplified expression to determine inherent mobility at any location within an LNAPL plume:

$$\overline{M_o} = \frac{b_o \overline{K_o}}{b_o \phi \overline{S_o}} = \frac{\overline{K_o}}{\phi \overline{S_o}} \qquad (1.6)$$

Where:

$\overline{M_o}$ = mean inherent oil mobility (ft/day)

Therefore, the mean inherent oil mobility is equivalent to the ratio of the average oil conductivity to the effective free oil porosity (API, 2004).

It is important to recognize that the inherent LNAPL mobility only defines the potential for LNAPL movement (API, 2004). Although described in terms of "length per time" (feet per day, centimeters per second), it does not explicitly define plume migration. <u>To determine the movement of a LNAPL requires defining the oil gradient in addition to inherent mobility, both of which are needed to evaluate LNAPL plume stability</u>.

Equation 1.6 is expressed as a function of "mean" or "average" saturation and oil conductivity to yield a mean mobility value. A mean value is typically used for mobility calculations because LNAPL saturation, conductivity and relative permeability vary across the vertical LNAPL impacted zone both above and below the water table. The use of mean or average values for LNAPL saturation, relative permeability and conductivity is deemed to represent the inherent mobility of LNAPL on a macro-scale or plume-scale.

The mean oil conductivity is expressed as:

$$\overline{K_o} = \frac{\rho_o}{\mu_o} \overline{k_{ro}} k g \qquad (1.7)$$

Where:

$\overline{K_o}$ = mean oil conductivity (ft/day)
$\overline{k_{ro}}$ = mean oil relative permeability (dimensionless)
k = soil permeability (ft^2)
g = gravitational constant (ft/day^2)

The permeability of the soil is expressed as:

$$k = \frac{K_w \mu_w}{\rho_w g} \tag{1.8}$$

Consequently, Equation 1.7 can be re-written as:

$$\overline{K_o} = \overline{k_{ro}} K_w \frac{\rho_o \mu_w}{\rho_w \mu_o} \tag{1.9}$$

The density and viscosity values for water are close to one, and therefore may be eliminated from Equation 1.9.

The relative permeability of LNAPL represents the ability of the LNAPL to flow in the presence of water. Assuming that the LNAPL residual saturation in both the vadose zone and saturated zone are zero, LNAPL relatively permeability can be expressed as a function of LNAPL saturation and water saturation based on the following three phase integration of the Burdine (1953) equations and Brooks and Corey (1964) soil characteristic model (API, 2003):

$$k_{ro}(S_w, S_o) = S_o^2 \left[\left(\frac{S_t - S_{wr}}{1 - S_{wr}} \right)^{\frac{\lambda+2}{\lambda}} - \left(\frac{S_w - S_{wr}}{1 - S_{wr}} \right)^{\frac{\lambda+2}{\lambda}} \right] \tag{1.10}$$

Where:

S_w = water saturation (dimensionless)
S_o = oil saturation (dimensionless)
S_t = total saturation ($S_w + S_o$)
λ = pore size distribution index (dimensionless)
S_{wr} = water residual (or irreducible) saturation (dimensionless)

The pore size distribution index is expressed as (API, 2003):

$$\lambda = \frac{M}{1-M}(1 - 0.5^{1/M}) \tag{1.11}$$

Where:

M = model fitting parameter (dimensionless)

M is determined from the expression (API, 2003):

$$M = 1 - \frac{1}{N} \tag{1.12}$$

Where:

N = van Genuchten model fitting parameter (dimensionless)

Alternatively, LNAPL relatively permeability can be expressed as a function of LNAPL saturation and water saturation based on the following three phase integration of the Mualem (1976) equation with van Genuchten's soil characteristics function (Parker et al., 1987; API, 2003):

$$k_{ro}(S_w, S_o) = S_o^{1/2} \left\{ \left[1 - \left(\frac{S_w - S_{wr}}{1 - S_{wr}} \right)^{1/M} \right]^M - \left[1 - \left(\frac{S_t - S_{wr}}{1 - S_{wr}} \right)^{1/M} \right]^M \right\}^2 \tag{1.13}$$

Equations 1.10 and 1.13 predict different distributions of LNAPL relative permeability for the same set of fluid saturation values, with Equation 1.10 generally predicting smaller values for LNAPL relative permeability. Generally speaking, the Mualem equation (Equation 1.13) is believed to better predict LNAPL relative permeability in clays, whereas the Burdine equation (Equation 1.10) is believed to better predict LNAPL relative permeability in sands (U.S. EPA, 2005).

The mean (or effective) relative permeability of the LNAPL may be calculated from:

$$\overline{k_{ro}} = \frac{1}{b_o} \int_{z_1}^{z_2} k_{ro} \, dz \tag{1.14}$$

Equation 1.14 cannot be evaluated analytically. However, the mean oil relative permeability may be approximated from the relative oil permeability profile (graph) by:

$$\overline{k_{ro}} = \frac{1}{n} \sum_{i=1}^{n} k_{roi} \tag{1.15}$$

Where:

n = number of equally spaced points between z_1 and z_2 where the oil relative permeability is read off the relative permeability graph

k_{roi} = LNAPL relative permeability value (dimensionless) at point '*i*' on the LNAPL relative permeability profile

i = the specific point number on the relative permeability profile

Alternatively, the mean oil relative permeability may be approximated using a piecewise linear function (Note: some computer models including the API Interactive LNAPL Guide software calculate a mean oil relative permeability value).

As shown in Figure 3.1, LNAPL or oil saturation varies as a function of depth across the vertical LNAPL impacted zone. Assuming vertical equilibrium of the LNAPL and water, the water saturation across the LNAPL impacted zone may be expressed as (API, 2003):

$$S_w(z) = S_{wr} + (1 - S_{wr} - S_{ors})\left[\frac{1}{1 + (\alpha_{ow}(z - z_{ow}))^N}\right]^M \tag{1.16}$$

Where:

S_{ors} = oil residual saturation in the saturated zone (dimensionless)

α_{ow} = capillary pressure head parameter between LNAPL and water (1/ft)

z_{ow} = elevation of the oil-water interface in a monitoring well (ft)

The capillary pressure head between LNAPL and water is scaled appropriately to reflect the densities and interfacial tensions of the two fluids and is expressed as (API, 2003):

$$\alpha_{ow} = \left(1 - \frac{\rho_0}{\rho_w}\right)\left(\frac{\sigma_{aw}}{\sigma_{ow}}\right)\alpha \tag{1.17}$$

Where:

σ_{aw} = air-water interfacial tension (dynes/cm)

σ_{ow} = oil-water interfacial tension (dynes/cm)

α = van Genuchten model fitting parameter (dimensionless)

The total liquid saturation (LNAPL plus water) across the LNAPL impacted zone is expressed as (API, 2003):

$$S_t(z) = S_{wr} + S_{orv} + (1 - S_{wr} - S_{orv})\left[\frac{1}{1 + (\alpha_{ao}(z - z_{ao}))^N}\right]^M \qquad (1.18)$$

Where:

S_{orv} = oil residual saturation in the vadose zone (dimensionless)
α_{ao} = capillary pressure head parameter between air and LNAPL (1/ft)
z_{ao} = elevation of the air-oil interface in a monitoring well (ft)

The capillary pressure head between air and LNAPL is scaled appropriately to reflect the densities and interfacial tensions of the two fluids and is expressed as (API, 2003):

$$\alpha_{ao} = \frac{\rho_o}{\rho_w}\left(\frac{\sigma_{aw}}{\sigma_{ao}}\right)\alpha \qquad (1.19)$$

Where:

σ_{ao} = air-LNAPL interfacial tension (dynes/cm)

Hence, the LNAPL saturation is obtained from the expression (API, 2003):

$$S_o(z) = S_t(z) - S_w(z) \qquad (1.20)$$

A typical LNAPL saturation profile (as determined by Equations 1.16 through 1.20), and relative permeability profile (as determined by Equations 1.10 through 1.13), corresponding to an in-well LNAPL thickness of 2.0 feet in a sandy soil, is illustrated in Figure 3.1.

The mean oil saturation may be calculated from:

$$\overline{S_o} = \frac{1}{b_o}\int_{z_1}^{z_2} S_o dz \qquad (1.21)$$

Equation 1.21 cannot be evaluated analytically. However, the mean oil saturation may be approximated from the oil saturation profile (graph) by:

$$\overline{S_o} = \frac{1}{n}\sum_{i=1}^{n} S_{oi} \qquad (1.22)$$

Where:

n = number of equally spaced points between z_1 and z_2 where the oil saturation is read off the oil saturation graph
S_{oi} = LNAPL saturation value (dimensionless) at point 'i' on the LNAPL saturation profile
i = the specific point number on the saturation profile

Alternatively, the mean oil saturation may be approximated using a piecewise linear function (Note: some computer models including the API Interactive LNAPL Guide software calculate a mean oil saturation value).

As shown in Figure 3.1, the LNAPL saturation varies across the LNAPL impacted zone. For the purposes of calculating LNAPL mobility, one can use "mean" or "average" values for relative permeability, conductivity and saturation to calculate (using Equation 1.6) the average LNAPL mobility across the vertical LNAPL impacted zone. Alternatively, if one determines the maximum LNAPL saturation value, either through calculation or a combination of field and laboratory techniques, then an approximate "worst-case" scenario for LNAPL mobility may be calculated using Equation 1.6.

3.4 LNAPL SPECIFIC DISCHARGE AND VELOCITY CALCULATIONS

As previously mentioned, to determine the movement of a LNAPL requires defining the oil gradient in addition to inherent mobility, both of which are needed to evaluate LNAPL plume stability. The LNAPL specific discharge is expressed as:

$$\overline{q_o} = \overline{K_o} i_w \qquad (1.23)$$

Where:

$\overline{q_o}$ = mean oil specific discharge (ft/year)
i_w = oil gradient, assumed to be equal to the water table gradient

The seepage velocity of the LNAPL is based on the specific discharge while correcting for the effective porosity of the formation. The seepage velocity is the potential average velocity of the LNAPL within connected or continuous pore throats and is expressed as:

$$v_o = \frac{\overline{q_o}}{\phi_{eff}} \tag{1.24}$$

Where:

v_o = oil seepage velocity (ft/year)
ϕ_{eff} = effective porosity (dimensionless)

The effective porosity of the oil or the free oil porosity is expressed as:

$$\phi_{eff} = \phi \overline{S_o} \tag{1.25}$$

Consequently, equation 1.24 may be re-written as:

$$v_o = \frac{\overline{K_o}}{\phi \overline{S_o}} \cdot i_w \tag{1.26}$$

Which represents the inherent oil mobility (M_o) from Equation 1.6, multiplied by the LNAPL gradient.

3.5 LNAPL IMMOBILITY

LNAPL plumes are spatially self-limiting unless continually supplied from an on-going release, thus distinguishing LNAPLs from dissolved and vapor plumes that may migrate significant distances (API, 2004). Typically, once the release of free product stops, LNAPL in the water table region will eventually cease to move as the resistive forces in the saturated soils balance the driving forces in the LNAPL pool (Huntley and Beckett, 2001). The endpoint of this movement is when the LNAPL reaches field residual saturation, a condition where effective hydraulic conductivity of the LNAPL is zero (Huntley and Beckett, 2001).

The LNAPL seepage velocity from Equation 1.26 does not account for the resistive forces impeding plume movement at the periphery. This may lead to misleading calculations of LNAPL seepage velocities that are not evident in the field. It is recommended that a lower limit to velocity potential be used as a screening value; for instance, landfill liners may have allowable seepage potentials of 1 x 10^{-6} cm/s (American Society for Testing and Materials (ASTM), 2005). An LNAPL seepage velocity of 1 x 10^{-6} cm/s or less is considered to represent a *de minimus* mobility level for LNAPL (ASTM, 2005).

4.0 LNAPL MOBILITY EVALUATION METHODOLOGY

To complete the LNAPL mobility evaluation, EEC:

- Conducted a Laser Induced Fluorescence (LIF) survey using Rapid Optical Screening Tool (ROST) technology to further investigate, delineate, and qualify the extent of LNAPL impacts in the subsurface;
- Collected relatively undisturbed Shelby Tube soil cores in select locations of soil zones exhibiting the greatest relative fluorescence during ROST; and
- Submitted the soil cores for laboratory photography and physical testing of key LNAPL mobility parameters.

The methodology used to conduct the ROST survey, collect soil cores and complete the laboratory testing is presented below. The results of the ROST and laboratory testing are presented in Section 5.0. A discussion regarding the mobility evaluation results is presented in Section 6.0.

4.1 LIF/ROST SURVEY

EEC conducted a LIF/ROST survey in and around the vicinity of LNAPL within the AIR (excluding LNAPL Area 3). The ROST was conducted with the use of a specialized Cone Penetration Testing (CPT) 25-ton capacity rig. The CPT enabled the geological classification of unconsolidated soils via the penetration of a probe vertically downward through the soil. Classification was based on the resistance to penetration of an electronically instrumented cone which was continuously advanced into the subsurface. The cone was advanced at a rate of approximately two centimeters per second. The standard geological sensors within the cone measured resistance and friction which formed the basis for soil classification (sand, silt, clay, etc.).

CPT was performed simultaneously with ROST, yielding real-time stratigraphic data. ROST technology was used to screen for the presence of polyaromatic hydrocarbons (PAH's) during the advancement of the CPT probe. The CPT probe is equipped with a sapphire window through which a laser is directed. The laser light is adsorbed by aromatic hydrocarbon molecules in contact with the window as the probe is advanced. This addition of energy (photons) to the aromatic hydrocarbons causes them to fluoresce as they return to ground state after being excited. A portion of the fluorescence emitted from any encountered aromatic constituents is returned through the sapphire window and conveyed by a fiber optic cable to a detection system within the CPT rig. The emission data from the pulsed laser light is averaged into one reading per one-second intervals and is recorded continuously. The intensity of the fluorescence is proportional to the amount of aromatic hydrocarbon present (i.e. LNAPL saturation).

At each given ROST location, the ROST process continued until:

- The CPT probe tip was advanced approximately 10 feet into the saturated zone at locations where no petroleum impacts were encountered; or
- The CPT probe tip was advanced approximately 10 feet past the deepest identified petroleum impacts identified in the saturated zone.

The use of CPT/ROST enabled the delineation of LNAPL without having to obtain soil samples from the subsurface. The time saved on collecting subsurface soil samples meant that additional locations could be investigated for the presence of LNAPL versus conventional soil sampling methods (CPT/ROST can enable the investigation of 3 to 5 times the amount of locations as compared to traditional soil sampling in a given time period). This technology provided an effective means of conducting a comprehensive LNAPL delineation program.

4.2 SHELBY TUBE SOIL CORE SAMPLING

EEC collected relatively undisturbed Shelby Tube soil cores in select locations in the soil zones based on the ROST results. Boreholes were advanced at strategic locations using hollow stem auger and rotosonic drilling methods. Strategic locations were decided upon based on the following considerations:

- Relative fluorescence response, as indicated by the ROST results;
- Proximity of nearby existing or historical wells (monitoring or recovery wells) exhibiting the presence of LNAPL;
- Local geology; and
- Areal coverage of soil cores across the LNAPL areas within the AIR.

Once at the appropriate depth below ground surface, Shelby Tube soil cores were collected in accordance with ASTM Standard D 1587-00, *Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes*. In general, two (2) Shelby Tubes were collected (one on top of the other) from each borehole to obtain an approximate 4 to 5 foot vertical soil profile across the LNAPL impacted zone. In certain situations, where the ROST data identified the presence of multiple discrete impacted zones, the Shelby Tubes were collected from separate depths within a given borehole. The Shelby tubes, once retrieved from the ground, were appropriately sealed, marked, and placed on dry ice for freezing prior to shipment to the laboratory for mobility parameter testing.

4.3 LABORATORY PHOTOGRAPHY AND TESTING

EEC submitted the Shelby Tube soil cores for laboratory photography and physical testing of key LNAPL evaluation parameters as described below.

4.3.1 CORE PHOTOGRAPHY

Frozen Shelby Tubes were cut open along the vertical length of the tube (with the use of a diamond segmented horizontal bandsaw) to enable photographs to be taken of the soil cores. Soil cores were allowed to partially thaw along the surface prior to photographing. The partial thawing was required to enable LNAPL, where present, to pool to the surface of the profile. Photographs were taken in both white light and ultraviolet (UV) light. The white light photographs displayed the natural state (color, texture) of the soil profile including any pooled LNAPL, where applicable. The UV photos were used to identify LNAPL. LNAPL, when exposed to UV light, tends to fluoresce. The intensity of fluorescence corresponds to the amount of LNAPL, with higher intensities corresponding to greater LNAPL saturations. UV photos also provide qualitative information regarding the type of LNAPL. Generally speaking, lighter end petroleum compounds, such as gasoline or kerosene, tend to fluoresce white or blue; middle distillates including diesel and No. 2 fuel oil tend to fluoresce yellow or gold; and heavier end compounds such as oils and coal tars tend to fluoresce red or brown.

Core photographs were provided by the laboratory to EEC to enable the identification of discrete (two tenths of a foot) intervals of maximum UV fluorescence. Select intervals were then designated for laboratory testing of mobility parameters.

4.3.2 LABORATORY TESTING

The discrete soil intervals of maximum UV fluorescence were determined qualitatively from the core photography and cross-referenced with the relative fluorescence results for the corresponding ROST testing. These locations in the core soil samples were selected for the following laboratory testing (with methods shown in parentheses where applicable). Core photography of the soil in the core under white light was also considered to evaluate the pore structure and gradation of the soil samples in the respective sample zones for maximum porosity.

- Soil bulk density and grain density measurements (ASTM D422/4464M);

- Total soil porosity (API RP40);
- Pore fluid (water and LNAPL) saturations (API RP40);
- Initial and final fluid (water and LNAPL) saturations using a single point centrifugal testing method (ASTM D425M); and/or
- Fluid saturations (water and LNAPL) using a drainage and imbibition capillary pressure test (ASTM D6836/API RP40).

All soil cores were subject to pore fluid saturation testing. However, select boreholes were also subject to initial and final fluid saturation testing via the single point centrifugal method and/or the capillary pressure test. For these select boreholes, the discrete soil interval of maximum UV fluorescence was subject to single point centrifugal testing; the second highest interval of UV fluorescence was subject to capillary pressure testing; and the third highest interval of UV fluorescence was subject to pore fluid saturation testing. For soil cores where neither the single point centrifugal testing nor capillary pressure testing were performed, the soil interval of maximum UV fluorescence was analyzed for pore fluid saturation conditions.

The final LNAPL endpoint saturations obtained from the single point centrifugal testing and capillary pressure testing were deemed to represent the residual LNAPL saturations for the soil interval. The single point centrifugal method, which requires that a force of 1,000 times the force of gravity be exerted on the sample for one hour, is considered to yield a lower residual saturation, and hence, more conservative LNAPL residual value. The methodology for the single point centrifugal method is described by Brady and Kunkel (2005). Conversely, the capillary pressure method (that also uses centrifugal pressure typically at lower level driven by the sample drainage behavior), proceeds to the irreducible water saturation as water is displaced by LNAPL during the drainage phase. Water is subsequently imbibed back into the sample, displacing LNAPL. This test is considered to yield a LNAPL residual saturation value that is more representative of LNAPL mobility and recoverability conditions under site pressure gradients and drainage conditions.

In addition to soil testing, samples of LNAPL and underlying groundwater were collected from select wells in the AIR and submitted for the following analyses:

- LNAPL specific gravity, density and viscosity at three temperatures, and
- interfacial/surface tensions for air/water, air/LNAPL and LNAPL/water pairs (ASTM D1481, D445, and D971).

5.0 LNAPL MOBILITY EVALUATION RESULTS

5.1 ROST SURVEY

EEC retained Fugro Geosciences Inc. of Houston, Texas to conduct the ROST survey in the AIR. The ROST survey was conducted from February 21 through March 20, 2006 at the locations identified on Figure 5.1. A total of 128 ROST locations were completed as part of the mobility evaluation in order to delineate the LNAPL horizontally and vertically, as well as to approximate the LNAPL saturation profile at each location. An EEC geologist was on-Site to identify ROST test locations and oversee the ROST process.

The ROST results (graphs of relative fluorescence response and CPT lithology) are provided in Appendix A. The corresponding CPT data are provided in Appendix B. In general, the results indicate that the majority of LNAPL impacts detected were consistent with a medium distillate compound such as diesel or No. 2 fuel oil. The lone exceptions were identified in the shallow unsaturated soils in LNAPL Area 11, where it appeared that a lighter end petroleum compound was identified.

As indicated in the ROST graphs, LNAPL impacts were detected in numerous hole locations across the LNAPL areas within the AIR. In comparison to water table elevations, the majority of impacts appear to be at or near the water table, with some impacts penetrating deeper into the water table. In an attempt to better visualize the presence of LNAPL impacts, EEC created:

- A plan view interpolation of the maximum ROST results across LNAPL areas within the AIR; and
- Strategic two-dimensional (2-D) cross sections showing profiles of the ROST interpolations in the subsurface.

The plan view of the maximum ROST results and interpolations are provided in Figure 5.2. The maximum ROST readings are summarized in Table 5.1. The 2-D cross sections are provided in Figures 5.3 through 5.11.

The ROST plan view and cross sections indicate various peak fluorescence readings and maximum impact thicknesses within each of the key LNAPL areas (1/2/7, 9/10 and 11) in the AIR. In general, the ROST results confirm the presence of the LNAPL areas previously identified by EEC using conventional methods (drilling with soil screening using visual and olfactory techniques, shake tests, Sudan IV, monitoring well observations, etc.).

It is important to note that some of the maximum fluorescence intensities identified by ROST in various locations (as shown on the plan view drawing in Figure 5.2) were only measured over a very small (less than three inches) vertical interval, and that the majority of intensities over larger vertical intervals decreased significantly. To compare maximum fluorescence intensities against fluorescence intensities over a larger vertical interval, EEC reviewed the ROST graphs and, using the program software provided by Fugro, identified average fluorescence intensities over the maximum impacted one-foot interval at each location. The one-foot soil intervals and corresponding fluorescence intensities are presented in Table 5.1. A plan view interpolation of ROST responses averaged over the one-foot intervals is provided in Figure 5.12. This second ROST plot provides a more realistic depiction of LNAPL impacts normalized for vertical extent at each location.

5.2 SOIL CORE SAMPLING

Based on the results of the ROST survey, EEC identified strategic locations and sample depths for the collection of undisturbed Shelby Tube soil cores. EEC retained Prosonic Corporation of Marietta, Ohio to conduct the soil core sampling in the AIR. The soil core sampling was conducted at various times from March 14 through May 2, 2006 at the locations identified on Figure 5.1 (as well as Figures 5.2 and 5.12). An EEC geologist was on-Site to identify borehole locations and sampling depths and oversee the soil core collection process.

All soil cores were appropriately wrapped, preserved on dry ice and submitted to PTS Laboratories (PTS) of Sante Fe Springs, California to be photographed in white light and UV light, and to be tested for key LNAPL mobility parameters.

5.3 SOIL CORE PHOTOGRAPHY

The core photographs are provided in Appendix C. The photos indicate that many of the sample cores contained LNAPL at varying degrees as evidenced by the UV fluorescence. EEC reviewed the photographs and identified discrete intervals of UV fluorescence and corresponding soil types for each sample location. In addition, EEC identified the zone (two tenths of a foot) of maximum UV fluorescence for each sample location. The zones of maximum fluorescence from the core photos were then cross-referenced with the ROST results to confirm that the results from the different methods were in general agreement. The fluorescence intervals with corresponding soil types, and zones of maximum fluorescence are identified in Table 5.1.

5.4 LABORATORY TEST RESULTS

A summary of the laboratory test program completed by PTS is provided in Table 5.2. The laboratory results are provided in Appendix D, with select results summarized in Table 5.1. The results are discussed in the following subsections.

5.4.1 LNAPL SATURATIONS

LNAPL saturations in soil (or initial saturations and final saturations) were determined by PTS using the RP40 Method that utilized a Dean Stark Extraction procedure. One discrete soil zone from each borehole location was tested for LNAPL saturation via API RP40. Other discrete soil zones from select boreholes were submitted for fluid saturation testing (water and LNAPL) using the single point centrifugal test method in accordance with ASTM Method D425M, or the capillary pressure test method in accordance with ASTM D6836/RP40. These additional selected tests provided initial saturation values for the sample (and final saturation value after pressure drainage of the NAPL from the sample). These samples were also deemed to represent the most LNAPL impacted soil in the core. The range of initial LNAPL saturation results are provided in Appendix D and summarized in Tables 5.1 and 5.3.

The LNAPL initial saturation results obtained from the above testing indicate that:

- LNAPL saturations in Area 9/10 range from 0.6% to 50.7%;
- LNAPL saturations in Area 1/2/7 range from 1.3% to 44.0%; and
- LNAPL saturations in Area 11 range from 1.9% to 42.0%.

5.4.2 LNAPL RESIDUAL SATURATIONS

LNAPL residual saturations were determined by PTS using the single point centrifugal testing, via ASTM Method D425M, and the capillary pressure drainage and imbibition testing, via ASTM D6836/API RP40. The residual saturation results are presented in Appendix D and summarized in Tables 5.1 and 5.3.

5.4.3 FLUID TEST RESULTS

Free phase product samples and underlying groundwater samples were collected from each of the LNAPL areas in the AIR (1/2/7, 9/10, 11) and submitted for analysis of LNAPL specific gravity, density and viscosity, and interfacial/surface tensions. The laboratory results are provided in Appendix D and summarized in Table 5.4.

In terms of LNAPL densities, the results suggest that the LNAPLs in Areas 1/2/7, 9/10 and 11 are similar. However, in terms of viscosity, the results suggest that the LNAPLs are different, with the LNAPL in Area 1/2/7 being the most viscous and the LNAPL in Area 11 being the least viscous.

5.4.4 SOIL GRAIN SIZE ANALYSIS

The Shelby Tube soil cores were submitted to PTS for grain size analysis. The laboratory results are provided in Appendix D.

The grain size analyses indicate that the mean grain size of the most LNAPL impacted vertical soil zones collected in the Shelby Tubes are as follows:

• LNAPL Area 9/10	Coarse sand (1 sample); Medium sand (4 samples); Fine sand (3 samples); Silt (1 sample).
• LNAPL Area 1/2/7	Medium sand (1 sample); Fine sand (4 samples); Silt (2 samples).
• LNAPL Area 11	Fine sand (3 samples); Silt (5 samples).

Based on field observations during drilling and sample collection, LNAPL Area 9/10 contains much more sand than Areas 1/2/7 and 11. The majority of UV fluorescence in soil cores from Area 9/10 was present in the sand.

6.0 LNAPL MOBILITY EVALUATION DISCUSSION

A detailed discussion on LNAPL mobility and plume stability was provided in Section 3.0. As shown in Figure 3.1, LNAPL saturation varies across the vertical LNAPL impacted zone, both above and below the water table, extending from the air-oil interface down to the oil-water interface. For the purposes of calculating LNAPL mobility, one can use "mean" or "average" values for LNAPL relative permeability, conductivity and saturation, averaged across the vertical impacted zone, to calculate an average or effective LNAPL mobility. Alternatively, one may use the maximum LNAPL relative permeability, conductivity and saturation to approximate an upper limit scenario for potential LNAPL mobility. The maximum LNAPL saturation may be obtained through calculation or a combination of field and laboratory techniques. This maximum saturation may then be used to calculate the maximum LNAPL relative permeability, conductivity and mobility potential.

For the purposes of this report, EEC used several different approaches to evaluate LNAPL mobility. These approaches are summarized as follows:

- Comparing initial LNAPL saturations to residual saturations from the single point centrifugal testing and the capillary pressure testing;
- Comparing ROST relative fluorescence responses to laboratory measured LNAPL saturation values on an area-specific basis;
- Utilizing the laboratory measured LNAPL conductivity values generated by the capillary pressure testing to determine corresponding LNAPL mobility and velocity values; and
- Utilizing the laboratory measured assumed maximum LNAPL saturations to determine corresponding LNAPL relative permeability, conductivity, mobility and velocity values using API methodology.

The details and results of each of these evaluations are discussed in the following sections.

6.1 LNAPL SATURATION AND RESIDUAL SATURATION

The LNAPL saturation and residual saturation (via single point centrifugal testing) results in Appendix D and Table 5.3 suggest that the LNAPL at the following locations exhibits inherent mobility due to a saturation value significantly exceeding (greater than 30 percent) residual saturation: L9/10-RI-01, L9/10-RI-04, L11-RI-02, and L1/2-RI-24.

Conversely, the results suggest that the LNAPL at the remaining locations is less mobile or near immobile. Locations where the single point centrifugal testing showed results only slightly above residual saturation can be assumed to be immobile for practical purposes. This is due to the fact that the conservative nature of the single point centrifugal test produces gradients much greater than what would be expected to exist under normal hydraulic conditions. Therefore, in these situations, field residual saturation would be expected to be higher than the residual saturation identified by the single point centrifugal test.

The drainage and imbibition (capillary pressure test) results indicate that some of the measured LNAPL residual saturation values were higher than the corresponding residual saturations determined via single point centrifugal testing (as expected), and some were lower. The samples exhibiting inherent mobility due to a saturation value significantly exceeding residual saturation included: L9/10-RI-01, L11-RI-02 and L1/2-RI-06. In general, NAPL drainage equilibrium in sands is typically achieved through asymptotic changes in saturation with applied pressure. Since a high percentage of the LNAPL drainage and saturation reduction in the test is achieved at low pressure, both tests are not expected to have extreme variances in NAPL saturation endpoint when run to the asymptotic limit of drainage to define residual levels. The differences are, in part, attributed to the fact that the discrete soil zones (two-tenths of a foot) on which the testing at a given location was conducted, are at different depths/soil conditions (albeit the difference in depth is typically minor). Consequently, the variation in test results are representative of actual variations in the field.

In general, the LNAPL saturation and residual saturation results indicate that some potential for mobility exists in certain interior portions of the LNAPL areas, but that the plume fringes exhibit limited potential for mobility. These results are consistent with the Site history (i.e. the LNAPL has existed in the subsurface for at least 10 years, and possibly much longer, and has likely had time to reach a steady-state equilibrium), historical monitoring results (in-well LNAPL thicknesses), and the current ROST results which suggest greater LNAPL impacts and mobility potential in the interior portions of the plume(s) with limited impacts/mobility potential at the plume fringe areas. These lines of evidence support the overall assessment of plume stability in the areas of concern. Furthermore, these results confirm the understanding that:

- LNAPL plumes are spatially self-limiting unless continually supplied from an on-going release, thus distinguishing LNAPLs from dissolved and vapor plumes that may migrate significant distances (API, 2004). Typically, once the release of free product stops, LNAPL in the water table region will eventually cease to move as the resistive forces in the saturated soils balance the driving forces in the LNAPL pool (Huntley and Beckett, 2001); and

- On a plume scale, LNAPL is often present above residual saturation in the center of the plume and thus could be considered to have inherent mobility. However, that fact <u>is not sufficient</u> to describe the footprint of the entire plume. Because LNAPL saturation decreases to residual toward the fringe of the plume, the fringe of the plume may be immobile, while the body of the plume is considered to be stable (U.S EPA, 2005).

6.2 <u>ROST / LNAPL SATURATION CORRELATION</u>

In an effort to obtain a more comprehensive coverage of LNAPL saturation values across the LNAPL areas, EEC attempted to correlate the ROST relative fluorescence responses corresponding to the 24 laboratory measured LNAPL saturation values, grouped by LNAPL area. If a satisfactory correlation could be established between the two, then it would be possible to establish qualitative saturations and LNAPL mobility parameters at each of the 128 ROST locations in the AIR.

EEC generated plots of ROST fluorescence versus LNAPL saturation for each of the 24 soil core sampling locations, grouped by the respective LNAPL area. More specifically, the ROST reading averaged over the approximate interval (two tenths of a foot) where the portion of the soil core was submitted for laboratory saturation analysis was plotted against the measured laboratory saturation for the same interval. The plots are provided in Figures 6.1-6.3. The data used to generate the plots are provided in Table 6.1.

The plots in Figures 6.1-6.3 indicate that the correlations (R^2 values) between ROST fluorescence and LNAPL saturation were: 0.90 for Area 1/2/7, 0.86 for Area 9/10, and 0.95 for Area 11. These correlation values are considered to be reasonably good and suggest that one could use the appropriate straight line plot to approximate the LNAPL saturation for each of the 128 ROST survey points throughout the AIR. EEC did not carry through with this exercise; however, the fact that a good correlation was established between ROST fluorescence and laboratory measured LNAPL saturation does lend additional credibility to the ROST process and EECs general understanding of the LNAPL impacted areas in the AIR.

It should be noted that there may be some small discrepancies between the actual depth of the discrete (two-tenths of a foot) soil sample for LNAPL saturation testing and the discrete (two-tenths of a foot) zone from which the ROST fluorescence data was obtained. The potential discrepancies are due to the different methods used to record depth below ground surface during conventional drilling and ROST. Despite reasonable and appropriate attempts by EEC to minimize the potential for discrepancies, the potential nevertheless exists.

6.3 LNAPL MOBILITY CALCULATIONS BASED ON CAPILLARY PRESSURE TEST RESULTS

The LNAPL conductivity values generated by the laboratory during the capillary pressure tests at six (6) locations were utilized by EEC to determine the corresponding LNAPL mobility and velocity values according to methodology described in Section 3.0 (i.e., Equations 1.6 and 1.26, respectively). Velocity values were then compared to the mobility de minimus threshold of 1x 10^{-6} cm/sec (ASTM, 2005).

The calculation inputs were determined as follows:

- LNAPL Saturation (S_o): Laboratory values obtained from initial oil saturations on sub-sample selected for capillary pressure testing for each of the six (6) locations via API RP40;
- Total Soil Porosity (Φ): Laboratory values obtained for each sub-sample selected for capillary pressure testing via API RP40; and
- Hydraulic Gradient (i_w): Value obtained from data contained within the Site RFI Report (ENCORE, 2002).

The results of these calculations are detailed in Table 6.2. The results indicate that three (3) of the locations (L1/2-RI-24, L9/10-RI-01 and L9/10-RI-12) exhibit potential for mobility by exceeding the de minimus threshold LNAPL velocity threshold. The remaining locations are below the threshold. These results support the conclusion that the LNAPL in the fringe areas of the plume(s) has not saturated to levels of potential mobility where they are conductive and/or would likely contribute to plume instability.

6.4 LNAPL MOBILITY CALCULATIONS BASED ON MAXIMUM SATURATION RESULTS AND API METHODOLOGY

EEC used the methodology outlined in Section 3.0 and the laboratory determined LNAPL saturation and water saturation values to generate an assumed maximum LNAPL relative permeability value for each of the twenty-four Shelby Tube soil core locations. EEC then used the calculated relative permeability values to calculate maximum LNAPL conductivity, mobility and velocity values at each soil core location. Specifically, EEC:

- Obtained assumed maximum LNAPL saturation values for each soil core from PTS lab results;
- Calculated maximum LNAPL relative permeability values using Equations 1.10 through 1.13 (note: Equation 1.10 used for sands, Equation 1.13 used for silt);
- Calculated maximum LNAPL conductivity values using Equations 1.7, 1.8 and 1.9;
- Calculated maximum LNAPL mobility values using Equation 1.6; and
- Calculated maximum LNAPL velocity values using Equation 1.26.

The calculation inputs were determined as follows:

- LNAPL Saturation (S_o): Laboratory values obtained from pore fluid saturation testing on interval of assumed maximum LNAPL saturation via API RP40;
- Water Saturation (S_w): Laboratory values obtained from pore fluid saturation testing on interval of assumed maximum LNAPL saturation via API RP40;
- Irreducible Water Saturation (S_{wr}): Laboratory values obtained from single point centrifugal testing;
- Van Genuchten N (N): Values selected from API Interactive LNAPL Guide (2004) parameter tables based on laboratory mean grain size values determined via ASTM D422/D4464M;
- LNAPL Density (ρ_o): Laboratory values based on samples from 5 locations across the AIR;
- LNAPL Viscosity (μ_o): Laboratory values based on samples from 5 locations across the AIR;
- Total Soil Porosity (Φ): Laboratory values obtained for each sub-sample selected for pore fluid saturation testing via API RP40;
- Hydraulic Gradient (i_w): Value obtained from data contained within the Site RFI Report (ENCORE, 2002); and
- Hydraulic Conductivity (K_w):Values for Areas 1/2/7 and 9/10 taken from geometric mean of multiple area-specific single well response (slug) tests. The value for Area 11 was a conservative assumption based on soil type/gradation from literature values.

The calculations for LNAPL Areas 9/10, 11, and 1/2/7 are provided in Tables 6.3, 6.4 and 6.5, respectively. All LNAPL velocity values calculated by this methodology were less than the de minimus velocity value of 1 x 10^{-6} cm/s (ASTM, 2005). Therefore, according to this calculation methodology, all the LNAPL across in the AIR area has limited potential for mobility and/or is effectively immobile.

Because the measured laboratory saturations provided by PTS were considered to be representative of the greatest LNAPL impacts (based on cross-referencing ROST results and UV core photography), the calculated LNAPL relative permeability values and corresponding LNAPL conductivity, mobility and velocity values were considered to represent a conservative or “worst-case” scenario for LNAPL mobility.

7.0 LNAPL RECOVERABILITY

Aggressive LNAPL recovery was conducted in Area 9/10 in early 2005. Specifically, LNAPL recovery was conducted from January 19 through February 8, 2006 using high vacuum multi-phase extraction (MPE). The MPE was conducted using a Multi-Phase Vacuum Extraction (MPVE) 27100 unit manufactured by Ground Effects Environmental Services Inc. (ENCORE, 2006). Unlike Areas 1/2/7 and 11, Area 9/10 was targeted for aggressive LNAPL recovery due to the abundance of coarse grained soils (sands) in the area (i.e., the potential for LNAPL mobility and recovery was deemed to be greatest in Area 9/10).

LNAPL recovery was conducted from an extraction well network consisting of 50 4-inch diameter PVC wells. The locations of the extraction wells, piping and remediation equipment are provided in Figure 7.1.

A full round of baseline water levels was collected in Area 9/10 on January 17, 2006, prior to initiating LNAPL recovery activities. The water level data indicated that LNAPL was present in 18 wells at thicknesses ranging from 0.05 to 6.02 feet. The January 17, 2006 water level data is provided in Appendix E.

Throughout the duration of MPE activities, LNAPL recovery efforts were focused on those extraction wells containing the greatest in-well LNAPL thicknesses. System performance was monitored in the field and remotely on a daily basis (excepting weekends). Active extraction was limited to wells deemed to yield the greatest LNAPL recovery. After approximately 104 hours of MPE operation, a total of 28 gallons of LNAPL and 28,165 gallons of water were recovered. These recovery amounts translate into the following overall average daily recovery rates: 6.5 gallons per day LNAPL and 6,500 gallons per day water. Based on the relatively low LNAPL recovery rates, and costs to run the MPVE 27100, LNAPL recovery was terminated in Area 9/10.

It should be noted that the MPVE 27100 shut down several times between January 19 and February 8 due to high water production (exceeding the capacity of the MPVE water handling system). Further, numerous operational efforts were made to minimize water production and maximize LNAPL recovery and system run time. However, despite these efforts, LNAPL recovery remained relatively low.

Water level data were collected in Area 9/10 after termination of MPE operations, and periodically throughout 2006. The water level data is provided in Appendix E. The data indicates that in-well LNAPL thickness rebounded after termination of MPE activities, even though aggressive recovery attempts at these wells produced limited LNAPL.

The low LNAPL recovery results in Area 9/10 suggest that the LNAPL is not feasibly recoverable in the interior portions of Area 9/10, where the ROST results and laboratory testing identified the greatest LNAPL saturations and potential for mobility (note: the ROST survey and soil core testing program in Area 9/10 was conducted after the termination of aggressive LNAPL recovery in the area). Further, the low LNAPL recovery coupled with the laboratory (LNAPL saturation) test results suggest that LNAPL saturations within the interior portions of Area 9/10 were not significantly affected by the MPE operations. These findings represent an additional line of evidence suggesting the overall assessment of plume stability in the AIR.

8.0 CONCLUSIONS AND RECOMMENDATIONS

EEC conducted a comprehensive ROST survey (128 points) and follow-up laboratory investigation (24 points) to evaluate the mobility of LNAPL within the AIR (excluding LNAPL Area 3). The purpose of the ROST survey and laboratory investigation was to conduct a conservative evaluation of LNAPL mobility by identifying maximum LNAPL saturation values and residual saturation values throughout the LNAPL impacted areas. EEC then evaluated the potential for LNAPL mobility by three methods. First, maximum LNAPL saturations were compared against LNAPL residual saturations (at select locations) to determine the potential for LNAPL mobility. Second, LNAPL conductivity values generated by the laboratory during capillary pressure testing were utilized to calculate LNAPL mobility and velocity values for comparison against the de minimus velocity value of 1.0 x 10^{-6} cm/sec (ASTM, 2005). Third, laboratory-measured maximum LNAPL saturations were used to calculate assumed maximum LNAPL relative permeability, conductivity, mobility and velocity values for comparison against the de minimus LNAPL velocity.

The results of the first evaluation suggested that the LNAPL in five test locations (L9/10-RI-01, L9/10-RI-04, L11-RI-02, L1/2-RI-06 and L1/2-RI-24) exhibited the potential for inherent mobility. These test locations were located in the interior of their respective LNAPL areas and are not likely to affect the overall stability of the plume as the fringe areas (based on historical monitoring data, ROST results and laboratory testing) exhibit a strong trend toward residual saturations and consequently, immobility.

The results of the second evaluation suggest that three interior locations (L9/10-RI-01, L9/10-RI-12 and L1/2-RI-24) exhibit a potential for mobility. The remaining locations included in this analysis were at or below the de minimus velocity value. These results provide a further line of evidence of overall stability of the LNAPL areas.

The results of the third evaluation suggest that LNAPL velocities in all of LNAPL Areas 1/2/7, 9/10 and 11 are below the de minimus velocity value. Consequently, the results provide a third line of evidence of immobility and overall stability of the LNAPL areas.

The results of the mobility evaluation suggest that the overall LNAPL impacted plume areas have limited potential for mobility (to expand or move) due to the fact that the LNAPL saturations at or near the fringes of the impacted areas appear to be near field residual saturation. Further, calculated LNAPL velocities by two different methodologies indicate that localized internal areas of potential mobility may exist, but overall the LNAPL areas are stable and have limited potential for mobility.

Aggressive LNAPL recovery was conducted in Area 9/10 using high vacuum MPE. Unlike Areas 1/2/7 and 11, Area 9/10 was targeted for aggressive LNAPL recovery due to the abundance of coarse grained soils (sands) in the area (i.e. the potential for LNAPL recovery was deemed to be greatest in Area 9/10). After 104 hours of MPE operation, a total of 28 gallons of LNAPL and 28,165 gallons of water were recovered. These recovery amounts translate into the following overall average daily recovery rates: 6.5 gallons per day LNAPL and 6,500 gallons per day water. Based on the relatively low LNAPL recovery rates, and costs to run the MPVE system, LNAPL recovery was terminated in Area 9/10. Notwithstanding the aggressive recovery attempts that produced minimal product, in-well LNAPL thicknesses in some wells have since rebounded to pre-remediation values since the termination of active recovery.

The aggressive LNAPL recovery findings suggest that the LNAPL is not feasibly recoverable in the interior portions of Area 9/10, where the ROST results and laboratory testing identified the greatest LNAPL saturations and potential for mobility (note: the ROST survey and soil core testing program in Area 9/10 was conducted after the termination of aggressive LNAPL recovery in the area). Further, the low LNAPL recovery coupled with the laboratory (LNAPL saturation) test results suggest that LNAPL saturations within the interior portions of Area 9/10 were not significantly affected by the MPE operations. These findings represent an additional line of evidence suggesting the overall assessment of plume stability in the AIR.

In light of the above information and findings, EEC does not believe that performing further LNAPL recovery in the AIR is technically warranted based on the lack of potential mobility and the low expected recoverability. Rather, EEC recommends that a series of strategic monitoring wells be placed in the AIR to continue to monitor the presence of the LNAPL, to confirm that the overall LNAPL impacted areas remain stable and immobile. Since the USPS is presently occupying a rather large portion of the AIR, the placement of new wells will be limited to accessible areas only.

9.0 REFERENCES

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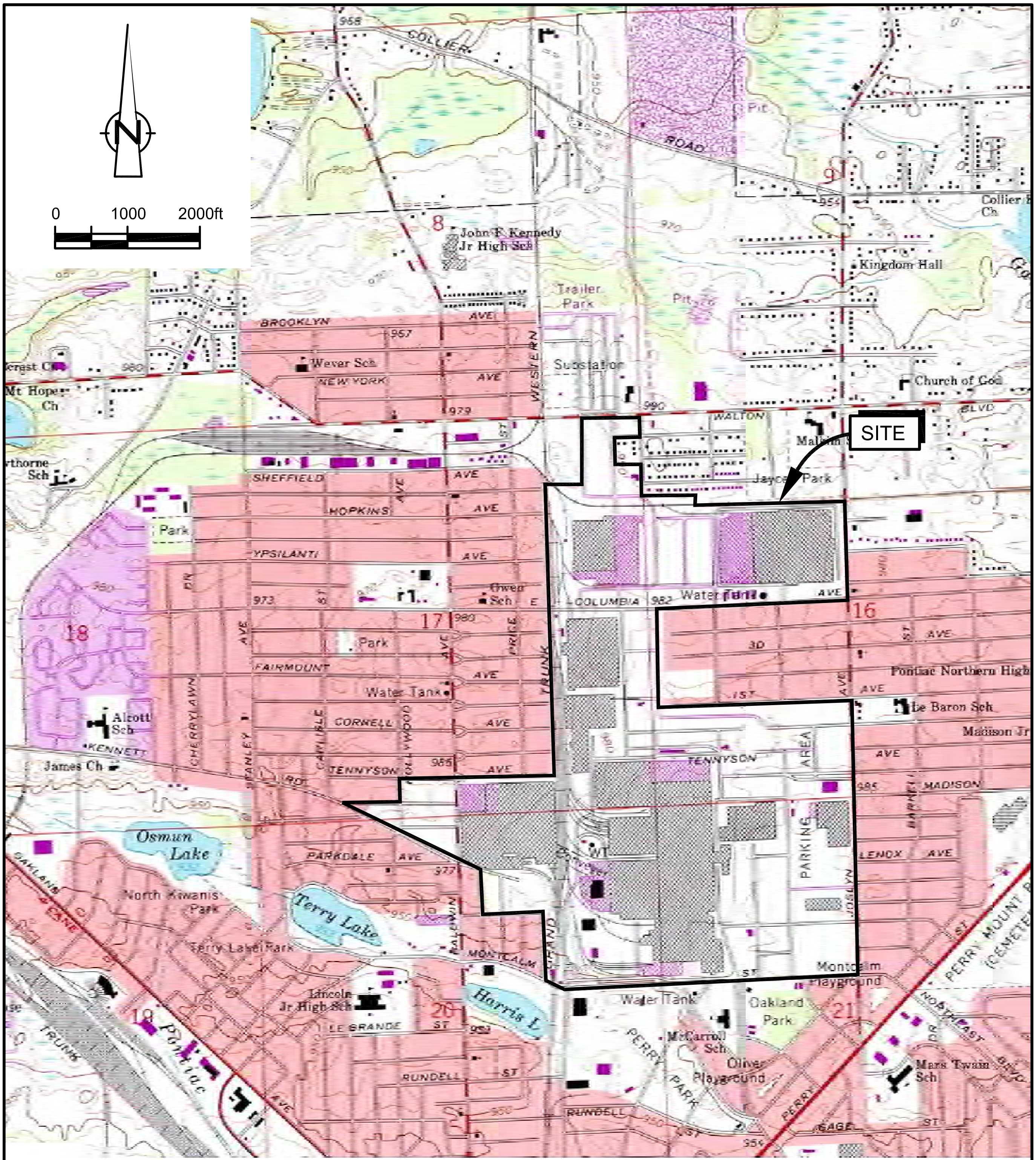
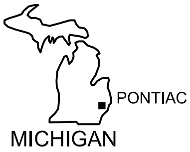
Figures



SOURCE: USGS QUADRANGLE MAP;
PONTIAC NORTH, MICHIGAN



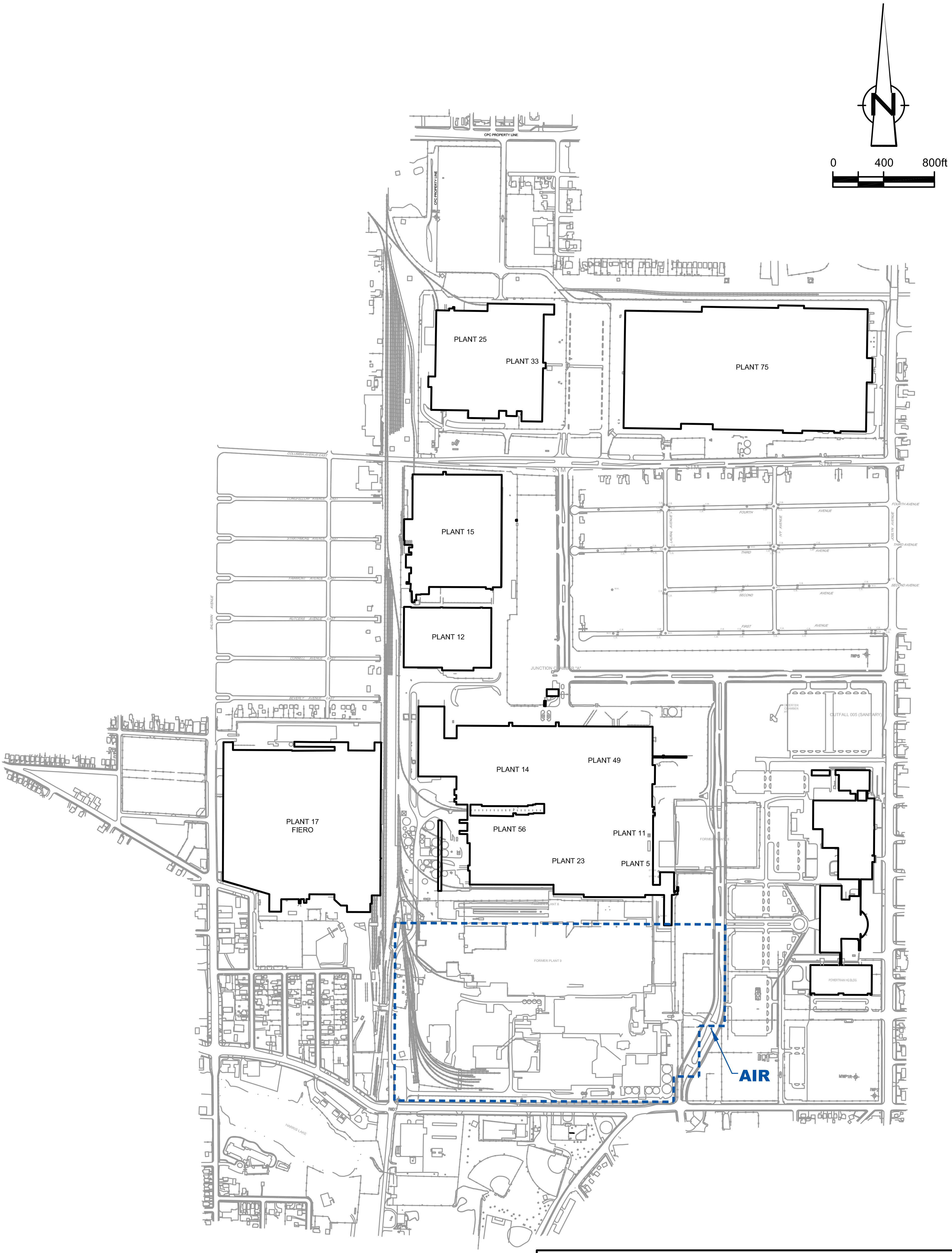
GENERAL MOTORS
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

SITE LOCATION

ENCORE

FIGURE
1.1

17487-00(029)GN-WI002 JAN 31/2007



GENERAL MOTORS
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

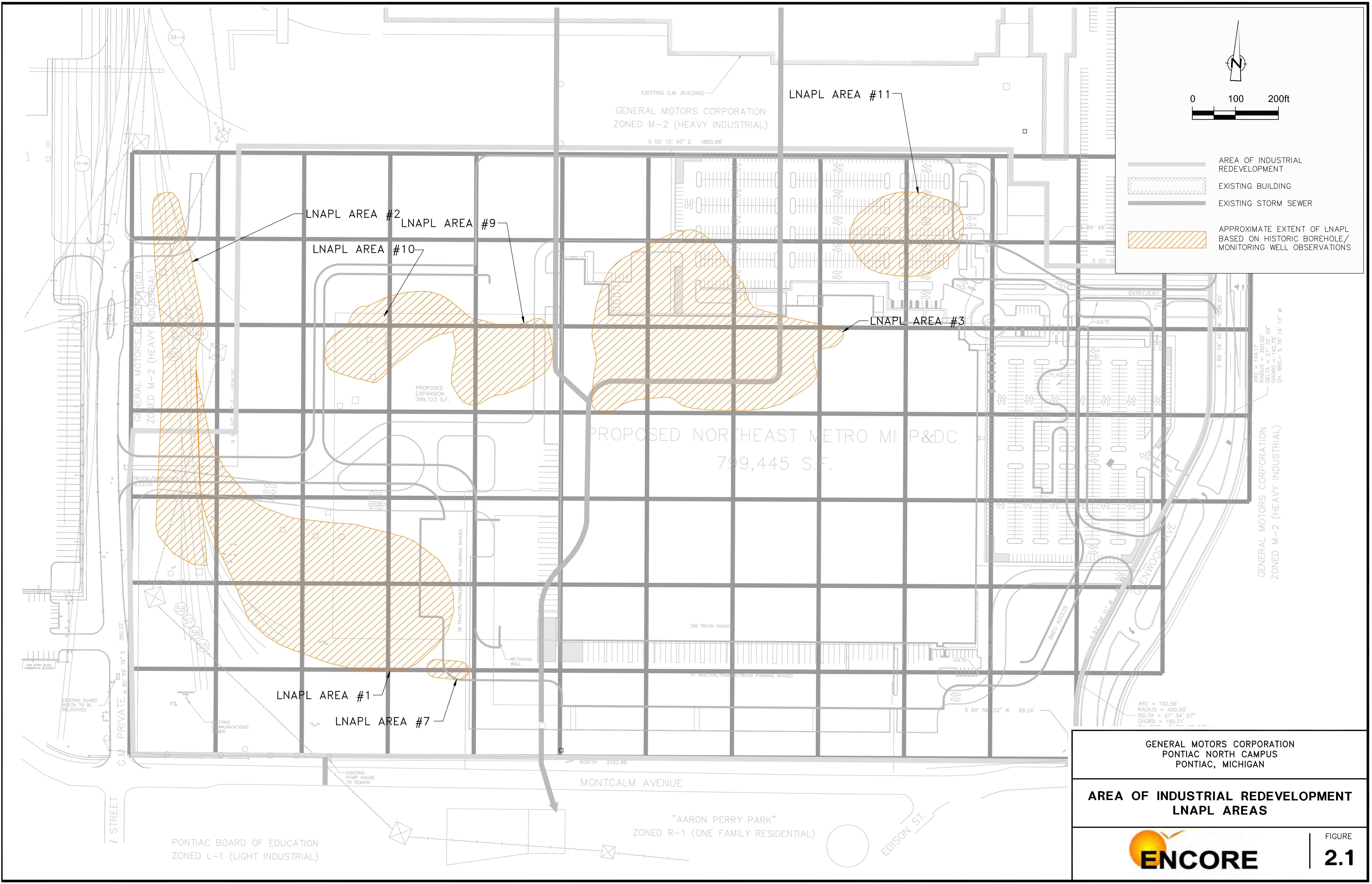
AREA OF INDUSTRIAL REDEVELOPMENT (AIR) LOCATION

ENCORE

FIGURE
1.2

17487-00(029)GN-WI003 JAN 31/2007

17487-00(029)GN-WI004 FEB 01/2007



▬	AREA OF INDUSTRIAL REDEVELOPMENT
▨	EXISTING BUILDING
▬	EXISTING STORM SEWER
▨	APPROXIMATE EXTENT OF LNAPL BASED ON HISTORIC BOREHOLE/ MONITORING WELL OBSERVATIONS

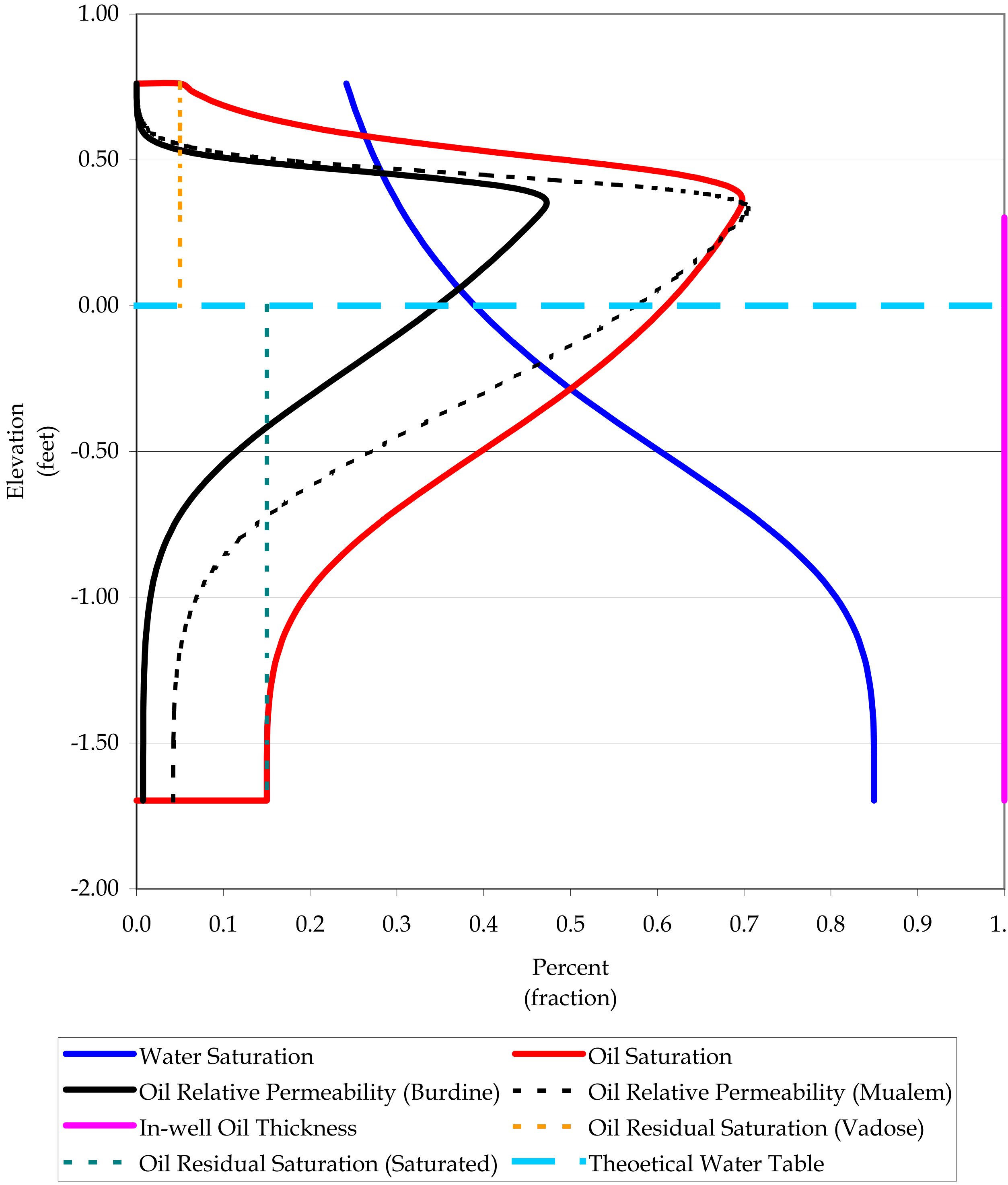
GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

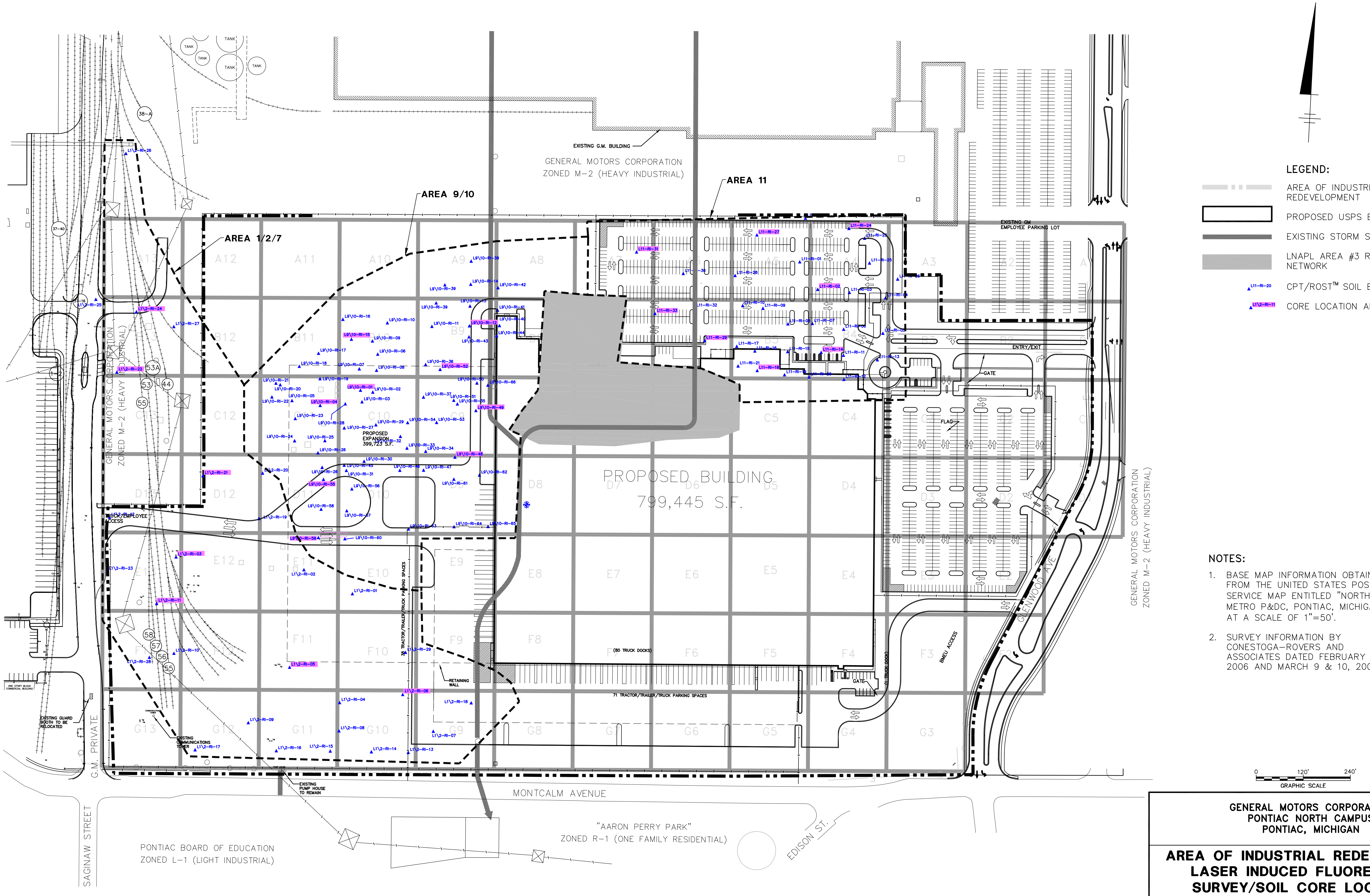
AREA OF INDUSTRIAL REDEVELOPMENT LNAPL AREAS

ENCORE

FIGURE
2.1

Figure 3.1
Typical LNAPL Saturation and Relative Permeability Profiles
for a Sandy Soil





LEGEND:

- ▬ ▪ ▪ ▬ AREA OF INDUSTRIAL REDEVELOPMENT
- ☐ PROPOSED USPS BUILDING
- ▬ EXISTING STORM SEWER
- ▨ LNAPL AREA #3 RECOVERY WELL NETWORK
- ▲ L11-RI-20 CPT/ROST™ SOIL BORING
- ▲ L1\2-RI-11 CORE LOCATION ANALYSIS

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM THE UNITED STATES POSTAL SERVICE MAP ENTITLED "NORTHEAST METRO P&DC, PONTIAC, MICHIGAN" AT A SCALE OF 1"=50'.
2. SURVEY INFORMATION BY CONESTOGA-ROVERS AND ASSOCIATES DATED FEBRUARY 24, 2006 AND MARCH 9 & 10, 2006.

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

**AREA OF INDUSTRIAL REDEVELOPMENT
LASER INDUCED FLUORESCENCE
SURVEY/SOIL CORE LOCATIONS**

ENCORE

FIGURE
5.1

SYR-85-LJP EAB SYR-85-AMS BRI-85-ADF L: ON=*, OFF=REF, |PR-FUTURE, |BOUNDARY
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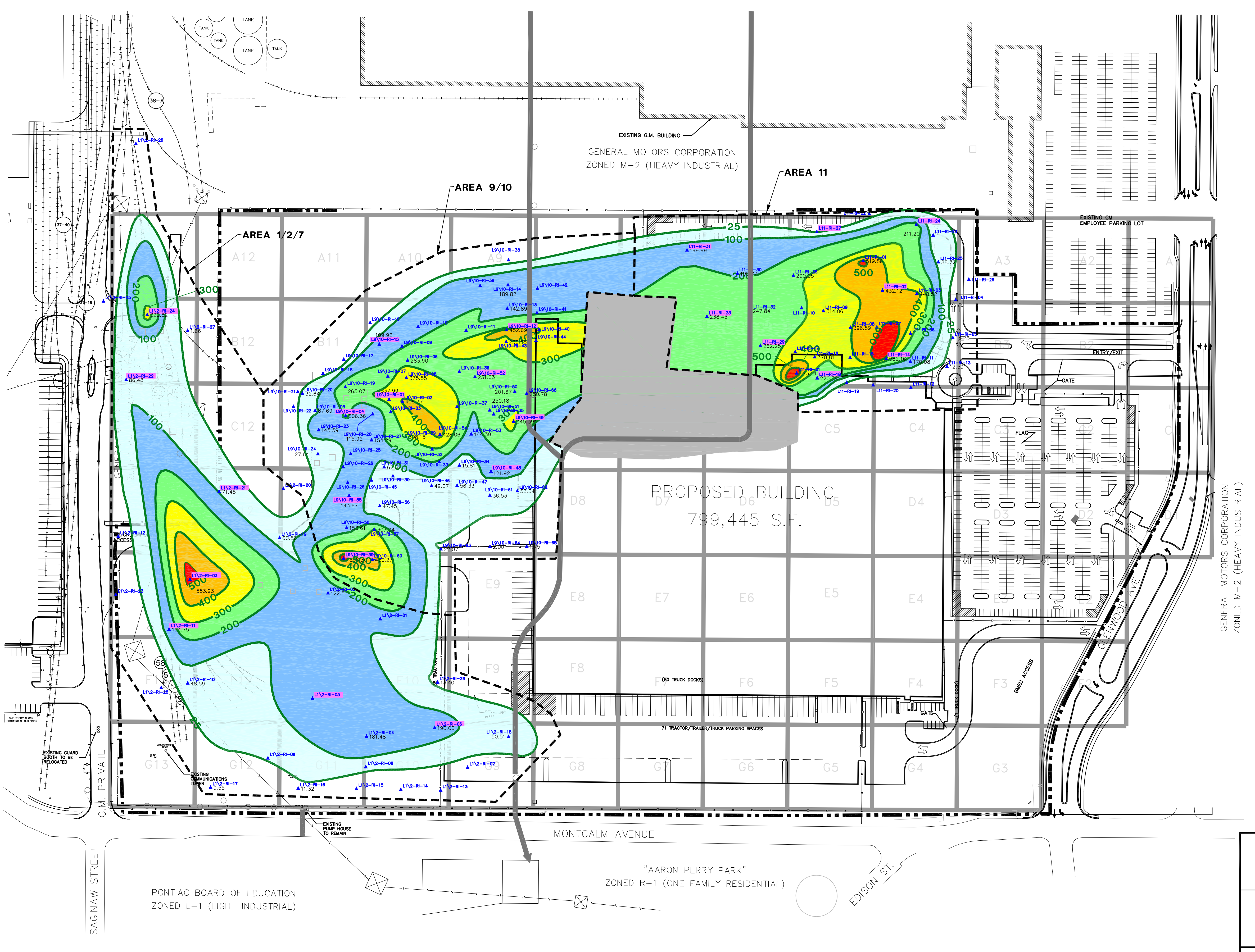


LEGEND:

— · —	AREA OF INDUSTRIAL REDEVELOPMENT
▭	PROPOSED USPS BUILDING
—	EXISTING STORM SEWER
▒	LNAPL AREA #3 RECOVERY WELL NETWORK
▲ L11-RI-20	CPT/ROST™ SOIL BORING
211.28	MAXIMUM FLOURESCENCE PERCENTAGE
▲ L11-RI-14	CORE ANALYSIS LOCATION

LIF INTENSITY (DASHED WHERE INFERRED)

🟥	> 500
🟧	401–500
🟨	301–400
🟩	201–300
🟦	101–200
▭	25–100

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM THE UNITED STATES POSTAL SERVICE MAP ENTITLED "NORTHEAST METRO P&DC, PONTIAC, MICHIGAN" AT A SCALE OF 1"=50'.
2. SURVEY INFORMATION BY CONESTOGA-ROVERS AND ASSOCIATES DATED FEBRUARY 24, 2006 AND MARCH 9 & 10, 2006.

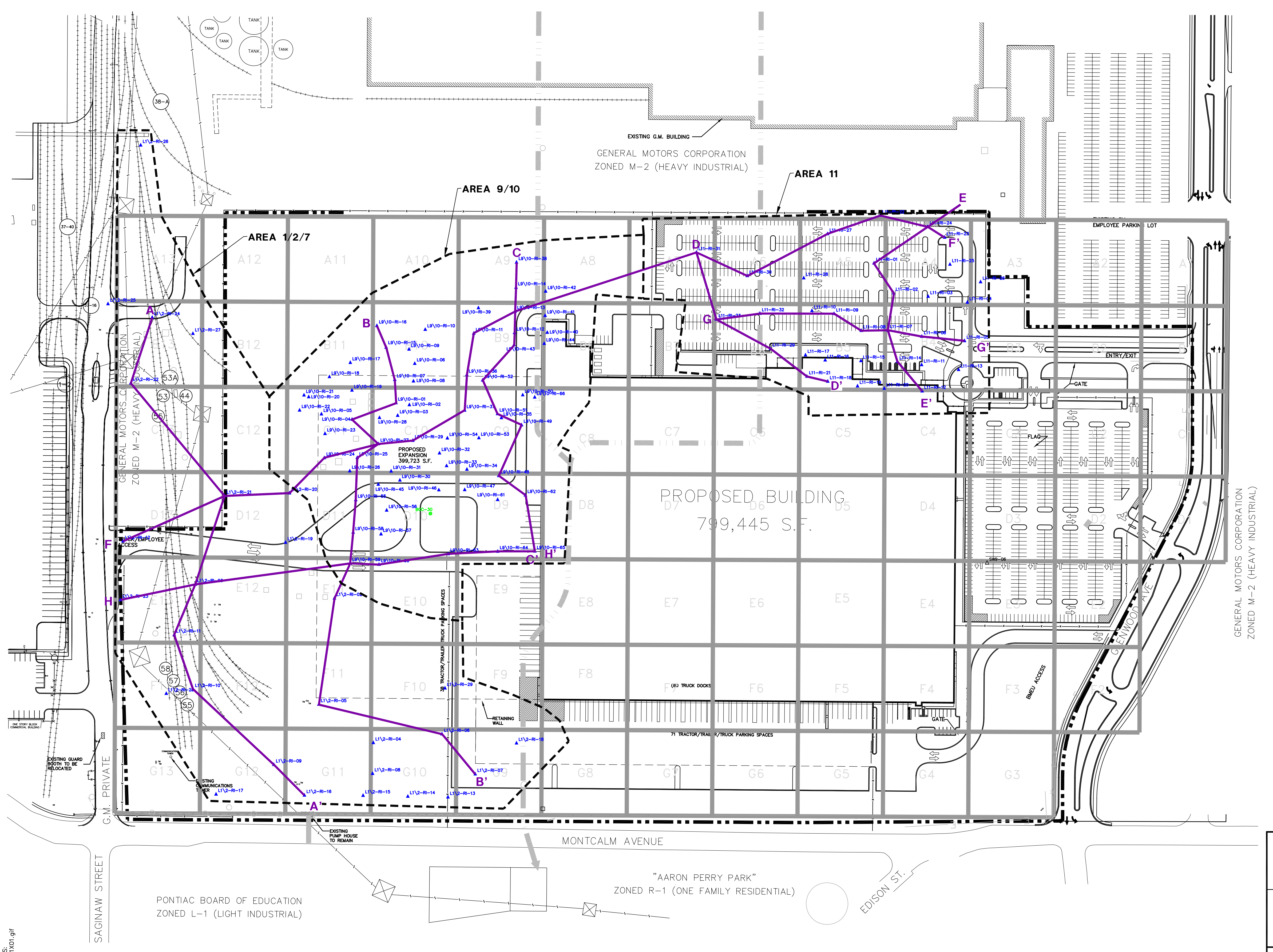
0 120' 240'
GRAPHIC SCALE

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
LASER INDUCED FLUORESCENCE
SURVEY - MAXIMUM RESULTS

ENCORE

FIGURE
5.2



LEGEND:

▬ ▪ ▪ ▬	AREA OF INDUSTRIAL REDEVELOPMENT
☐	EXISTING BUILDING
▬ ╎ ╎ ▬	EXISTING STORM SEWER
▲L1\2-RI-17	ROST™ LOCATION
A———A'	CROSS SECTION LOCATOR LINE

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM THE UNITED STATES POSTAL SERVICE MAP ENTITLED "NORTHEAST METRO P&DC, PONTIAC, MICHIGAN" AT A SCALE OF 1"=50'.
2. ALL LOCATIONS ARE APPROXIMATE.

0 150' 300'
GRAPHIC SCALE

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT ROST™ CROSS SECTION LOCATIONS

ENCORE

FIGURE
5.3

SYR-85-LJP EAB SYR-85-AMS BRI-85-ADF L: ON=*, OFF=REF, |PR-FUTURE, |BOUNDARY
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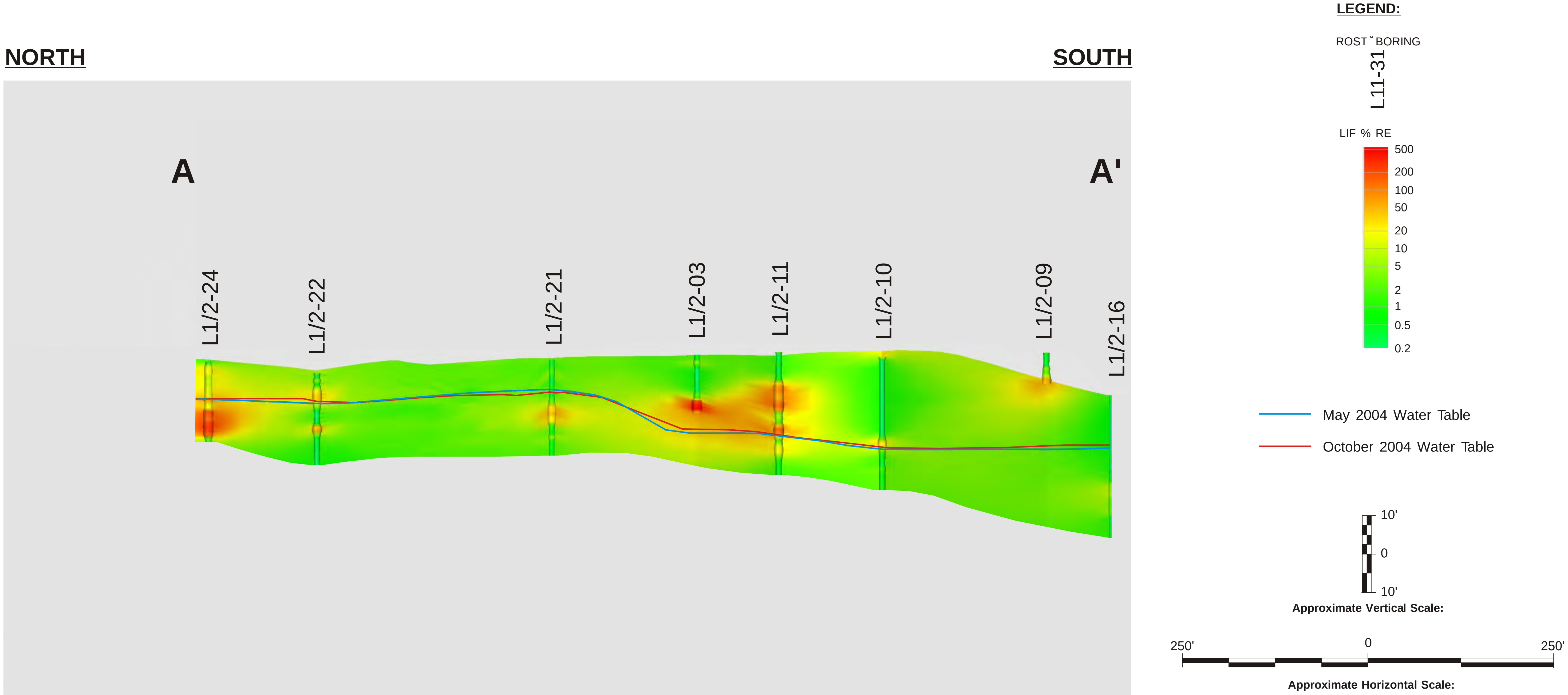

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT ROST™ CROSS SECTION A-A'

ENCORE

FIGURE
5.4

02/06/07 SYR-D85-DJH
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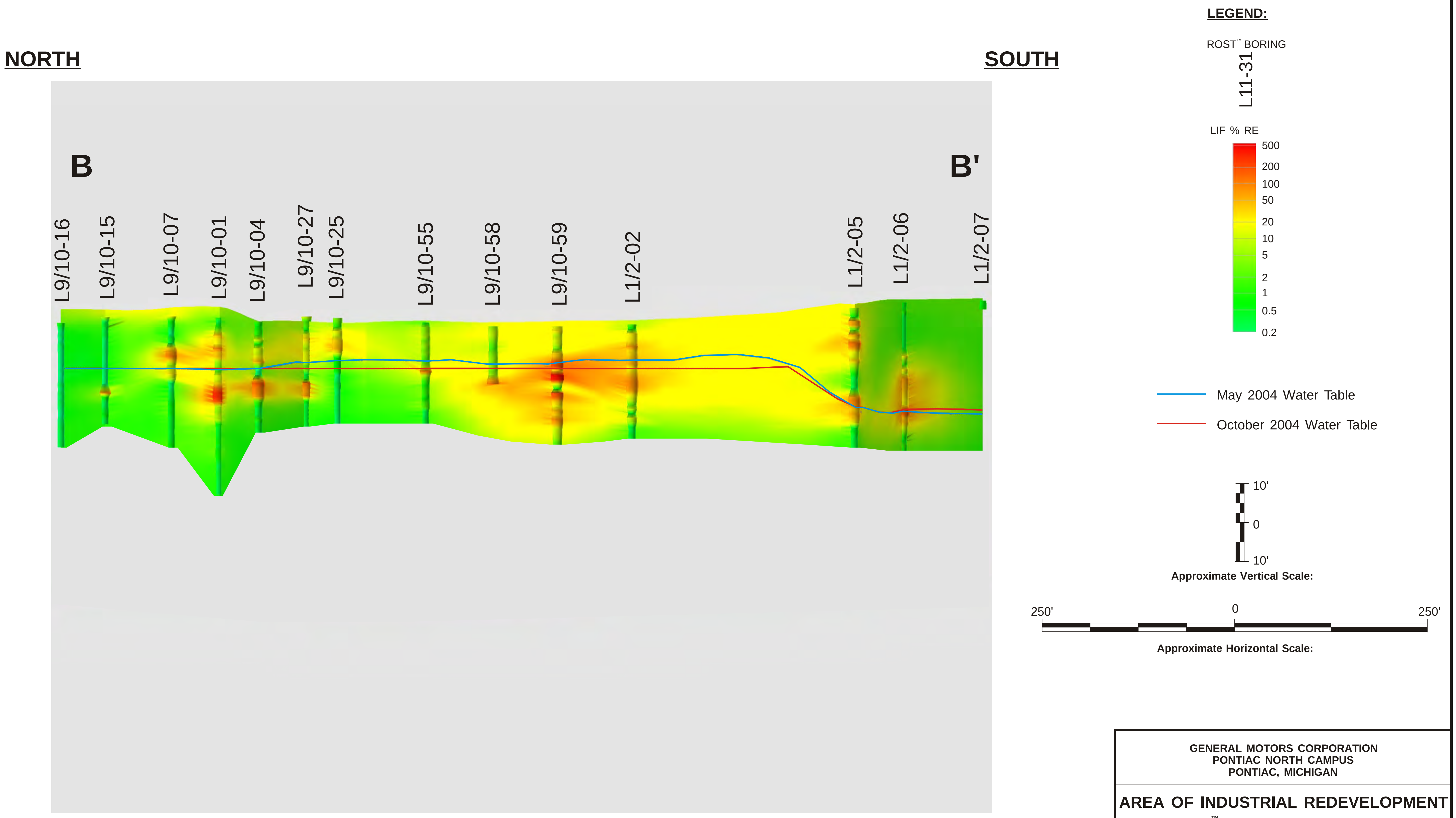

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION B-B'

ENCORE

FIGURE
5.5

02/06/07 SYR-D85-DJH
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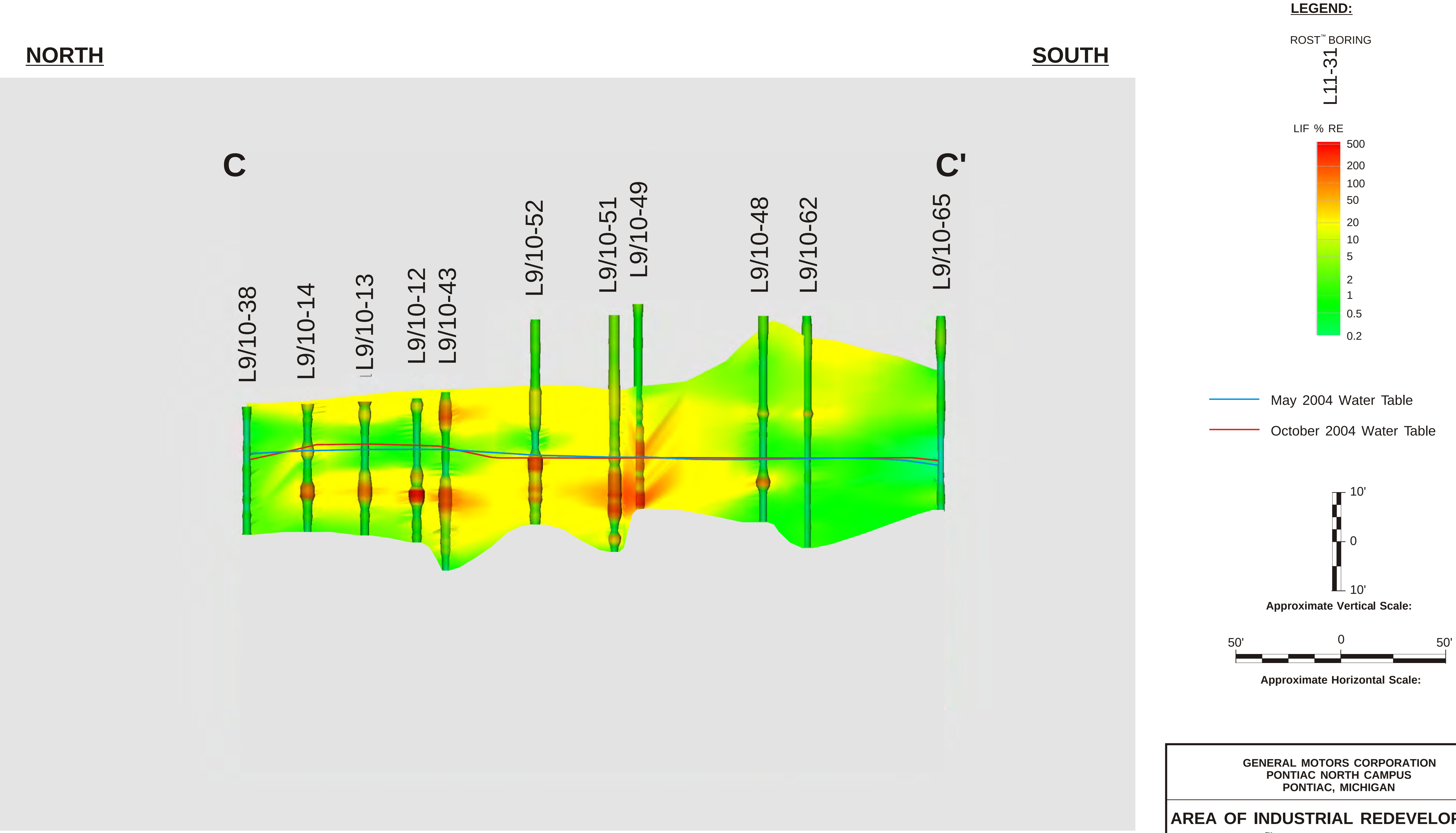

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION C-C'

ENCORE

FIGURE
5.6

02/06/07 SYR-D85-DJH
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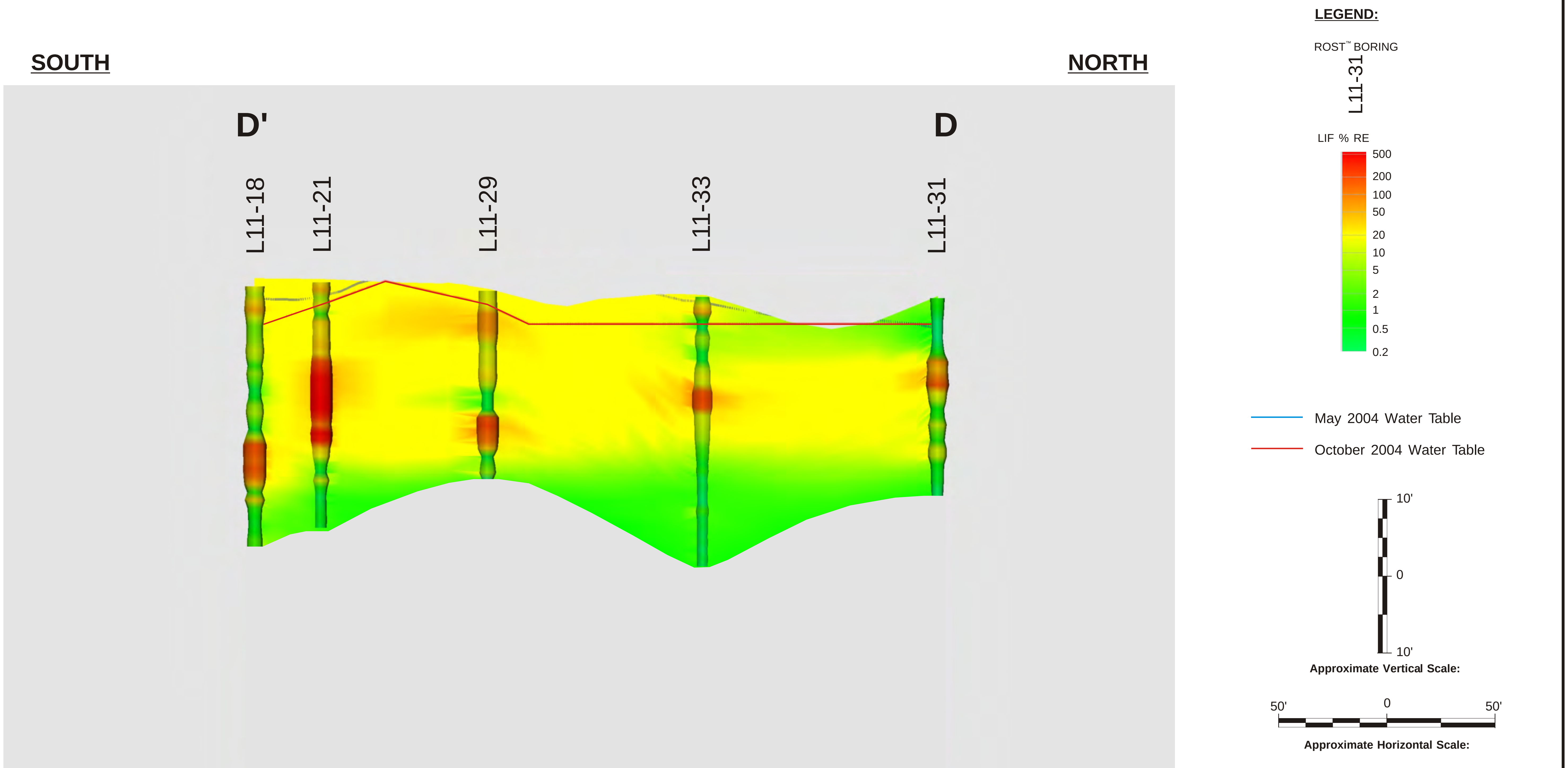

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT ROST™ CROSS SECTION D-D'

ENCORE

FIGURE
5.7

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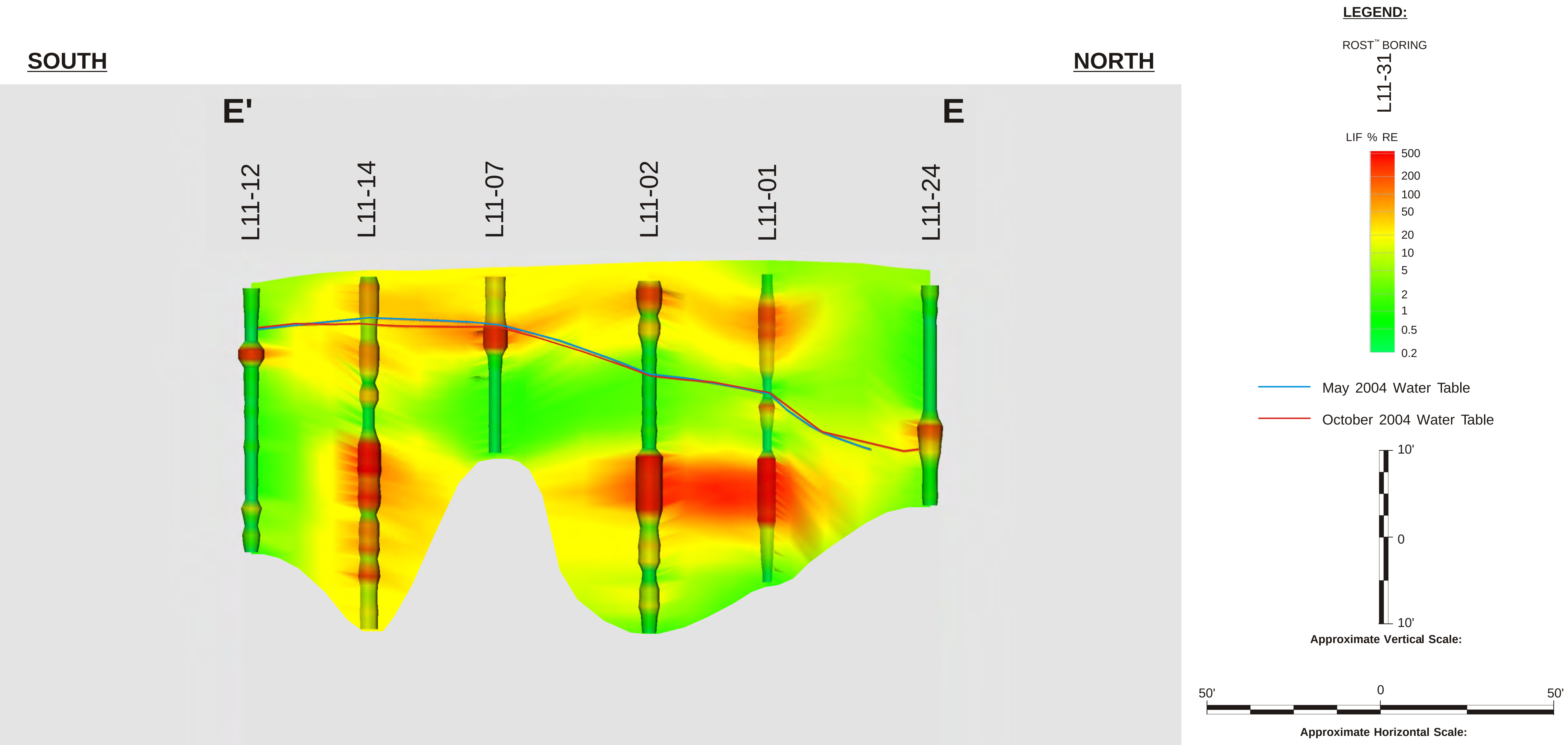

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION E-E'

ENCORE

FIGURE
5.8

02/06/07 SYR-D85-DJH
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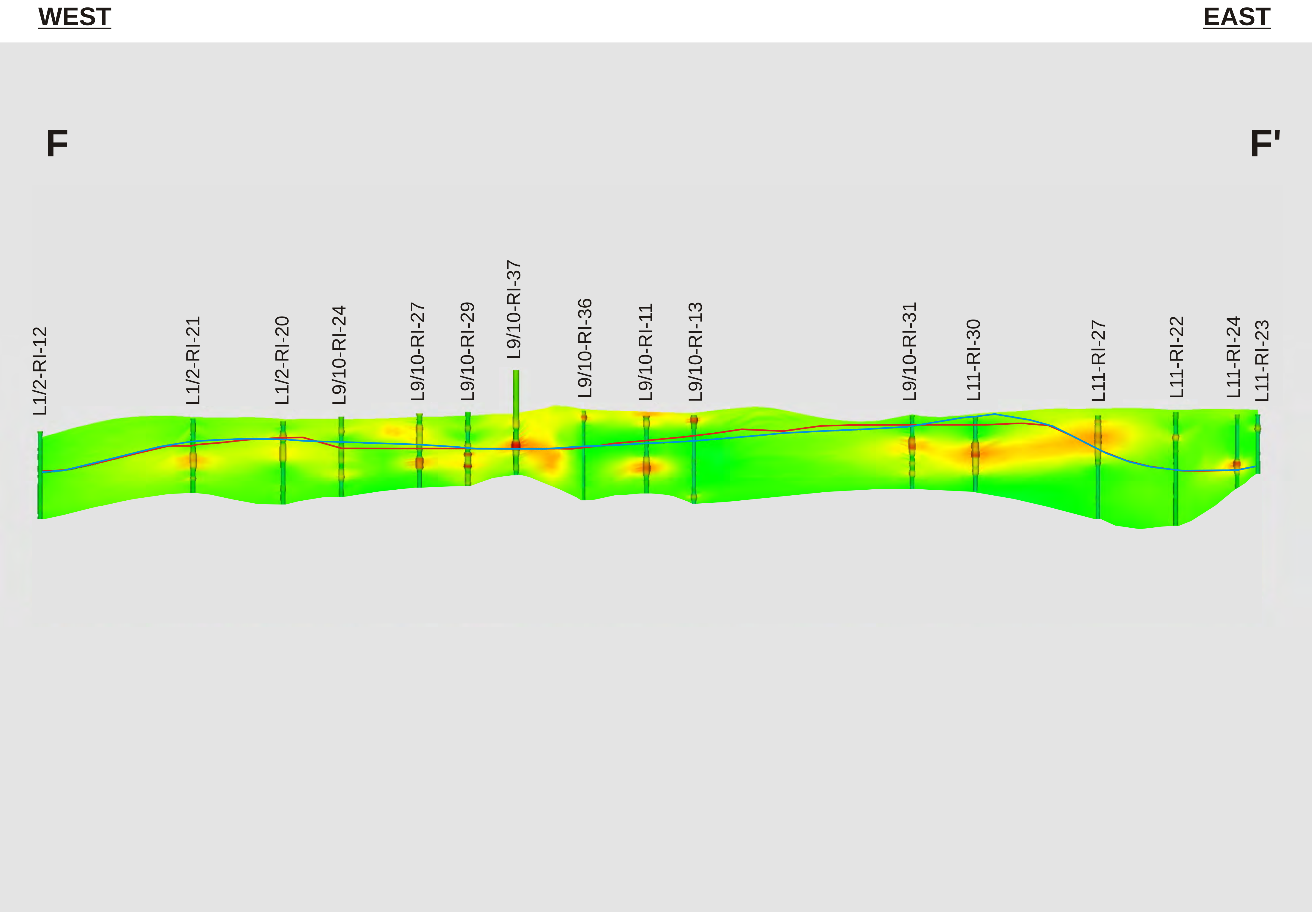
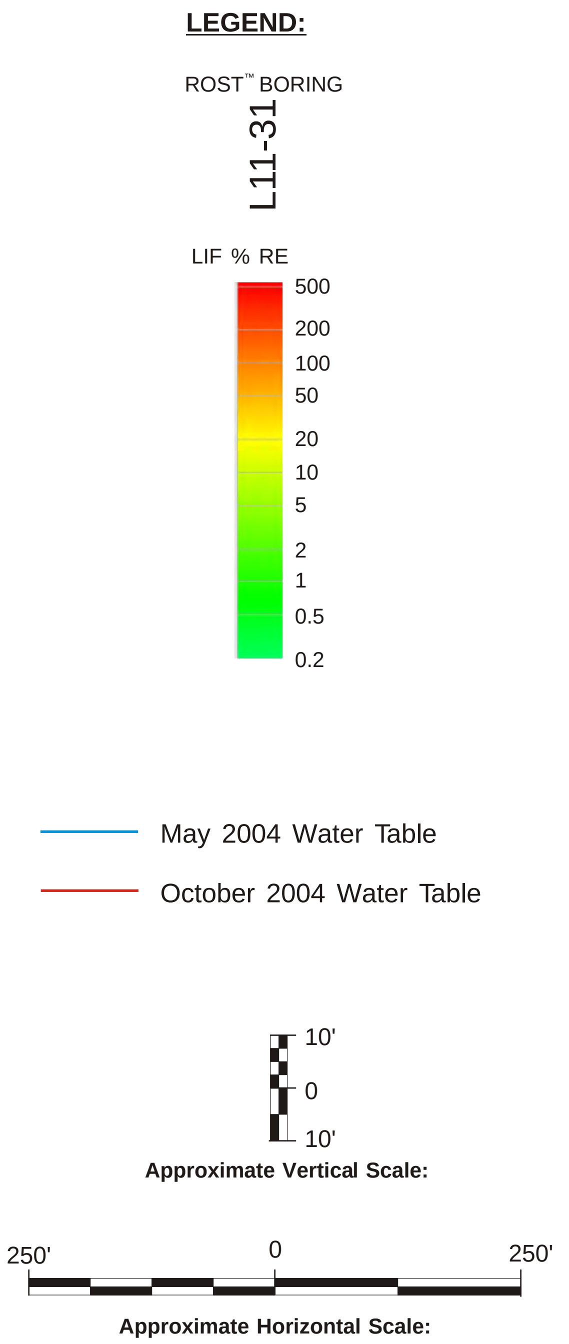




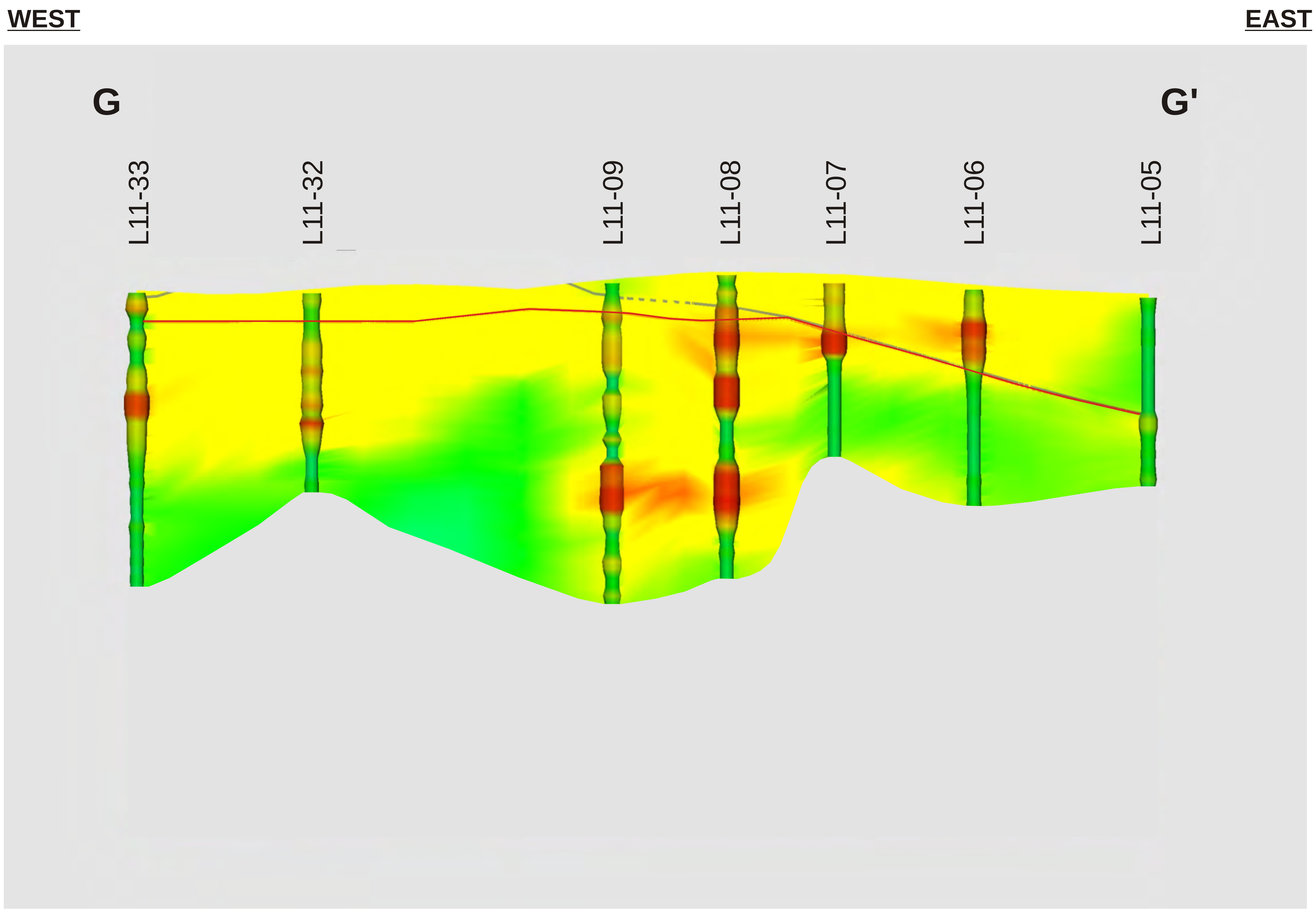
GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION F-F'

ENCORE

FIGURE
5.9

02/06/07 SYR-D85-DJH
64411185/64411g14.cdr

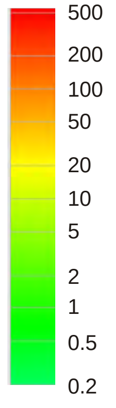


LEGEND:

ROST™ BORING

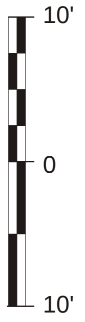
L11-31

LIF % RE



May 2004 Water Table

October 2004 Water Table



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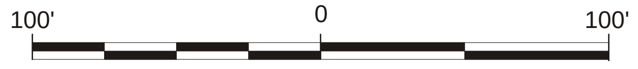


Approximate Horizontal Scale:

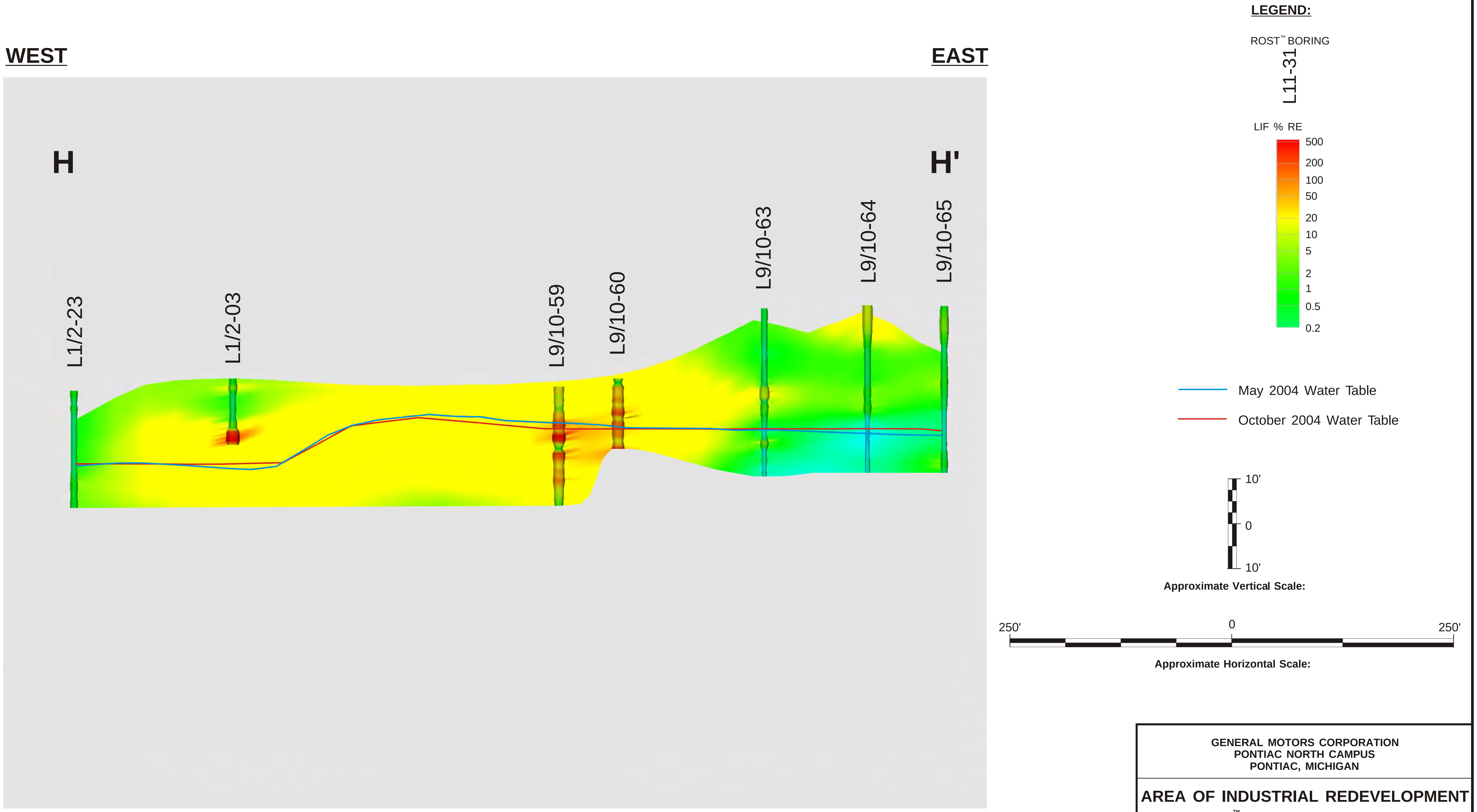
GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION G-G'

ENCORE

FIGURE
5.10

02/06/07 SYR-D85-DJH
64411185/64411g15.cdr



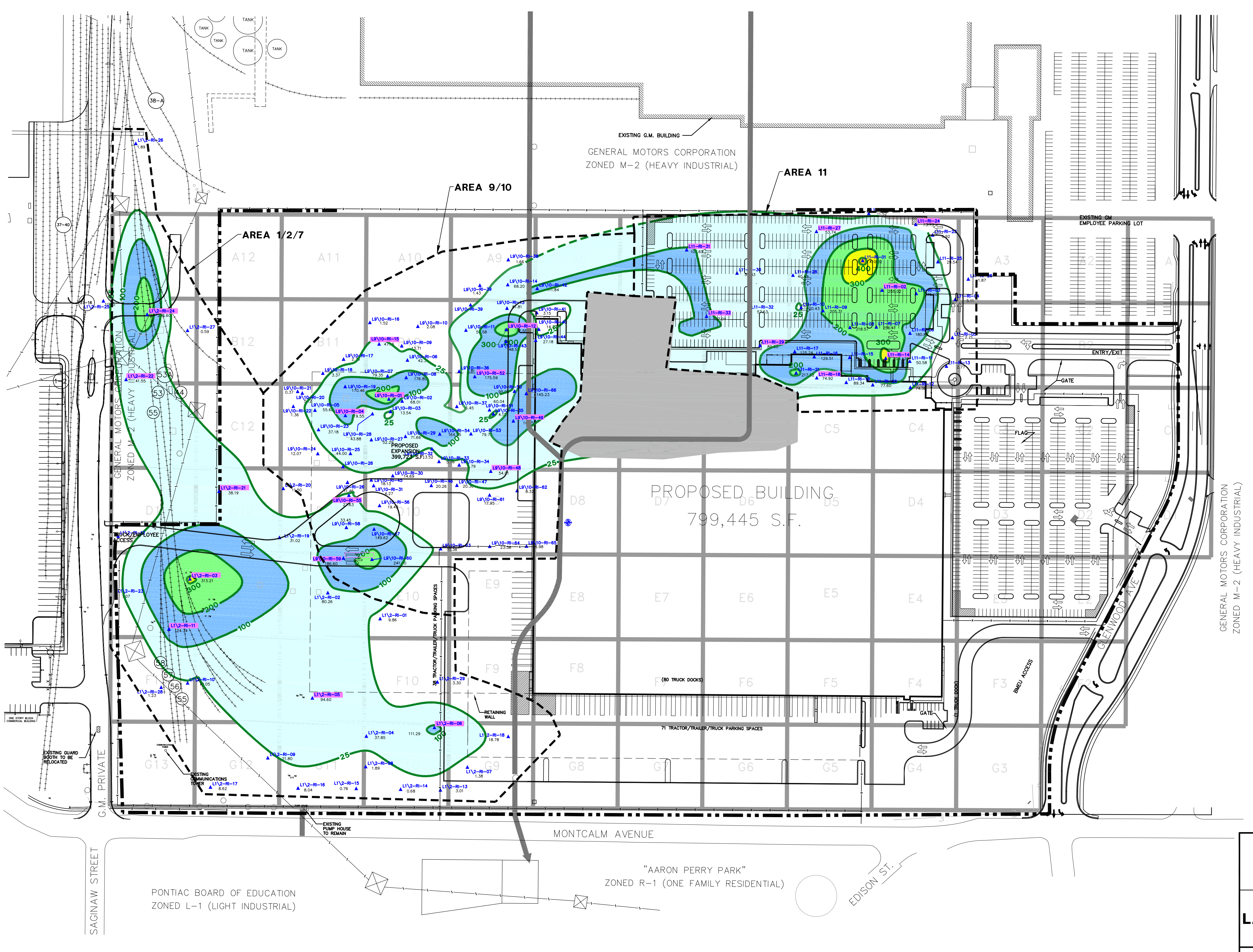
GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT
ROST™ CROSS SECTION H-H'

ENCORE

FIGURE
5.11

02/06/07 SYR-D85-DJH
64411185/64411g16.cdr



LEGEND:

- AREA OF INDUSTRIAL REDEVELOPMENT
- PROPOSED USPS BUILDING
- EXISTING STORM SEWER
- LNAPL AREA #3 RECOVERY WELL NETWORK
- ▲ L11-RI-20 CPT/ROST™ SOIL BORING
- 211.28 AVERAGE FLUORESCENCE PERCENTAGE +/- 0.5-FOOT FROM MAXIMUM FLOURESCENCE POINT
- ▲ L1\2-RI-11 CORE LOCATION ANALYSIS

LIF INTENSITY (DASHED WHERE INFERRED)

🟥	> 500
🟧	401–500
🟨	301–400
🟩	201–300
🟦	101–200
⬜	25–100

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM THE UNITED STATES POSTAL SERVICE MAP ENTITLED "NORTHEAST METRO P&DC, PONTIAC, MICHIGAN" AT A SCALE OF 1"=50'.
2. SURVEY INFORMATION BY CONESTOGA-ROVERS AND ASSOCIATES DATED FEBRUARY 24, 2006 AND MARCH 9 & 10, 2006.

0 120' 240'
GRAPHIC SCALE

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

AREA OF INDUSTRIAL REDEVELOPMENT LASER INDUCED FLUORESCENCE SURVEY - AVERAGE RESULTS

ENCORE

FIGURE
5.12

SYR-85-LJP EAB SYR-85-AMS BRI-85-ADF L: ON=*, OFF=REF, IPR-FUTURE_BOUNDARY PENTABLE:PLTFULL.CTB PRINTED:1/30/2007 11:51 AM BY:AFOX
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Figure 6.2
LNAPL Saturation vs. Average ROST Fluorescence - LNAPL Area 9/10
(Comparing the same 0.2' Vertical Intervals)

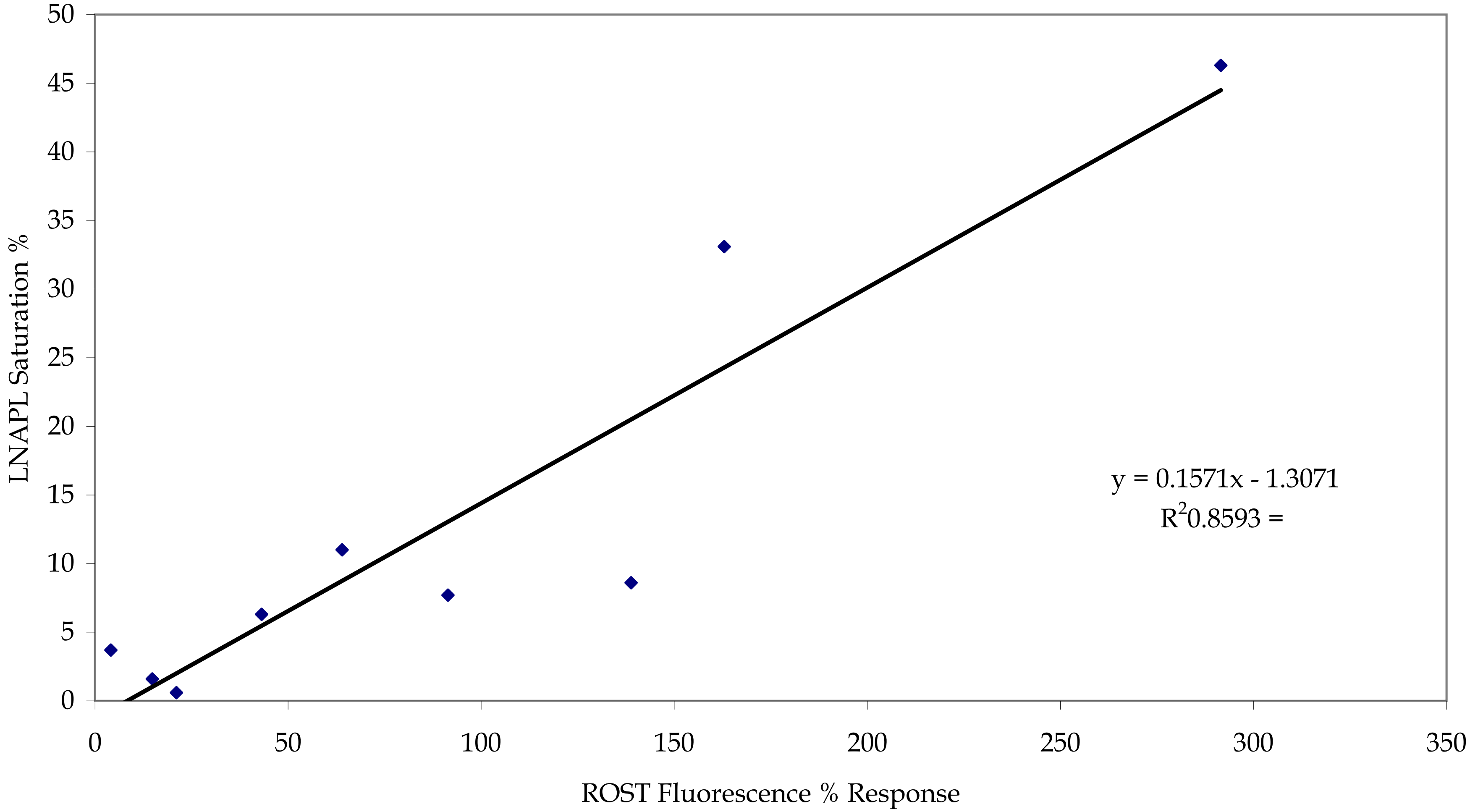


Figure 6.3
LNAPL Saturation vs. Average ROST Fluorescence - LNAPL Area 11
(Comparing the same 0.2' Vertical Intervals)

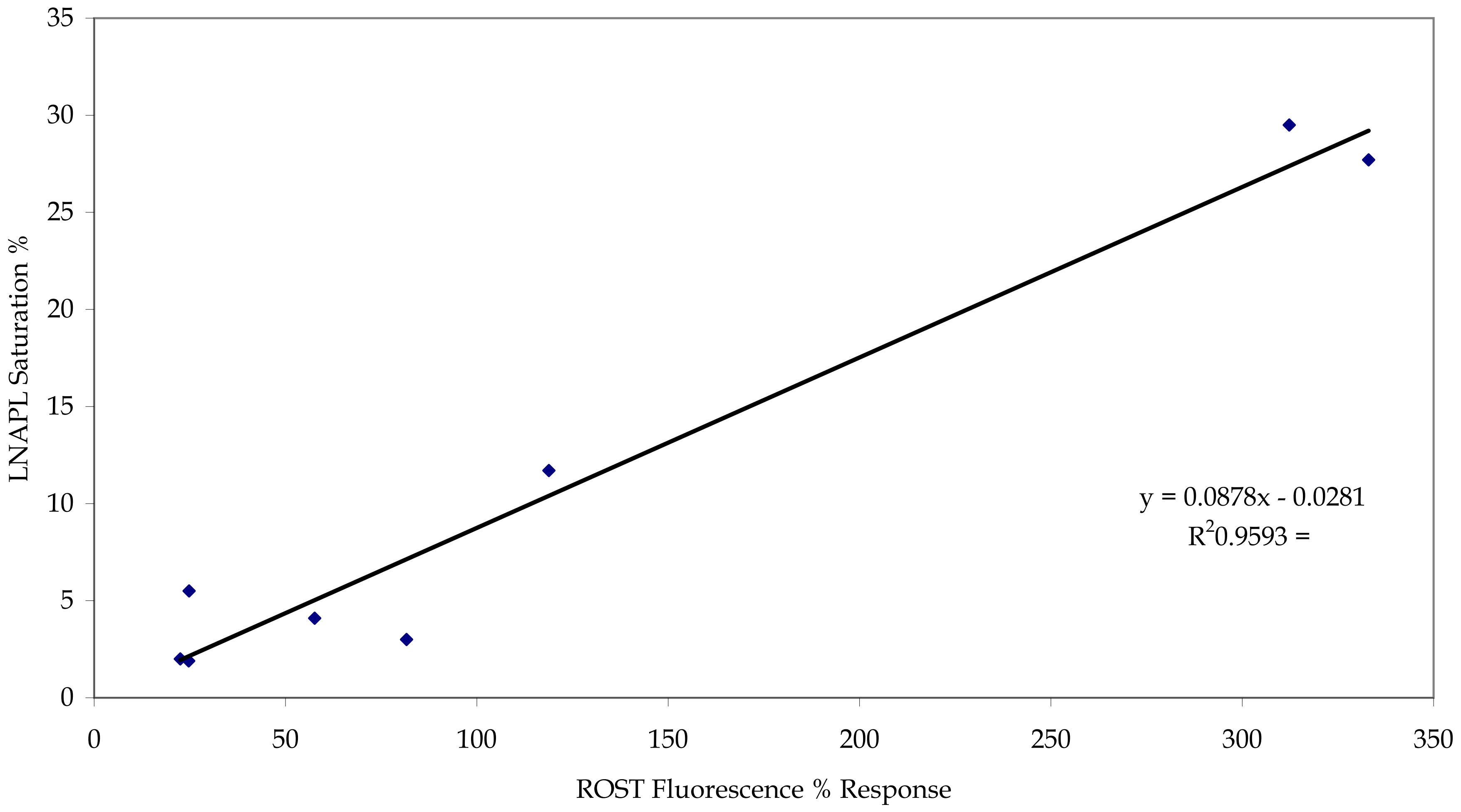
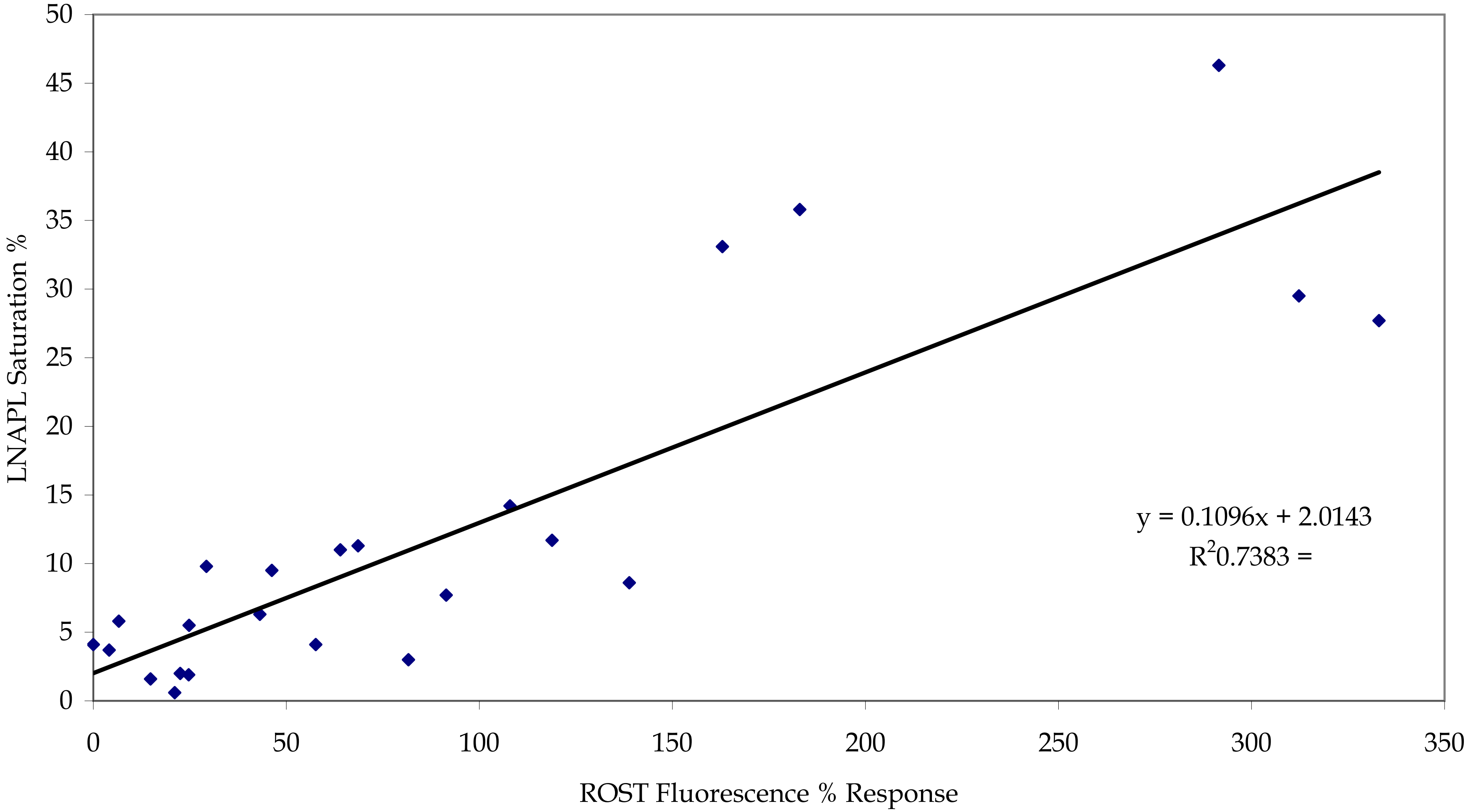
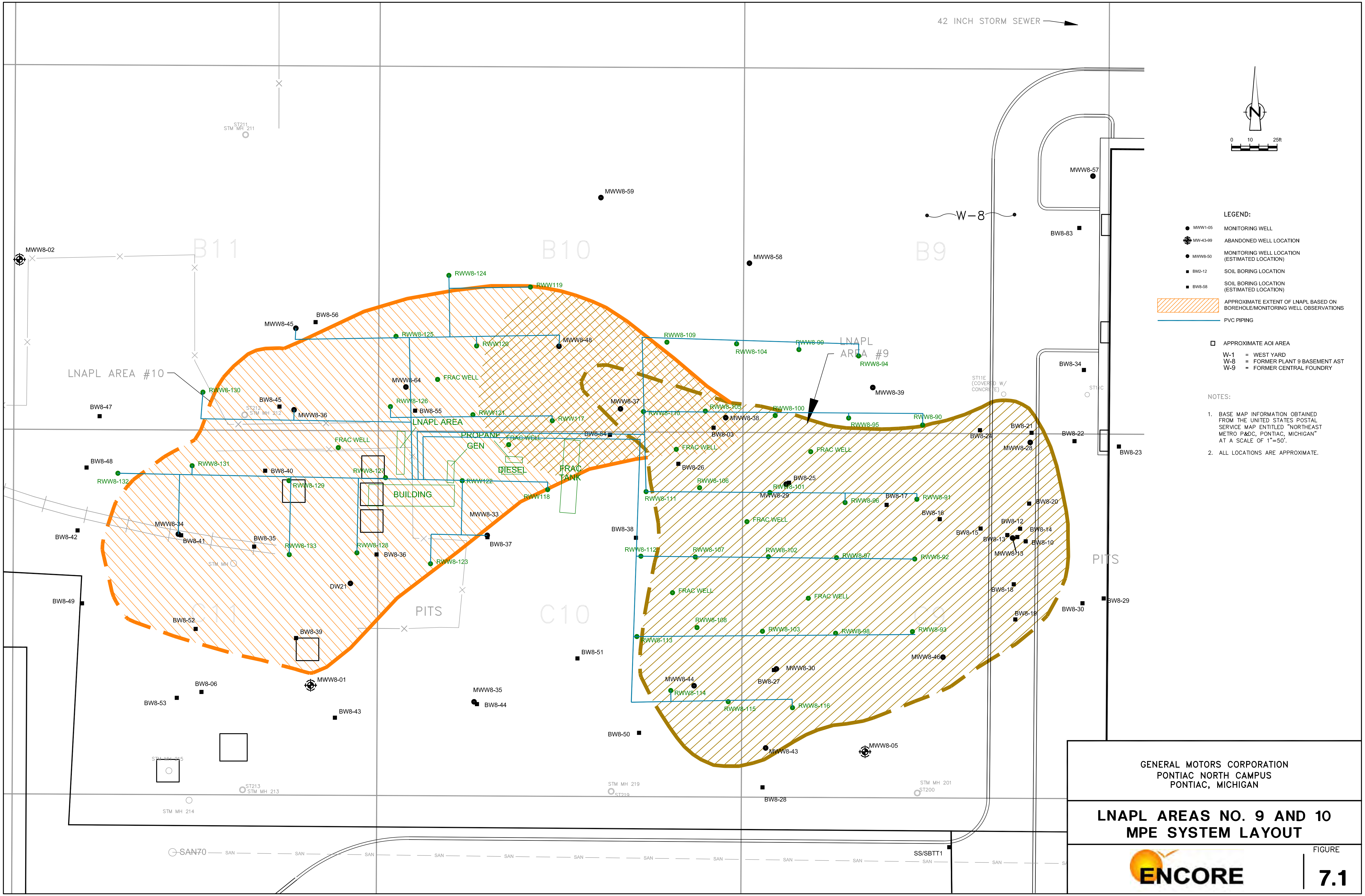


Figure 6.4
LNAPL Saturation vs. Average ROST Fluorescence - All Areas Combined
(Comparing the same 0.2' Vertical Intervals)





LEGEND:

● MWW1-05	MONITORING WELL
MW-43-99	ABANDONED WELL LOCATION
● MWW8-50	MONITORING WELL LOCATION (ESTIMATED LOCATION)
■ BM2-12	SOIL BORING LOCATION
■ BW8-58	SOIL BORING LOCATION (ESTIMATED LOCATION)
▨	APPROXIMATE EXTENT OF LNAPL BASED ON BOREHOLE/MONITORING WELL OBSERVATIONS
—	PVC PIPING
☐	APPROXIMATE AOI AREA

W-1 = WEST YARD
W-8 = FORMER PLANT 9 BASEMENT AST
W-9 = FORMER CENTRAL FOUNDRY

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM THE UNITED STATES POSTAL SERVICE MAP ENTITLED "NORTHEAST METRO P&DC, PONTIAC, MICHIGAN" AT A SCALE OF 1"=50'.
2. ALL LOCATIONS ARE APPROXIMATE.

GENERAL MOTORS CORPORATION
PONTIAC NORTH CAMPUS
PONTIAC, MICHIGAN

LNAPL AREAS NO. 9 AND 10 MPE SYSTEM LAYOUT

ENCORE

FIGURE
7.1

Tables

Table 5.1
Summary of ROST, Core Photo, And Laboratory Saturation Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

ROST DATA						CORE PHOTOGRAPHY DATA													
										SUBSAMPLE DATA FROM LABORATORY TESTING									
										Capillary Pressure Test			Single Point Centrifugal Test			Saturation Only Test			
Rost ID	Maximum Fluorescence (% Response)	Depth (feet bgs)	Thickness (feet)	Thickness Interval +/- 1' from Maximum Response	Average Fluorescence Over 1' Interval (% Response)	Core ID	Observed Impacted Interval(s) (feet bgs)	CPT Soil Type	Interval of Maximum Saturation (feet bgs)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Selected Corresponding ROST Interval (feet bgs)	Average Fluorescence Over Selected Interval (% Response)
L1_2-03	553.93	14.06	0.42	13.56-14.56	313.21	**L1/2-RI-03**	13.15-13.25 13.6-14.1 15.15-15.3 15.3-15.4 15.4-15.5 15.5-15.75 15.75-15.8 15.8-16.1	CLAYS CLAYS SANDS SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS SILTY SAND SANDS	15.7-15.9	15.5-15.7	1.30	8.10	15.7-15.9	5.30	5.10	15.9-16.1	4.10	13.90-14.10	426.14
L1_2-05	157.64	8.41	1.07	7.91-8.91	94.60	**L1/2-RI-05**	20-21.25 21.35-21.65	CLAYEY SANDY SILT & SILT CLAYEY SANDY SILT & SILT	20.1-20.3				20.8-21	14.70	13.10	20.05-20.25	9.50	20.60-20.80 21.3-21.5	64.71 86.17
L1_2-06	190.00	25.11	0.55	24.61-25.61	111.29	**L1/2-RI-06**	25.2-26	SILTY SAND	25.4-25.6	25.2-25.4	19.80	11.60	25.4-25.6	18.20	16.80	25.6-25.8	11.30	25-25.2	137.50
L1_2-11	194.75	14.40	0.53	13.90-14.90	124.34	**L1/2-RI-11**	13.05-13.2 13.2-13.6 13.6-13.65 13.65-13.8 13.8-14.3 20.4-20.9	CLAYEY SANDY SILT & SILT SILTY SAND CLAYEY SANDY SILT & SILT SILTY SAND CLAYEY SANDY SILT & SILT SANDS	14.7-14.9*				13.05-13.25	14.00	12.80	13.8-14	14.20	14.2-14.4	174.74
L1_2-21	71.45	14.79	0.21	14.29-15.29	38.19	**L1/2-RI-21**	13.4-13.45 13.45-13.6 13.6-13.8 14.85-14.95 14.95-15.3	SILTY SAND CLAYEY SANDY SILT & SILT SILTY SAND CLAYEY SANDY SILT & SILT SILTY SAND	14.9-15.1				14.9-15.1	9.70	8.80	13.45-13.65	9.80	14.75-14.95	49.41
L1_2-22	86.48	15.13	0.48	14.63-15.63	41.55	**L1/2-RI-22**	15.5-16.4	SANDS	15.8-16							15.8-16	5.80	15.1-15.3	70.22

Table 5.1
Summary of ROST, Core Photo, And Laboratory Saturation Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

ROST DATA						CORE PHOTOGRAPHY DATA														
Rost ID	Maximum Fluorescence (% Response)	Depth (feet bgs)	Thickness (feet)	Thickness Interval +/- 1' from Maximum Response	Average Fluorescence Over 1' Interval (% Response)	Core ID	Observed Impacted Interval(s) (feet bgs)	CPT Soil Type	Interval of Maximum Saturation (feet bgs)	SUBSAMPLE DATA FROM LABORATORY TESTING									Selected Corresponding ROST Interval (feet bgs)	Average Fluorescence Over Selected Interval (% Response)
										Capillary Pressure Test			Single Point Centrifugal Test			Saturation Only Test				
										Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)			
L1_2-24	320.83	17.29	1.37	16.79-17.79	296.60	**L1/2-RI-24**	16.5-19.7	SANDS	18.3-18.5	17.7-17.9	2.90	4.30	18.3-18.5	44.00	13.90	18.1-18.3	35.80	17.85-18.05	260.99
L9_10-01	337.98	18.44	1.87	17.94-18.94	284.45	**L9/10-RI-01**	17.5-20.2	SANDS	18.6-18.8	18.4-18.6	44.20	28.20	18.6-18.8	50.70	20.40	18.2-18.4	46.30	18.5-18.7	292.75
L9_10-04	206.35	14.46	0.75	13.96-14.96	119.55	**L9/10-RI-04**	14-16 16.4-17.7 17.7-18.2	SANDS SANDS SILTY SAND	14.3-14.5				14.3-14.5	37.70	12.50	14.1-14.3	33.10	14.4-14.6	193.13
L9_10-12	452.68	18.89	1.41	18.39-19.39	307.55	**L9/10-RI-12**	19.1-19.95 19.95-20.05 20.05-21.8 21.8-22.95 22.95-23.15 23.15-23.3	SANDS SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS CLAYS CLAYEY SILT & SILTY CLAYS	19.7-19.9	20.7-20.9	10.10	9.90	19.7-19.9	11.30	10.90	19.5-19.7	8.60	19.2-19.4	357.03
L9_10-15	109.92	17.34	0.68	16.84-17.84	47.16	**L9/10-RI-15**	16.8-17.55	SANDS	17.2-17.4							17.3-17.5	7.70	17.21-17.41	95.33
L9_10-48	124.93	32.53	1.44	32.03-33.03	54.01	**L9/10-RI-48**	31.2-31.3 31.3-31.5 31.5-31.7 31.7-31.95 31.95-32.2 32.2-32.35 32.35-32.4 35.1-35.8	CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT SILTY SAND SANDS SILTY SAND CLAYEY SILT & SILTY CLAYS	32-32.2							32-32.2	0.60	32.5-32.7	90.65
L9_10-49	345.38	39.40	0.67	38.90-39.90	147.52	**L9/10-RI-49**	28-28.2 28.2-28.9 38-38.25 38.25-38.65 38.65-38.85 38.85-38.9	SANDS SILTY SAND SANDS SILTY SAND CLAYEY SANDY SILT & SILT SILTY SAND	38-38.2				38.55-38.75	14.50	13.90	38-38.2	6.30	38.40-38.60	110.79

Table 5.1
Summary of ROST, Core Photo, And Laboratory Saturation Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

ROST DATA						CORE PHOTOGRAPHY DATA													
										SUBSAMPLE DATA FROM LABORATORY TESTING									
										Capillary Pressure Test			Single Point Centrifugal Test			Saturation Only Test			
Rost ID	Maximum Fluorescence (% Response)	Depth (feet bgs)	Thickness (feet)	Thickness Interval +/- 1' from Maximum Response	Average Fluorescence Over 1' Interval (% Response)	Core ID	Observed Impacted Interval(s) (feet bgs)	CPT Soil Type	Interval of Maximum Saturation (feet bgs)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Selected Corresponding ROST Interval (feet bgs)	Average Fluorescence Over Selected Interval (% Response)
L9_10-52	231.04	27.87	1.33	27.37-28.37	175.59	**L9/10-RI-52**	27.5-28	SILTY SAND	31.7-31.9				31.7-31.9	6.40	6.10	31.3-31.5	1.60	29.05-29.25	175.80
							28-28.7	CLAYEY SANDY SILT & SILT											
							28.7-29	SILTY SAND											
							29.1-29.3	SILTY SAND											
							29.55-29.65	SILTY SAND											
							30-30.65	CLAYEY SILT & SILTY CLAYS											
							30.65-31.3	CLAYEY SANDY SILT & SILT											
							31.3-31.5	CLAYEY SILT & SILTY CLAYS											
							31.5-31.8	CLAYS											
							31.8-31.95	CLAYEY SILT & SILTY CLAYS											
							31.95-32.15	CLAYEY SANDY SILT & SILT											
L9_10-55	143.67	11.56	0.38	11.06-12.06	27.63	**L9/10-RI-55**	12.7-12.95	SANDS	12.5-12.7							12.5-12.7	3.70	11.45-11.65	0.71
							13.1-13.4	SANDS											
L9_10-59	508.30	11.96	1.17	11.46-12.46	186.60	**L9/10-RI-59**	11.1-11.2	CLAYEY SANDY SILT & SILT	12.2-12.4				12.2-12.4	28.60	23.30	11.5-11.7	11.00	11.9-12.10	367.41
							11.2-11.35	SILTY SAND											
							11.35-11.7	CLAYEY SANDY SILT & SILT											
							11.7-12	CLAYEY SILT & SILTY CLAYS											
							12-12.2	CLAYS											
							12.2-12.3	CLAYEY SILT & SILTY CLAYS											
							12.3-12.5	CLAYEY SANDY SILT & SILT											
							12.8-12.9	CLAYEY SILT & SILTY CLAYS											
							12.9-13	CLAYS											
							15.2-15.35	SILTY SAND											
							15.35-15.7	SANDS											
							15.7-17.2	SILTY SAND											
							17.2-17.8	CLAYEY SANDY SILT & SILT											

Table 5.1
Summary of ROST, Core Photo, And Laboratory Saturation Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

ROST DATA						CORE PHOTOGRAPHY DATA														
										SUBSAMPLE DATA FROM LABORATORY TESTING										
										Capillary Pressure Test			Single Point Centrifugal Test			Saturation Only Test				
Rost ID	Maximum Fluorescence (% Response)	Depth (feet bgs)	Thickness (feet)	Thickness Interval +/- 1' from Maximum Response	Average Fluorescence Over 1' Interval (% Response)	Core ID	Observed Impacted Interval(s) (feet bgs)	CPT Soil Type	Interval of Maximum Saturation (feet bgs)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Selected Corresponding ROST Interval (feet bgs)	Average Fluorescence Over Selected Interval (% Response)
L11-02	423.13	20.89	0.40	20.39-21.39	255.02	**L11-RI-02**	20.5-20.75 20.75-21.1 21.1-21.4 22.1-22.9 22.9-23	SILTY SAND CLAYEY SANDY SILT & SILT SILTY SAND SILTY SAND CLAYEY SANDY SILT & SILT	22.3-22.5	20.8-21	25.60	6.10	22.3-22.5	42.00	28.20	22.1-22.3	27.70	21.8-22	356.21
L11-14	582.19	22.22	0.67	21.72-22.72	335.42	**L11-RI-14**	19.6-20 20-20.3 21-21.5 21.5-21.85 21.85-21.9	CLAYEY SANDY SILT & SILT SILTY SAND SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS	19.65-19.85				19.65-19.85	9.80	9.40	20-20.2	29.50	20.15-20.35	297.21
L11-18	220.38	20.10	0.35	19.60-20.60	74.92	**L11-RI-18**	21.3-21.4 21.4-22.2 22.85-23.2 23.2-23.4 23.4-23.75 23.75-24.2	SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SANDY SILT & SILT SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS	23.7-23.9				23.5-23.7	10.40	9.90	23.7-23.9	11.70	23.2-23.4	185.33
L11-24	211.19	16.33	0.66	15.83-16.83	73.73	**L11-RI-24**	17.4-17.7 17.7-17.9 18-18.75	CLAYEY SILT & SILTY CLAYS CLAYS CLAYEY SILT & SILTY CLAYS	17.6-17.8							17.6-17.8???	2.00	17.4-17.6	70.86
L11-27	93.98	7.49	0.39	6.99-7.99	53.74	**L11-RI-27**	6.4-6.8 6.8-7.1 7.1-7.4 7.4-8.35 8.35-8.45 8.45-9.75	CLAYEY SILT & SILTY CLAYS CLAYS CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT	7.3-7.5							7.3-7.5	4.10	7.4-7.6	70.68

Table 5.1
Summary of ROST, Core Photo, And Laboratory Saturation Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

ROST DATA						CORE PHOTOGRAPHY DATA													
										SUBSAMPLE DATA FROM LABORATORY TESTING									
										Capillary Pressure Test			Single Point Centrifugal Test			Saturation Only Test			
Rost ID	Maximum Fluorescence (% Response)	Depth (feet bgs)	Thickness (feet)	Thickness Interval +/- 1' from Maximum Response	Average Fluorescence Over 1' Interval (% Response)	Core ID	Observed Impacted Interval(s) (feet bgs)	CPT Soil Type	Interval of Maximum Saturation (feet bgs)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Residual Saturation (%)	Depth (feet bgs)	Saturation (%)	Selected Corresponding ROST Interval (feet bgs)	Average Fluorescence Over Selected Interval (% Response)
L11-29	262.25	17.01	0.40	16.51-17.51	89.63	**L11-RI-29**	19.8-20	CLAYS	19.8-20							19.8-20	3.00	19.8-20	81.63
L11-31	200.00	11.53	0.34	11.03-12.03	103.62	**L11-RI-31**	9.1-9.2 9.2-9.85 9.85-10 10.15-10.2 10.2-10.45	CLAYS CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS	9.4-9.6							9.4-9.6	5.50	8.9-9.1	39.55
L11-33	238.45	13.95	0.36	13.45-14.45	107.04	**L11-RI-33**	14-14.05 14.05-14.35 14.35-14.65 14.65-14.85 14.85-15.6 15.6-16.2	SILTY SAND CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS CLAYEY SANDY SILT & SILT CLAYEY SILT & SILTY CLAYS CLAYS	14.8-15				14.6-14.8	2.20	1.70	14.8-15	1.90	13.8-14	155.38

Notes:
ROST - Rapid Optical Screening Tool
bgs - below ground surface
CPT - cone penetrometer

Table 5.2
Summary of LNAPL Mobility Evaluation Laboratory Test Program
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

CORE ID	Depth (feet bgs)	Core Recovery (feet)	Core Photo	Grain Size Analysis	Saturation Only	Single Point Centrifugal Test	Capillary Pressure Test
L9/10-RI-01-17.5-19.5-030806	17.5-19.5	2.25	Y	18.6-18.8	18.2-18.4	18.6-18.8	18.4-18.6
L9/10-RI-04-14-16-030906	14-16	2.20	Y	14.3-14.5	14.1-14.3	14.3-14.5	--
L9/10-RI-04-16-18-031006	16-18	2.25	Y				
L9/10-RI-01-19.5-21.5-031006	19.5-21.5	2.20	Y				
L9/10-RI-12-19-21-031106	19-21	2.30	Y	19.7-19.9	19.5-19.7	19.7-19.9	20.7-20.9
L9/10-RI-12-21-23-031106	21-23	2.50	Y				
L9/10-RI-52-27.5-29.5-030906	27.5-29.5	2.30	Y				
L9/10-RI-52-30-32-030906	30-32	2.20	Y	31.7-31.9	31.3-31.5	31.7-31.9	--
L9/10-RI-48-(31-33')040506	31-33	2.30	Y	32.0-32.2	32.0-32.2	--	--
L9/10-RI-48-(35-36')040506	35-36	1.00	Y				
L1/2-RI-21-(12-14')040506	12-14	2.30	Y	--	13.45-13.65	--	--
L1/2-RI-21-(14-16')040506	14-16	2.30	Y	14.9-15.1	--	14.9-15.1	--
L11-RI-33(12-14)041006	12-14	1.80	Y				
L11-RI-33(14-16)041006	14-16	2.30	Y	14.6-14.8	14.8-15.0	14.6-14.8	--
L11-RI-29(16-18)041006	16-18	2.35	Y				
L11-RI-29(18-20)041006	18-20	2.30	Y	19.8-20.0	19.8-20.0	--	--
L9/10-RI-15(16-18)041006	16-18	1.55	Y	17.3-17.5	17.3-17.5	--	--
L11-RI-27(6-8)040706	6-8	2.35	Y	7.3-7.5	7.3-7.5	--	--
L11-RI-27(8-10)040706	8-10	1.80	Y				
L11-RI-24(16-18)040606	16-18	2.20	Y				
L11-RI-24(18-20)040606	18-20	1.50	Y	17.6-17.8	17.6-17.8	--	--
L11-RI-02(20-22)040606	20-22	1.45	Y				
L11-RI-02(22-24)040606	22-24	1.10	Y	22.3-22.5	22.1-22.3	22.3-22.5	20.8-21.0
L11-RI-14(19-21)040606	19-21	1.50	Y	19.65-19.85	20.0-20.2	19.65-19.85	--
L11-RI-14(21-23)040606	21-23	1.10	Y				
L11-RI-18(20-22)040606	20-22	2.30	Y				
L11-RI-18(22-24)040606	22-24	2.30	Y	23.5-23.7	23.7-23.9	23.5-23.7	--
L9/10-RI-49(27-29)040506	27-29	2.20	Y				
L9/10-RI-49(38-40)040506	38-40	1.00	Y	38.0-38.2	38.0-38.2	38.55-38.75	--
L9/10-RI-55(12-12.5)040506	12-12.5	1.30	Y	12.5-12.7	12.5-12.7	--	--
L1/2-RI-03(12-14)040406	12-14	2.20	Y				
L1/2-RI-03(14-16)040406	14-16	2.20	Y	15.9-16.1	15.9-16.1	15.7-15.9	15.5-15.7
L1/2-RI-11(13-15)040406	13-15	1.95	Y	13.05-13.25	13.8-14.0	13.05-13.25	--
L1/2-RI-11(20-22)040406	20-22	2.20	Y				
L1/2-RI-06(17-19)040406	17-19	1.80	Y				
L1/2-RI-06(24-26)040406	24-26	2.10	Y	25.4-25.6	25.6-25.8	25.4-25.6	25.2-25.4
L11-RI-31(9-11)041006	9-11	1.65	Y	9.4-9.6	9.4-9.6	--	--
L11-RI-31(11-13)041006	11-13	0.65	Y				
L1/2-RI-05-SO(20-22')041406	20-22	1.85	Y	20.8-21.0	20.05-20.25	20.8-21.0	--
L9/10-RI-59-SO(11-13')041406	11-13	2.15	Y	12.2-12.4	11.5-11.7	12.2-12.4	--
L9/10-RI-59-SO(15-17')041406	15-17	2.00	Y				
L1/2-RI-24(16.5-19)042806	16.5-19	2.05	Y	18.3-18.5	18.1-18.3	18.3-18.5	17.7-17.9
L1/2-RI-24(19-20)042806	19-20	1.0	Y				
L1/2-RI-22(13.5-15)042806	13.5-15.5	1.8	Y				
L1/2-RI-22(15.5-18)042806	15.5-18	2.4	Y	15.8-16.0	15.8-16.0	--	--

Table 5.3
Comparison of LNAPL Saturations and Residual Saturations
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

Sample ID	Depth	Initial LNAPL Saturation (%Pv)	Residual LNAPL Saturation (%Pv)		% LNAPL Saturation Above Residual	
			Single Point Centrifugal Test	Capillary Pressure Test	Single Point Centrifugal Test	Capillary Pressure Test
L9/10-RI-01	18.3	46.3				
	18.7	50.7	20.4		148.5	
	18.5	44.2		28.2		56.7
L9/10-RI-04	14.2	33.1				
	14.4	37.7	12.5		201.6	
L9/10-RI-12	19.6	8.6				
	19.8	11.3	10.9		3.7	
	20.8	10.1		9.9		2.0
L9/10-RI-15	17.4	7.7				
L9/10-RI-48	32.1	0.6				
L9/10-RI-49	38.1	6.3				
	38.7	14.5	13.9		4.3	
L9/10-RI-52	31.2	1.6				
	31.8	6.4	6.1		4.9	
L9/10-RI-55	12.6	3.7				
L9/10-RI-59	11.6	11.0				
	12.3	28.6	23.3		22.7	
L11-RI-02	22.2	27.7				
	22.4	42.0	28.2		48.9	
	22.9	25.6		6.1		319.7
L11-RI-14	20.1	29.5				
	19.8	9.8	9.4		4.3	
L11-RI-18	23.8	11.7				
	23.6	10.4	9.9		5.1	
L11-RI-24	19.0	2.0				
L11-RI-27	7.4	4.1				
L11-RI-29	19.8	3.0				
L11-RI-31	9.5	5.5				
L11-RI-33	14.9	1.9				
	14.7	2.2	1.7		29.4	
L1/2-RI-03	16.0	4.1				
	15.8	5.3	5.1		3.9	
	15.6	1.3		8.1		-84.0
L1/2-RI-05	20.2	9.5				
	20.9	14.7	13.1		12.2	
L1/2-RI-06	25.7	11.3				
	25.5	18.2	16.8		8.3	
	25.3	19.8		11.6		70.7
L1/2-RI-11	13.9	14.2				
	13.2	14.0	12.8		9.4	
L1/2-RI-21	13.6	9.8				
	15.0	9.7	8.8		10.2	
L1/2-RI-22	15.9	5.8				
L1/2-RI-24	18.2	35.8				
	18.4	44.0	13.9		216.5	
	17.8	2.9		4.3		-32.6

Notes:
%Pv - percent of pore volume

Table 5.4
Summary of Fluid (LNAPL and Water) Test Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

Sample ID	Location	Matrix	Temperature (°F)	Density (g/cm³)	Viscosity (cP)	Interfacial Tension @ 75 °F (dynes/cm)	
RWW8-122	L 9/10	LNAPL	70	0.8488	8.28	Water-Air	61.4
						LNAPL-Air	30.3
						Water-LNAPL	8.9
MWW8-63	L 11	LNAPL	70	0.8357	5.57	Water-Air	60.6
						LNAPL-Air	29.5
						Water-LNAPL	22.3
MWW10-01	L 1/2	LNAPL	70	0.8780	24.1	Water-Air	62.6
						LNAPL-Air	31.2
						Water-LNAPL	12.7

Table 6.1
ROST Fluorescence and LNAPL Saturation Correlation Data
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Mighigan

Sample ID	LNAPL Saturation from Laboratory Analysis (via Dean-Stark)	Average Fluorescence Over the Corresponding 0.2' Interval Selected for Laboratory Analysis
1/2-RI-03	4.1	0
1/2-RI-05	9.5	46.23
1/2-RI-06	11.3	68.57
1/2-RI-11	14.2	107.95
1/2-RI-21	9.8	29.3
1/2-RI-22	5.8	6.62
1/2-RI-24	35.8	182.98
11-RI-02	27.7	333.01
11-RI-14	29.5	312.28
11-RI-18	11.7	118.82
11-RI-24	2	22.51
11-RI-27	4.1	57.61
11-RI-29	3	81.63
11-RI-31	5.5	24.8
11-RI-33	1.9	24.72
9/10-RI-01	46.3	291.54
9/10-RI-04	33.1	162.93
9/10-RI-12	8.6	138.84
9/10-RI-15	7.7	91.41
9/10-RI-48	0.6	21.09
9/10-RI-49	6.3	43.13
9/10-RI-52	1.6	14.81
9/10-RI-55	3.7	4.1
9/10-RI-59	11	63.99

Table 6.2
LNAPL Mobility and Velocity Calculations based on Capillary Pressure Test Results
Area of Industrial Redevelopment
General Motors Pontiac North Campus
Pontiac, Michigan

	Location, Data Input and Calculations (1)					
Data Input Values	**L1/2-RI-03**	**L1/2-RI-06**	**L1/2-RI-24**	**L9/10-RI-01**	**L9/10-RI-12**	**L11-RI-02**
LNAPL Saturation (S_o)	0.013	0.198	0.029	0.442	0.101	0.256
Total Soil Porosity (Φ)	0.512	0.403	0.393	0.406	0.287	0.328
Hydraulic Gradient	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
LNAPL Conductivity (K_o) - (cm/s)	1.19E-06	5.29E-06	3.10E-04	5.45E-04	8.10E-06	1.14E-06
Calculated Parameters						
LNAPL Mobility (M_o) - (cm/s)	1.79E-04	6.63E-05	2.72E-02	3.04E-03	2.79E-04	1.36E-05
LNAPL Velocity (V_o) - (cm/s)	8.40E-07	3.12E-07	1.28E-04	1.43E-05	1.31E-06	6.38E-08

Notes:

(1) - Blue highlighted data input values were based on Site-specific laboratory test results and/or field measurements.

Table 6.3
LNAPL Mobility and Velocity Calculations based on Maximum Saturations and API Methodology
Area of Industrial Redevelopment - LNAPL Area 9/10
General Motors Pontiac North Campus
Pontiac, Michigan

	Location, Data Input and Calculations (3)								
	RI-01	RI-04	RI-12	RI-15	RI-48	RI-49	RI-52	RI-55	RI-59
Data Input Values									
LNAPL Saturation (S_o)	0.463	0.331	0.086	0.077	0.006	0.063	0.016	0.037	0.110
Water Saturation (S_w)	0.310	0.462	0.819	0.755	0.876	0.743	0.751	0.866	0.639
Total Fluid Saturation (S_t)	0.773	0.793	0.905	0.832	0.882	0.806	0.767	0.903	0.749
Irreducible Water Saturation (S_{wr})	0.148	0.129	0.477	0.150	0.150	0.393	0.441	0.150	0.344
van Genuchten N (N) (1)	1.900	2.700	2.700	1.900	2.800	2.700	1.900	2.700	1.400
LNAPL Density (ρ_o) - (g/cm^3)	0.849	0.849	0.849	0.849	0.849	0.849	0.849	0.849	0.849
LNAPL Viscosity (μ_o) - (cp)	8.280	8.280	8.280	8.280	8.280	8.280	8.280	8.280	8.280
Total Soil Porosity (Φ)	0.403	0.375	0.364	0.389	0.307	0.361	0.398	0.422	0.667
Hydraulic Gradient	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
Hydraulic Conductivity Water (K_w) - (cm/s)	3.78E-04	3.78E-04	3.78E-04	3.78E-04	3.78E-04	3.78E-04	3.78E-04	3.78E-04	3.78E-04
Calculated Parameters									
Model Parameter 1 (λ)	0.692	1.135	1.135	0.692	1.188	1.135	0.692	1.135	0.365
Model Parameter 2 (M)	0.474	0.630	0.630	0.474	0.643	0.630	0.474	0.630	0.286
LNAPL Relative Permeability (k_{ro}) (2),(4)	6.39E-02	4.41E-02	1.96E-03	9.38E-04	5.27E-07	5.03E-04	5.58E-06	1.27E-04	5.02E-04
LNAPL Conductivity (K_o) - (cm/s) (4)	2.47E-06	1.71E-06	7.61E-08	3.63E-08	2.04E-11	1.95E-08	2.16E-10	4.93E-09	1.95E-08
LNAPL Mobility (M_o) - (cm/s) (4)	1.33E-05	1.38E-05	2.43E-06	1.21E-06	1.11E-08	8.56E-07	3.40E-08	3.16E-07	2.65E-07
LNAPL Velocity (V_o) - (cm/s) (4)	6.23E-08	6.47E-08	1.14E-08	5.70E-09	5.21E-11	4.03E-09	1.60E-10	1.48E-09	1.25E-09

Notes:

(1) - Values taken from American Petroleum Institute (API) Interactive LNAPL Guide (Version 2.0, Release 2.0.2, August 2004) - Assessment Tools - Parameter Tables - van Genuchten Properties. Values selected based on site-specific particle size distribution analyses.

(2) - LNAPL relative permeability calculation for sands based on Burdine Equation 2.26 and Equation 2.27, and for silts based on Mualem Equation 2.28 in American Petroleum Institute (API) Publication Number 4729, *Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids*, August 2003.

(3) - Blue highlighted data input values were based on Site-specific laboratory test results and/or field measurements.

(4) - Calculations based on laboratory generated LNAPL saturation values.

Table 6.4
LNAPL Mobility and Velocity Calculations based on Maximum Saturations and API Methodology
Area of Industrial Redevelopment - LNAPL Area 11
General Motors Pontiac North Campus
Pontiac, Michigan

Data Input Values	Location, Data Input and Calculations (3)							
	RI-02	RI-14	RI-18	RI-24	RI-27	RI-29	RI-31	RI-33
LNAPL Saturation (S_o)	0.277	0.295	0.117	0.020	0.041	0.030	0.055	0.019
Water Saturation (S_w)	0.483	0.443	0.568	0.680	0.734	0.855	0.830	0.771
Total Fluid Saturation (S_t)	0.760	0.738	0.685	0.700	0.775	0.885	0.885	0.790
Irreducible Water Saturation (S_{wr})	0.150	0.166	0.150	0.150	0.150	0.150	0.150	0.150
van Genuchten N (N) (1)	1.400	1.900	1.900	1.900	1.400	1.400	1.400	1.400
LNAPL Density (ρ_o) - (g/cm^3)	0.836	0.836	0.836	0.836	0.836	0.836	0.836	0.836
LNAPL Viscosity (μ_o) - (cp)	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57
Total Soil Porosity (Φ)	0.324	0.283	0.260	0.294	0.410	0.258	0.327	0.252
Hydraulic Gradient	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
Hydraulic Conductivity Water (K_w) - (cm/s)	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Calculated Parameters								
Model Parameter 1 (λ)	0.365	0.692	0.692	0.692	0.365	0.365	0.365	0.365
Model Parameter 2 (M)	0.286	0.474	0.474	0.474	0.286	0.286	0.286	0.286
LNAPL Relative Permeability (k_{ro}) (2),(4)	4.34E-03	1.89E-02	1.39E-03	9.87E-06	1.44E-04	3.06E-04	1.17E-03	2.88E-05
LNAPL Conductivity (K_o) - (cm/s) (4)	6.52E-07	2.83E-06	2.09E-07	1.48E-09	2.17E-09	4.59E-09	1.75E-08	4.31E-10
LNAPL Mobility (M_o) - (cm/s) (4)	7.26E-06	3.39E-05	6.88E-06	2.52E-07	1.29E-07	5.93E-07	9.72E-07	9.01E-08
LNAPL Velocity (V_o) - (cm/s) (4)	3.41E-08	1.59E-07	3.23E-08	1.18E-09	6.06E-10	2.78E-09	4.57E-09	4.23E-10

Notes:

(1) - Values taken from American Petroleum Institute (API) Interactive LNAPL Guide (Version 2.0, Release 2.0.2, August 2004) - Assessment Tools - Parameter Tables - van Genuchten Properties. Values selected based on site-specific particle size distribution analyses.

(2) - LNAPL relative permeability calculation for sands based on Burdine Equation 2.26 and Equation 2.27, and for silts based on Mualem Equation 2.28 in American Petroleum Institute (API) Publication Number 4729, *Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids* , August 2003.

(3) - Blue highlighted data input values were based on Site-specific laboratory test results and/or field measurements.

(4) - Calculations based on laboratory generated LNAPL saturation values.

Table 6.5
LNAPL Mobility and Velocity Calculations based on Maximum Saturations and API Methodology
Area of Industrial Redevelopment - LNAPL Area 1/2/7
General Motors Pontiac North Campus
Pontiac, Michigan

Data Input Values	Location, Data Input and Calculations (3)						
	RI-03	RI-05	RI-06	RI-11	RI-21	RI-22	RI-24
LNAPL Saturation (S_o)	0.041	0.095	0.113	0.142	0.098	0.058	0.358
Water Saturation (S_w)	0.892	0.450	0.680	0.717	0.763	0.564	0.257
Total Fluid Saturation (S_t)	0.933	0.545	0.793	0.859	0.861	0.622	0.615
Irreducible Water Saturation (S_{wr})	0.553	0.143	0.064	0.108	0.118	0.150	0.132
van Genuchten N (N) (1)	1.400	1.900	1.900	1.900	1.400	1.400	2.700
LNAPL Density (ρ_o) - (g/cm^3)	0.878	0.878	0.878	0.878	0.878	0.878	0.878
LNAPL Viscosity (μ_o) - (cp)	24.1	24.1	24.1	24.1	24.1	24.1	24.1
Total Soil Porosity (Φ)	0.489	0.429	0.420	0.422	0.412	0.387	0.432
Hydraulic Gradient	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
Hydraulic Conductivity Water (K_w) - (cm/s)	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04	1.63E-04
Calculated Parameters							
Model Parameter 1 (λ)	0.365	0.692	0.692	0.692	0.365	0.365	1.135
Model Parameter 2 (M)	0.286	0.474	0.474	0.474	0.286	0.286	0.630
LNAPL Relative Permeability (k_{ro}) (2),(4)	1.46E-03	3.08E-04	2.32E-03	5.76E-03	2.74E-03	4.25E-05	2.48E-02
LNAPL Conductivity (K_o) - (cm/s) (4)	8.65E-09	1.83E-09	1.38E-08	3.42E-08	1.63E-08	2.52E-10	1.47E-07
LNAPL Mobility (M_o) - (cm/s) (4)	4.31E-07	4.49E-08	2.90E-07	5.70E-07	4.03E-07	1.12E-08	9.51E-07
LNAPL Velocity (V_o) - (cm/s) (4)	2.03E-09	2.11E-10	1.36E-09	2.68E-09	1.89E-09	5.28E-11	4.47E-09

Notes:

(1) - Values taken from American Petroleum Institute (API) Interactive LNAPL Guide (Version 2.0, Release 2.0.2, August 2004) - Assessment Tools - Parameter Tables - van Genuchten Properties. Values selected based on site-specific particle size distribution analyses.

(2) - LNAPL relative permeability calculation for sands based on Burdine Equation 2.26 and Equation 2.27, and for silts based on Mualem Equation 2.28 in American Petroleum Institute (API) Publication Number 4729, *Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids*, August 2003.

(3) - Blue highlighted data input values were based on Site-specific laboratory test results and/or field measurements.

(4) - Calculations based on laboratory generated LNAPL saturation values.