Considerations for Applying the Triad Approach Hartford Area Hydrocarbon Plume Site Hartford, Illinois

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Considerations for Applying the Triad Approach Hartford Area Hydrocarbon Plume Site Hartford, Illinois

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Superfund Triad Support Team

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Foreword

This document is one in a series designed to provide information about innovative technologies and approaches that support less costly and more representative site characterization. These documents include reports about new technologies as well as novel applications of familiar tools or processes. They are prepared to offer operational experience and to communicate information about ways to improve the efficiency of data collection at hazardous waste sites.

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ACRONYMS AND ABBREVIATIONS

AOC	Administrative Order on Consent
bgs	Below ground surface
CCD	Charged-coupled device
Clayton	Clayton Group Services
CPT	Cone penetrometer test
CSM	Conceptual site model
DNAPL	Dense nonaqueous phase liquid
EPA	U.S. Environmental Protection Agency
Hartford site	Hartford Area Hydrocarbon Plume
HSA	Hollow stem auger (HSA)
HS	Heavy sheen
HWG	Hartford Working Group
IEPA	Illinois Environmental Protection Agency
ITRC	Interstate Technology Regulatory Council
LED	Light-emitting diode
LIF	Laser induced fluorescence
mg/m^3	Milligrams per cubic meter
MIP	Membrane interface probe
MS	Moderate sheen
NAPL	Nonaqueous phase liquid
NS	No sheen
OSC	On-scene coordinator
OSRTI	Office of Superfund Remediation and Technology Innovation
PAH	Polynuclear aromatic hydrocarbons
PID	Photoionization detector
Praxis	Praxis Environmental Technologies, Inc.
RCRA	Resource Conservation and Recovery Act
ROI	Radius of influence
ROST	Rapid Optical Screening Tool
scfm	Standard cubic feet per minute
SS	Slight sheen
START	Superfund Technical Assessment and Response Team
SVE	Soil vapor extraction
TCE	Trichloroethylene
Tetra Tech	Tetra Tech EM Inc.

UVF	Ultraviolet fluorescence
VMP	Vapor monitoring points
VOC	Volatile organic compound

1.0 INTRODUCTION

Tetra Tech EM Inc. (Tetra Tech) prepared the following work products and related suggestions on integration of the principles of the Triad approach at the Hartford Area Hydrocarbon Plume (the Hartford site) in Hartford, Illinois. Tetra Tech prepared this document through its support to the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI), and in cooperation with the Superfund Technical Assessment and Response Team (START) and EPA Region 5. Intermittent fires related to vapor intrusion and odor complaints at the Hartford site have affected residences throughout the Village of Hartford. Subsequent investigations by a group of potentially responsible parties, known as the Hartford Working Group (HWG), have detected extensive hydrocarbon contamination beneath the site. The suggestions provided in this report are intended to provide input to the HWG so characterization and remedial design can be optimized.

1.1 THE TRIAD APPROACH

The START project team submitted a request for OSRTI to evaluate the planned approach for field activities to be conducted at the Hartford site, and in particular, to review the results obtained using a cone penetrometer test (CPT) equipped with the Rapid Optical Screening Tool (ROST). OSRTI authorized Tetra Tech to provide a set of comprehensive suggestions about the project as a whole, keeping in mind the most urgent needs at the Hartford site and the principles of the Triad approach. This assignment was based on review of on-going project documents and subsequent discussions with the Region 5 on-scene coordinators (OSC) and State of Illinois Environmental Protection Agency (IEPA) representatives. The suggestions provided are intended as a starting point for refining the existing conceptual site model (CSM) for the Hartford site so that an effective remedy can be designed and implemented as quickly as possible.

The Triad approach emphasizes the need for an aggressive, up-front systematic planning process to integrate dynamic work strategies and real-time measurements during site characterization and remedial design to streamline the cleanup process. The Triad approach also stresses a continuously refined, interactive process that relies on innovative technologies and strategies to increase the weight of evidence generated to support decision-making at environmental cleanup sites.

OSRTI is promoting the Triad approach as a means for streamlining site characterizations and remediation to improve cleanup decisions at Superfund, Resource Conservation and Recovery Act

(RCRA), Brownfields, and other revitalization sites. The Triad approach is becoming more widely accepted and used by many EPA regions, states, and local governments. The principles and tools used with the Triad approach have been demonstrated to reduce schedules and budgets required to reach project milestones at many sites across the country. OSTRI has forged partnerships with the U.S. Department of Energy, the U.S. Army Corps of Engineers, and the Interstate Technology Regulatory Council (ITRC). These partnerships have been forged to document use of the Triad approach at small and large sites to expedite reaching project milestones more quickly and economically while increasing the level of confidence in project decisions.

1.2 BACKGROUND

The Hartford site is located in the northern portion of the Village of Hartford, Illinois, along the historical edges of the active Mississippi River channel (Figure 1). Activities are currently being carried out at the Hartford site to mitigate hazards from vapor intrusion identified within the limits of the Village of Hartford. From 1966 through 1990, intermittent house fires occurred along East Watkins Street, East Date Street, and several other streets. More recently, homeowners have registered complaints about petroleum hydrocarbon odors that triggered the need to temporarily relocate the occupants of several households. Because of the concern related to petroleum hydrocarbon odor, EPA identified project objectives that included implementing effective short- and long-term vapor mitigation measures and delineating free phase and vapor phase hydrocarbons to support final remediation objectives.

A series of documents were reviewed in preparing this report. The documents Tetra Tech reviewed primarily address the geology and hydrogeology of the site, characterization and delineation of hydrocarbon impacts at the site, and mitigation of vapor intrusion. The suggestions provided in this report were prepared based on information obtained from references listed in the bibliography provided as part of this report. Clayton Group Services (Clayton) also provided valuable support in terms of raw data and files required to prepare these suggestions.

Tetra Tech's OSRTI support staff became involved at the Hartford site in February 2004. The data provided in this revised report were updated to include results available as of February 2006. Overall conclusions presented in this report have also been updated based on more recent results and reports.

In support of the project team's objectives as stated in various work plans, Tetra Tech compiled the attached figures to support development of a refined CSM for the Hartford site. A Triad systematic planning process relies heavily on the CSM as the primary tool to focus activities where they can provide the greatest value to decision-making and be used to identify data gaps, which may need to be filled to achieve project milestones. The CSM is also used to identify an optimal sequence of activities.

Many practitioners are accustomed to using specific types of CSMs, such as a geological or hydrogeologic CSM or a pathway-receptor diagram as is often used by the risk assessment community. Triad practitioners use these forms of a CSM, along with others. A Triad-type CSM also identifies the decision logic: a systematic process to identify and refine project decisions. Factors such as source geochemistry, the nature of any possible remedies, and practical considerations are weighed in establishing the most efficient and logical sequence of activities needed to address project issues and reach project milestones.

1.3 PROJECT OBJECTIVES

Tetra Tech has identified the following project requirements based on a review of the Administrative Order on Consent (AOC) and on discussions with the project team:

- "Abate any imminent and substantial threat to the public health or welfare in the area. More specifically any threat to fish, shellfish and wildlife, public and private property, habitat, and other living and nonliving natural resources" (Article 3 of the order).
- "Specific attention is to be paid to the investigation of the source and extent of contamination, implementation of EPA approved interim measures, and design of an active recovery system designed to abate the on-going threat of discharge to the Mississippi River" (Article 38 of the order).
- "Conduct a vapor extraction pilot test and provide options for improving and extending the existing vapor control system" (Article 43 of the order).
- "Implement a sentinel well monitoring program" (Article 47 of the order).
- "Establish the extent of dissolved phase hydrocarbons" (Article 51 of the order).
- "Identify preferential pathways such as utilities and pipelines and establish the extent of vapor phase and free phase hydrocarbons which could be impacting human health and the environment at the Hartford site" (Article 52 of the order).

1.4 PRINCIPAL STUDY QUESTIONS

Tetra Tech developed the following principal study questions based on the stated objectives in the AOC and on review of historical data available for the Hartford site.

1. What are the key, geologic, hydrogeologic, source, and or preferred pathway related factors that might control:

   (a) The release of petroleum fuel related vapors that pose a potential threat to human health and the environment.
   (b) Migration of free product and dissolved phase contamination in and away from potential source areas?

2. How can these factors be used collaboratively along with design optimization tools to expedite installation of:

   (a) A vapor mitigation system?
   (b) A free product extraction system?
   (c) A release control and monitoring system for groundwater and surface water?

The following sections of this report examine elements of the preliminary CSM for the Hartford site and demonstrate how they relate to the principal study questions. The intent is to identify physical characteristics of the Hartford site that can facilitate planning additional investigations. As the preliminary CSM is refined, the scale of heterogeneity and variation in environmental conditions can be understood in sufficient detail as to support implementation of an effective remedy. In addition, a mature CSM will allow the project team to select appropriate sample locations and sample densities and apply innovative strategies in the most efficient way possible given the physical constraints of the project.

2.0 PRELIMINARY CONCEPTUAL SITE MODEL

Efforts to mitigate vapors and other adverse environmental conditions at the Hartford site will be guided by the project team's understanding of several key elements of the preliminary CSM. These elements of the preliminary CSM include, but may not be limited to, the following:

- Geology and hydrogeology beneath the Hartford site
- Thickness of free product and dissolved phase contamination and proximity to preferred pathways
- Chemistry and geochemistry of the free product and dissolved-phase contamination

Limited data are available on the chemistry and geochemistry of the contamination beneath the Hartford site; therefore, interpretive efforts focus on the relationships among the geology, hydrology, and contaminant distributions across and surrounding the Hartford site. Tetra Tech attempted to link potential preferred migration pathways with these factors to identify when and where additional investigation might be warranted. However, details on the configurations of underground utilities or sewer lines were not available when these suggestions were developed; therefore, this link was not fully developed. General suggestions are provided on the type and quantity of chemical and geochemical data needed to support implementation of an effective remedy at the site.

Tetra Tech has developed work products based on the data provided in the references associated with this report. The work products include a generalized regional cross section (Figure 2) to show the approximate relationship between the Cahokia Alluvium and the underlying Main Sand. The Cahokia Alluvium contains silty or clayey sand units of limited extent, such as the North Olive, Rand, and EPA Strata, as well as fine-grained silty clay layers. The position of the Hartford site on the cross section in Figure 2 shows the potential for hydrocarbon contamination to affect both surface water and potential drinking water aquifers adjacent to the site.

Figure 3 is an enlargement of the Hartford site area that shows the general relationships between specific sand units known to be present. The estimated groundwater flow direction is shown to be toward the Mississippi River and may vary significantly between individual sand units at the Hartford site.

Based on the limited piezometric surface data that are currently available, the direction of groundwater flow adjacent to the Mississippi River near the Hartford site can trend from directly toward the river to directly away from the river. The direction of groundwater flow may fluctuate in response to changes in the river's elevation and local groundwater pumping. Significant changes in direction of flow between aquifers over time is demonstrated by the potentiometric surface maps provided in *"Work Plan - Dissolved Phase Groundwater Investigation, The Hartford Area Hydrocarbon Plume Site"* (Clayton 2004d) Figures 2-5 through 2-10.

Figure 4 is a CSM prepared by compiling data from the *"FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois"* (Clayton 2004b) and results from the *"Site Wide Free Product Investigation"* (Clayton 2006b). Figure 4 shows site-specific geological relationships and the extent of hydrocarbon contamination identified along select cross sections indicated on the block layout shown in the upper left-hand corner. The blocks extend beyond the boundaries of the Hartford site to show expected geologic relationships; however, data were not available for the areas surrounding the Hartford site when this report was generated. Although CSMs of this type are useful, they also introduce an element of spatial bias in that only select cross-sections can be presented. This same bias is not as significant in the isopach and top of formation maps discussed later in this report and used for understanding key geologic, hydrogeologic, and contaminant relationships.

2.1 CURRENTLY IDENTIFIED REGIONAL DATA GAPS

Based on information provided by Clayton, free product does appear to be moving off-site to the northwest. Data available for the site have been improved over the last 18 months. Figure 5 shows the locations where ROST data have been collected. The extent of the free product plume and the associated dissolved-phase plume have been adequately delineated in terms of the nature and extent, but additional characterization may be necessary to finalize system design and optimization. Significant data gaps remain, particularly in the design of optimized soil vapor extraction and product removal systems.

2.2 GENERAL SUGGESTIONS FOR FILLING REGIONAL DATA GAPS

ROST data have been collected in upgradient source areas from beneath the Premcor refinery (Clayton 2006b), but similar investigations are needed for other surrounding properties to assure that any proposed remedies are reliable. Historical information on upgradient sources should also be compiled as available.

Data for soil and groundwater in down gradient areas have been used to delineate the extent of the dissolve phase associated with the product plume (Clayton 2006a). A higher density of data is needed around source areas where geologic conditions are favorable for vapor intrusion and product removal is possible to improve the efficiency of the soil vapor extraction (SVE) and product removal systems. The specific locations and types of data suggested for collection in and immediately surrounding the Hartford site are also discussed in more detail later in this report.

2.3 GEOLOGY, HYDROGEOLOGY, AND CONTAMINANT DISTRIBUTIONS

According to "*Sedimentary Environments: Processes, Facies and Stratigraphy,"* (Reading 1996), the depositional environment beneath the Hartford site can be thought of as a mixed load river avulsion zone. The Hartford site is located in an area where the Mississippi River has shifted its position in recent geologic time, in a process referred to as an "avulsion" of the river channel. An avulsion occurs when the river breaches its natural levee and cuts a new channel in the floodplain. The river bed load is called a mixed load because widely variable sediment grain size — ranging from finer-grained levee deposits to coarse sands — can be deposited across a broad avulsion band such as is shown in Figure 6. These fluvial processes create a highly heterogeneous sediment package.

The typical sedimentary sequence includes thick sequences of sheet-like channel sands, lenticular splay sands, fine-grained levee, and floodplain deposits. Figure 7 depicts the variety of deposits that are generally associated with fluvial deposits in a major river avulsion band. Figures 6 and 7 are schematic diagrams and are not site-specific, but near-surface fine-grained sediments generally grade with depth to massive sands units. Although the cross section shown in Figure 7 is theoretical, site-specific cross sections provided in the *"FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois"* (Clayton, 2004b) seem to concur with this generalized geologic sequence. Keeping in mind the two principal study questions, this geologic setting suggests that better delineation of fine-grained sediments will yield important information on locations where vapors might be expected to be present at the highest concentrations. Fine-grained sediments can be substantial barriers to vapor-phase, as well as free-phase and dissolved–phase, hydrocarbons. Finer-grained sediments can also act as long-term source locations and pose significant challenges to source mitigation.

Tetra Tech's experience with free-product sites suggests that addressing coarse-grained contaminated aquifers without also addressing contamination in fine-grained sediments will reduce the effectiveness of a remedy. For example, applying high vacuums to coarse-grained sands can remove substantial quantities of free product from the sand units. However, once the system is turned off, residual contamination bound to fine-grained sediment units can re-contaminate the aquifer.

Based on the schematic diagrams shown in Figure 6 and 7, sands tend to thicken and merge toward the present-day river and can be in direct hydraulic communication with the river. Therefore, dissolved phase contamination may be discharged to the river. Thick sections of more fine-grained materials or levee deposits are also expected around the edges of the former channel sand deposits. Currently, vertical and lateral piezometric, geologic, and contaminant distribution data are insufficient, both inside and outside of the Hartford site boundaries, to begin to construct a detailed regional CSM adequate to address the requirements stipulated in the AOC for the Hartford area.

2.3.1 ROST Results, Contaminant Transport, and Source Areas

The response of the ROST to petroleum hydrocarbon contamination can be roughly correlated with the presence or absence of product (Tetra Tech 2004). With this in mind, the ROST responses (as shown as red, yellow, green and blue color bands depending on the range of hydrocarbons) in Figure 4 can be examined to distinguish primary sources from areas where contaminant migration may have resulted from transport of free-phase hydrocarbon along the top of the water table. Product source areas are generally indicated by ROST responses at depths at the surface to 10 feet below ground surface (bgs), depending on whether the release is suspected to have occurred at the surface or below a buried pipeline. From a review of Figure 4, it is apparent that source material (above 20 feet bgs) is present primarily along the eastern, western, and northern edges of the Hartford site. One exception is the area beneath the river pipeline that runs along Elm Street. New ROST data in this area also indicate the presence of free product at depths starting at approximately 8 feet. Most of the other product contamination indicated in the ROST responses is present near the water table or the smear zone, which is defined as the region where the upward and downward fluctuations in the groundwater table spread hydrocarbon contamination across a greater vertical interval of the soil. It is anticipated that additional surface source areas will be identified as the density of data for the site increases.

2.3.1.1 ROST Results and Product Recovery Challenges

As discussed in many of the reports reviewed in preparing these suggestions, most of the recorded incidents of fire and odors occur during high stands in groundwater. A review of Tables 2-1 through 2-3 of the work plan (Clayton 2004a) suggests that free product thickness can increase dramatically as water levels rise. This relationship is particularly evident at well HMW-22, suggesting that product recovery may need to focus on wells screened across intervals that correspond to high stands in water levels. Water is sometimes used to enhance the secondary recovery of petroleum in an oil field, although, fluctuations in water levels may also act as a hydraulic pump to enhance product recovery.

The relationship of apparent hydrocarbon sources to minimum and maximum groundwater levels can be used to focus areas where different types of cleanup might be most effective. For example, vapor extraction technologies could be used with only a minimal need for direct free product recovery in areas where little or no source material is located at or below a low stand in groundwater if the product present is in the gasoline range. Conversely, the focus of cleanup efforts might be on collecting free product during high stands in the water table where source material is present in the smear zone or below the water table. However, it is important that current efforts focus on monitoring both changes in water levels and in observed free product thickness on a finer scale than in the past.

At present, the project team has installed nested piezometers or extraction wells in each of the primary sand units and screened them across the upper portion or across the entire sand unit where the thickness permits (Clayton 2004b). This strategy may be inefficient, however, based on the observation that much of the free product underlying the Hartford site is likely present in the smear zone below the upper sand units. Free product recovery should be directed at those areas where thick columns of product are observed and should focus on design of a recovery system that target zones for removal based on geologic conditions and the proximity of product and the water table.

It is apparent from the ROST response observed in potential near-surface source areas, such as are indicated near ROST locations HROST-6 and HROST-10, that near-surface source areas are limited in extent. However, the heterogeneity of these areas indicates variation on a finer scale than can be understood based on existing ROST results. Therefore, additional characterization is needed before near-surface source areas can be addressed adequately. Outside of near-surface source areas, it may be possible to define regional trends in geology, hydrology, and product thicknesses and then to design free product removal and vapor intrusion mitigation systems on a more regional scale.

2.3.2 Sand and Clay Isopach, Formation Top, and Free Product Thickness Maps

Tetra Tech has developed top of stratum and hydrocarbon product thickness maps and top of formation and product ROST response maps (Figures 8 through 16) for each of the four major strata (North Olive, Rand, EPA, and Main sands) and the silty clay units that separate them. In addition, Tetra Tech prepared maps that show the top of free product (heavy, mid-range, and light range) and total product thickness (Figure 17 and 18). These maps were developed to identify (1) areas where vapor intrusion issues might be greatest, (2) areas where design of a product extraction system may be warranted, and (3) areas where monitoring the dissolved-phase plume or where additional characterization is needed. An isopach map of the total silty clay (Figure 12) has been developed, along with a map to indicate where the sand units may intersect known potential preferred pathways such as sewer lines and other buried utilities (Figure 19), as a first attempt at a more sophisticated level of interpretation.

Figure 19 is an example of the type of work product that could be important, as the CSM is refined. The geologic, hydrogeologic, and contaminant characteristics provided in Figures 8 through 18 can be combined on composite maps to drive a dynamic work strategy and guide future investigations. However, any additional integration of the materials presented or discussed in this report is beyond the scope of the support available through OSRTI to the Hartford Working Group and EPA Region 5.

The potential for vapor intrusion is likely highest where the uppermost extents of permeable sand units are closest to the surface, the total thickness of fine-grained alluvial deposits is lowest, and the total thickness of sand and product is the greatest. The maps discussed in the following sections attempt to identify specific geologic, hydrogeologic, and free product relationships that could directly influence the fate and transport of free product, distributions of vapor-phase contaminants, and distributions of dissolved-phase hydrocarbons.

2.3.2.1 North Olive Sand Maps

It appears that the North Olive Stratum thins across the central portion of the Hartford site and terminates here (i.e pinches out). Figure 8 shows the isopach thickness of the North Olive Stratum. This pinching out suggests that the North Olive Stratum is not in direct hydraulic communication with either the Rand or Main Sands except in the southeastern portion of the site, where the North Olive merges with the Main Sand. Free product or vapors within the North Olive unit cease beyond a point, as suggested by the general relationship between reported fires and the extent of the North Olive stratum.

Product was also detected in ROST locations HROST 51 and HROST 52 (Figure 8), where the North Olive merges with the Main Sand. Therefore, the potential for direct communication of contaminants from the North Olive Stratum into the Main Sand, or vice versa, exists in this area. Multiple fire events have occurred in this area.

As mentioned previously and as shown in the isopach of the North Olive Stratum in Figure 9, areas where fires have been historically reported across the Hartford site seem to correspond with areas where a measurable thickness of the North Olive Stratum has been mapped. It has also been observed that the silty clay layers thin out above the Main and Rand strata in this area.

2.3.2.2 Rand Stratum Maps

The Rand Stratum merges into the Main Sand adjacent to the eastern boundary of the Village of Hartford, as shown in Figure 10. Figure 11 presents the thickness of the Rand Stratum in feet. Contamination within the Rand Stratum in the southeastern portion of the site could therefore easily migrate in the vapor or free phase from the Rand Stratum into the area enclosed by the 12-foot bgs contour in the Main Sand. A potential also exists for contamination within the Rand Stratum near ROST locations HROST 26 and 33 (Figure 5) to migrate up into the structural high in the Main Sand shown in the north-central portion of the village.

Evaluation of the isopach of the silty clay above the Rand and Main sands further supports why fires have not been recorded in and around ROST locations HROST 23 and 24 (Figure 4). The silty clay in this area thickens to nearly 20 feet (Figure 12). The thickness of the silty clay above the Rand or Main Sand is generally less than 12 feet and the North Olive Stratum is also present throughout the area where fires have been recorded.

The thickening of the clay in this area may indicate that the need to mitigate vapors may be less urgent. However, the hydrocarbons appear thickest in this area. Product recovery in this location may be warranted because of the potential for product to move from this area toward the northwest, where the silty clay unit thins dramatically and fires have been reported.

2.3.2.3 EPA Stratum Maps

The EPA Stratum is limited in extent, as shown in Figures 13 and 14. However, contamination in the EPA Stratum would migrate directly up into the Main Sand in the northwest portion of the Hartford site.

2.3.2.4 Main Sand Maps

An isopach of the Main Sand could not be created because it represents the basal glacial outwash sand unit, which extends down to the limestone bedrock in the area. Stratigraphic information on the bottom of the unit is not available. An isopach of silty clay between the EPA stratum of Main Sand and the Rand stratum or the North Olive stratum is presented in Figure 15. The contour map of the top of the Main Sand (Figure 16) shows a northwest-trending structural high along the approximate axis of fires reported in the southern portion of the affected region beneath the village. This structural high is crudely aligned along the expected flow direction in the Main Sand, as depicted in the work plan (Clayton 2004d). This northwest-trending feature in the Main Sand suggests that a principal area of concern for contaminant migration away from the site could exist northwest of the current site boundaries. Migration of dissolved- and free-phase constituents might be expected downgradient of this structural high along the regional northwest direction of flow within the Main Sand. As will be discussed later in this section, product appears to extend off site and downgradient along this northwesterly trend (Clayton 2006a). The impacts from the presence of product west and north of the village are not thought to immediately affect the current remedial design efforts and are therefore not discussed further in this report.

2.3.2.5 Light Range Petroleum Hydrocarbon Maps

A large high in the top of the ROST response for lighter hydrocarbons is present along Elm Street (pipelines run from the refinery to the river along Elm Street). Figure 17 shows the approximate extent of lighter range, lower boiling point fuels in combination with the top of the ROST response. The depth of the response appears to coincide with the approximate depth of the pipelines in this area. Numerous spills have been recorded in this area and historical records for the pipelines indicate that these lines could have leaked throughout the history if their use.

Heavier hydrocarbons have a greater peak height at higher wavelengths of absorbance, as indicated by greater peak heights on the right-hand side of the ROST output file (the dwell profile). When peak heights are greater on the left-hand side of these dwell profiles, the fuel at this spot in the contaminant plume is likely made up of hydrocarbons such as gasoline, which have lower boiling points, usually considered light range hydrocarbons. Diesel fuels might be considered a mid-range hydrocarbon product with greater peak heights in the center of the profile. Motor oil or weathered product, which has been in the ground for extended periods, is usually considered a heavy range hydrocarbon product. Based on the general results shown in Figure 17, it appears that the preponderance of hydrocarbons present across the site are in the gasoline range.

2.3.2.6 Mid-Range Petroleum Hydrocarbon Maps

The distribution of mid range hydrocarbons shown in Figure 17 seems to indicate the potential for the presence of two source areas for this type of petroleum product. One is located along the northeastern boundary of the site near ROST location HROST 6 and 10 and another is located near the northwestern boundary of the site near HROST 2. The nature and extent of mid-range hydrocarbons may influence their treatability and their tendency to cause vapor intrusion and will therefore need to be examined more closely. The specific chemistry and constituent makeup of each of the source types identified should be examined to determine: (1) site-specific action levels for vapor intrusion, and (2) site-specific action levels that can be used to assess the need for removal. These action levels will be driven by the chemistry and type of potential associated risk or hazard identified for the area of interest within the site.

2.3.2.7 Heavy Range Petroleum Hydrocarbon Maps

Figure 17 shows the limited extent of heavier range hydrocarbons at the Hartford site. As expected, the extent does not generally correspond to areas where fire hazards have been reported. Since heavy hydrocarbons products tend to sorb to the soil and are generally more viscous, they have less of a tendency to migrate away from primary source areas. Primary concerns in these areas should be focused on limiting the potential for direct contact. Chemicals of potential concern in surface soil in this area might include polynuclear aromatic hydrocarbons (PAH). A close inspection of the ROST profiles in this area does indicate the presence of light hydrocarbons beneath these apparent heavier hydrocarbon source areas.

2.3.2.8 Total Petroleum Hydrocarbon Map

Figure 18 shows the extent of the total ROST response to all three ranges of hydrocarbons. The largest thickness in ROST response is along Elm Street. This supports the large high in the ROST response of lighter range hydrocarbons in that same location.

2.3.3 Interaction of Shallow Stratums with Sewers and Utilities

Tetra Tech prepared Figure 19 to identify areas where preferred pathways (sewers) might intersect permeable stratum units, allowing hydrocarbons to accumulate at shallow depths. Figure 19 shows the location of product pipelines, municipal sewer mains, and shallow stratum units (with upper extents above 12 feet bgs). The map identifies the upper extents of shallow sand intervals (primarily the North Olive Stratum, but also the Main Sand in the southern portion of the Hartford site). The 12-foot bgs contour shown in this figure is significant because the depth of buried pipelines is approximately 12 feet bgs, as noted in the "*Utility and Pipeline Investigation Work Plan, the Hartford Area Hydrocarbon Plume Site"* (Clayton 2004f). This work plan did not indicate the depth of the municipal sewer mains, but it can be assumed that they are above the 10-foot bgs contour. Notably, a sewer main crosses the 8- to 10-foot bgs contour interval in the eastern portion of the village. Five buildings where fires have been reported are located within 100 feet of this sewer main. This map, like those previously discussed, should be considered when the working group prioritizes locations where sewer and utility investigations and design-related activities are planned. The HWG also may consider using the presence or absence of light or mid-range free product in the shallow sand units as a means of prioritizing when and where to focus remediation efforts for sewers and utilities.

2.4 HYDROCARBON CHEMISTRY AND GEOCHEMISTRY

The chemistry and geochemistry of hydrocarbon product, geologic formations, and groundwater beneath the Hartford site will have a strong influence on the effectiveness of any remedy. These and other physical factors such as moisture content, permeability, and effective porosity should be used in conjunction with one another to support the design of any potential remedy. The HWG has not focused on the chemistry of the product found beneath the Hartford site up to this point, as is indicated by responses to comments provided by Clayton to EPA Region 5 dated June 21, 2004, and titled *"Letter to USEPA Region 5. Response to Comments to ROST Investigation Report and Work Plan."*) The response to U.S. EPA comment 1 part A, second sentence states, *"It is Clayton's opinion, based on experience at other petroleum sites, that the design of the remediation system will be primarily based upon geology of the area and the amount of product present not the type of product"* (Clayton 2004e).

Ignoring product-specific chemistry during remedial design could limit the effectiveness of any cleanup strategy. The petroleum industry has long recognized that the nature of various petroleum products can pose different challenges to extraction of petroleum from an oil reservoir. Heavier products often require more aggressive techniques to extract. For example, methods such as steam-enhanced recovery have been developed to address removal of heavier hydrocarbons where simple flooding methods have proven ineffective.

Not only is further characterization of the nature of the product necessary; the physical properties of the petroleum hydrocarbons need to be understood so their fate and transport can be estimated and input to a model to support the evaluation of impacts to surface water in the area. Further characterization of the product is also suggested to support risk estimation and development of field-based action levels related to both vapor intrusion and dissolved-phase fate and transport issues.

For example, one of the questions at the Hartford site is the impact of removing the free product and dissolved-phase hydrocarbons will have on vapor intrusion. This issue is chemistry related. Petroleum hydrocarbons consist of complex mixtures of carbon, hydrogen, ammonia, sulfur compounds, and other constituents, such as lead and oxygenates, used to improve fuel performance. Each mixture has a susceptibility to treatment at a particular moisture level in soil that is related to its Henry's Law constant. Therefore, the composition and physical properties of the mixture can affect the removal rate and estimated risk. Liquid-phase removal may also be affected by the chemical and physical properties of the free product, such as its tendency to form a physical or chemical emulsion that will be difficult to treat. Detailed data on chemistry, geochemistry, and physical properties are needed to design a system and then predict whether it can be successful in mitigating vapor or dissolved phase-related hazards.

The HWG should consider implementing a robust chemical, geochemical, and physical properties characterization effort to begin to understand differences in product chemistry. The analytical suite should include, but not necessarily be limited to, the following:

- Volatile organic analyses (using method 8260)
- Semivolatile organic analysis (using method 8270)
- PAH analyses (using modified method 8270 operated in the selective ion monitoring mode)
- Viscosity and density analyses
- Porosity, permeability, grain size, total organic carbon
- Nonaqueous phase liquid (NAPL) saturation
- Cation exchange capacity

In addition to these chemical and physical property analyses, site-specific testing in the form of core column tests might be considered. These tests can also be performed in situ using innovative tools such as the Praxis Environmental Technologies, Inc. (Praxis) PneuLog, which allows for the design of the SVE removal system to be optimized once a system has been installed. Since there is an existing system on site, this technology might be immediately applicable.

Core column studies may be conducted when there are significant questions on the applicability of one of several alternatives for treatment, such as in the area near ROST location HROST 2. Pilot testing with PneuLog could be used to optimize and expand an existing system design in areas where SVE already appears to be the logical alternative, such as the area surrounding HROST 51. Chemical data, along with concentrations present, should be used to estimate any risk that requires treatment. Additional information on the use of core column and well product removal pilot testing can be made available from Tetra Tech on request.

3.0 SUGGESTIONS FOR OPTIMIZING CLEANUP SYSTEM DESIGN AND IMPLEMENTATION

In the review of the primary study questions and the information presented thus far in this report, the working group faces the following issues at the Hartford site that will eventually need to be addressed:

- Immediate physical hazards, such as fires that result from vapor intrusion
- Impacts to human health from vapors
- Impacts from contaminated soil in the vadose zone to groundwater
- Impacts to groundwater from free product in the smear and saturated zone
- Impacts from dissolved- and free-phase hydrocarbons to surface water

A robust set of suggestions for each of these issues is beyond the scope of the support that Tetra Tech can provide under its current assignment for OSRTI. Therefore, the focus in this section is on providing general observational data and suggestions for most of the key elements that should be evaluated. HWG can then more fully evaluate the types of specific activities and decisions that will need to be made.

Installing and sampling vapor monitoring probes (VMP) is under way at the Hartford site to evaluate the potential hazards and risks to human health from vapors. The maps and suggestions provided by Tetra Tech in this document are intended to identify areas where the interaction among the sewer and utility system, geologic features, and free product should be further evaluated through VMPs. In addition, the maps and suggestions provided indicate where free product may be collecting in stratigraphic traps, such as the area near ROST location HROST 51. Tetra Tech believes this area might be more amenable to SVE than other areas where the presence of more fine-grained materials might pose a challenge to the use of SVE. Suggestions are also provided that identify areas where free product extraction should be the focus of the HWG efforts. Free product extraction may be warranted where free product is found at the greatest thicknesses (Figure 18) and has the greatest potential to continue to contribute to migration of dissolved-phase contamination away from source areas.

The current data set lacks sufficient information on hydrology and the chemistry and spatial distribution of contaminants to support the design of a free product extraction or dissolved-phase monitoring and treatment system. Therefore, this section discusses use of collaborative data sets and similar approaches to optimize the design of the vapor extraction system, investigate the dissolved-phase contamination, evaluate methods to remove free product from the smear and saturated zones, and implement an integrated monitoring system to track the progress of the remedial action.

3.1 SOIL VAPOR EXTRACTION SYSTEM DESIGN AND OPTIMIZATION

As mentioned previously, SVE may be an effective alternative in source areas at the Hartford site, particularly where free product is present above the water table and geologic conditions are favorable. PneuLog is a technology designed to reduce long-term operational costs and accelerate cleanup by optimizing SVE systems in unsaturated zones. The PneuLog technology uses in-well instrumentation to measure air permeability and contamination production continuously throughout an extraction well within the screened interval during SVE. This technology is intended to improve the assessment of geologic heterogeneity within the screened intervals of individual wells and identify mass transfer constraints in the vadose zone. Data from several wells can be used to optimize a cleanup strategy and estimate operation times needed to meet closure requirements.

Tetra Tech proposes using PneuLog technology to support the evaluation and optimization of any SVE systems planned for the Hartford site. Tetra Tech suggests that a dynamic work strategy may be used as an alternative to the traditional phased approach to limit the need for mobilizations and thus streamline product removal and vapor mitigation. The PneuLog technology can be used not only to target zones with the highest concentration in vapors; it can also be used to size pumps where contamination in concentrated in fine-grained soils. In contrast, conventional SVE design and optimization procedures rely on empirical data that do not adequately evaluate mass transfer constraints, limiting the effectiveness of the remedy. As a result, conventional systems may be overbuilt, inefficient, and expensive to operate.

The PneuLog approach incorporates short-term SVE testing with pneumatic well logging to delineate the horizontal and vertical extent of contaminants and quantify the permeability of soils throughout the screened interval. The PneuLog test is repeatable, and multiple deployments can track the progress of cleanup when combined with technologies such as passive or active soil gas surveys and vapor probe analysis in a collaborative data set. When used in a number of wells, this approach provides a more complete and accurate baseline evaluation for design and optimization of SVE systems. In addition, data on soil permeability and airflow rate data provided by PneuLog can be used in models to estimate removal action timeframes.

3.1.1 Traditional Vadose Zone Profiling and Monitoring Techniques

Traditional methods of delineating vadose zone contamination to implement SVE involve soil gas surveys and multipoint vapor probe sampling. Traditional methods of developing vertical contaminant profiles involve installing discrete VMPs at multiple depths at a single location. Similarly, traditional methods of developing lithology profiles require continuous split spoon sampling. SVE pilot testing is used to develop soil vapor production rates, contaminant concentrations, and radius of influence (ROI) information on a site-wide scale.

Before an SVE system can be constructed, the following types of data should be collected at specific targeted locations within the Hartford site at a density sufficient to characterize the heterogeneity of the hydrogeologic setting:

- Contaminant type and associated volatility
- Permeability of the soil
- Soil structure and stratification
- Soil moisture content
- Depth to groundwater and changes in product thickness and water level over time

The following sections briefly summarize methods Tetra Tech suggests for horizontal and vertical profiling of the vadose zone.

3.1.2 Soil Sampling

Vertical profiling is an important component of site characterization and CSM development. Before cleanup technologies for soil treatment can be evaluated, a site is usually investigated to characterize the geology and vertical distribution of contaminants on a site-specific scale. Lithologic and geotechnical parameters are usually collected at various depth intervals. New tools such as the membrane interface probe (MIP) and other real-time sensors, or near-continuously reading instruments such as PneuLog, are changing existing ideas about how contaminants are distributed in the environment. Small-scale heterogeneity seems to be the rule, rather than the exception, and can severely impair the effectiveness of a remedy.

Soil structure and stratification are important to the effectiveness of SVE because they affect vapor flow within the soil matrix under SVE conditions. For instance, it is widely accepted that SVE is generally less effective in moist, silty, or clayey soils. Structural characteristics (such as layering and fractures) can create preferential flow pathways that can short-circuit SVE systems, resulting in extended remedial timeframes if the extraction points are positioned such that the induced airflow bypasses the area of contamination.

Soil borings are typically completed using a hollow stem auger (HSA) or direct-push probe such as a Geoprobe. These borings are drilled to collect a continuous soil sample and characterize the subsurface. Instruments can be deployed with direct-push drilling equipment that can record nearly continuous measurements of the soil's physical and chemical characteristics, resulting in development of a continuous vertical profile. The MIP technology provides a continuous log of soil conductivity and the volatile organic compound (VOC) concentration as it is driven into the soil. The Simulprober technology is a modified split spoon sampler that can also be used with conventional direct-push drilling techniques and is intended to collect continuous soil and soil gas samples and conduct in situ single-point slug tests. These tools have significant limitations; an investigation must proceed with these limitations in mind and should not be conducted without consulting with an expert who has significant experience with these instruments.

3.1.3 Soil Permeability Testing

Permeability affects the rate of air and vapor movement through the soil: the higher the permeability of the soil, the faster the movement and (ideally) the greater the quantity of vapors that can be extracted. High moisture content in soils can reduce permeability and, consequently, the effectiveness of SVE by restricting the flow of air through soil pores. Fine-grained soils produce a thicker capillary fringe than coarse-grained soils. SVE is generally not effective in treating soils below the top of the capillary fringe. Pumps can be used to depress the water table; however, pumping to lower the water table is not feasible because of the volume of water in the aquifers beneath the Hartford site. Site-specific data on water levels and soil permeability will be integral in optimizing the effectiveness of SVE or when SVE is selected as the preferred remedial alternative. Combining this information with characterization data on a finer scale can help engineers understand the limitations of a proposed system. For example, a site where the CSM indicates contamination in the finer-grained portions of the soil profile may not be effectively remediated using SVE alone. This level of understanding on the potential for SVE as a remedy at specific locations within the Hartford site (such as near HROST-2) can be developed only by collecting data on soil permeability and contaminant concentration on a finer scale using pneumatic tests.

3.1.4 Vapor Monitoring Points

VMPs are the traditional method for developing initial vertical contaminant profiles at SVE sites and may also be used as a tool for optimizing existing systems. VMPs are constructed by installing several relatively short-screened interval wells separated by bentonite seals within a single borehole. VMPs are used to measure vertical variations of vapor-phase contaminant concentrations and pressure and vacuum response (and, indirectly, permeability) along the soil profile when they are placed at varying depth intervals. Soil vapor chemistry is assessed at each discrete depth interval by withdrawing and analyzing soil vapor samples. The vacuum pressure required to extract the soil vapor from each individually screened depth interval indirectly indicates permeability. Soil permeability dictates the amount of airflow. Relatively high airflow indicates higher permeability, and relatively low airflow indicates low permeability.

Continuous soil borings are typically used to install VMPs. This method can be labor intensive and does not yield a continuous soil profile. Optimal locations for these points are best identified using high-quality geologic, contaminant distribution, and pneumatic test data. Conducting MIP profiles or a headspace soil gas survey before the VMPs are installed can improve efficiency when vapor probes are designed and installed. Installing VMPs without these data can result in poor system design and ineffectiveness of the remedy.

3.1.5 SVE Pilot Testing

A pilot test is recommended for evaluating SVE effectiveness and design parameters at any site, particularly where SVE is expected to be only marginally to moderately effective. Data provided by pilot testing are necessary to properly design the full-scale SVE system. Pilot tests also provide information on the concentration of VOCs that are likely to be extracted during the early stages of operation of the SVE system.

Various extraction rates and wellhead vacuums must be evaluated to estimate optimal operating conditions. Pilot studies typically involve extraction of soil vapors for a short period (1 to 30 days) from a single extraction well, which may be an existing monitoring well at the Hartford site. However, longer pilot studies (up to 6 months) using more than one extraction well may be appropriate for larger sites. More information on methods for system operation can be found in *"Innovative Site Remediation Technology, Design and Application, Volume 7, Vacuum Extraction and Air Sparging"* (EPA 1998).

Vapor concentrations should be measured at two or more intervals during the pilot study to estimate initial vapor concentrations that may be expected during operation of a full-scale system. The vapor concentration, vapor extraction rate, and vacuum data should also be used in the design process to select extraction and treatment equipment.

Estimating the ROI of each extraction point is important for proper design of an SVE system. The ROI is defined as the greatest distance from an extraction well where a sufficient vacuum and vapor flow can be induced to adequately enhance volatilization and extraction of contaminants in the soil. Practitioners can increase their confidence that the pilot test design accommodates site conditions with better characterization methods and pneumatic logging techniques.

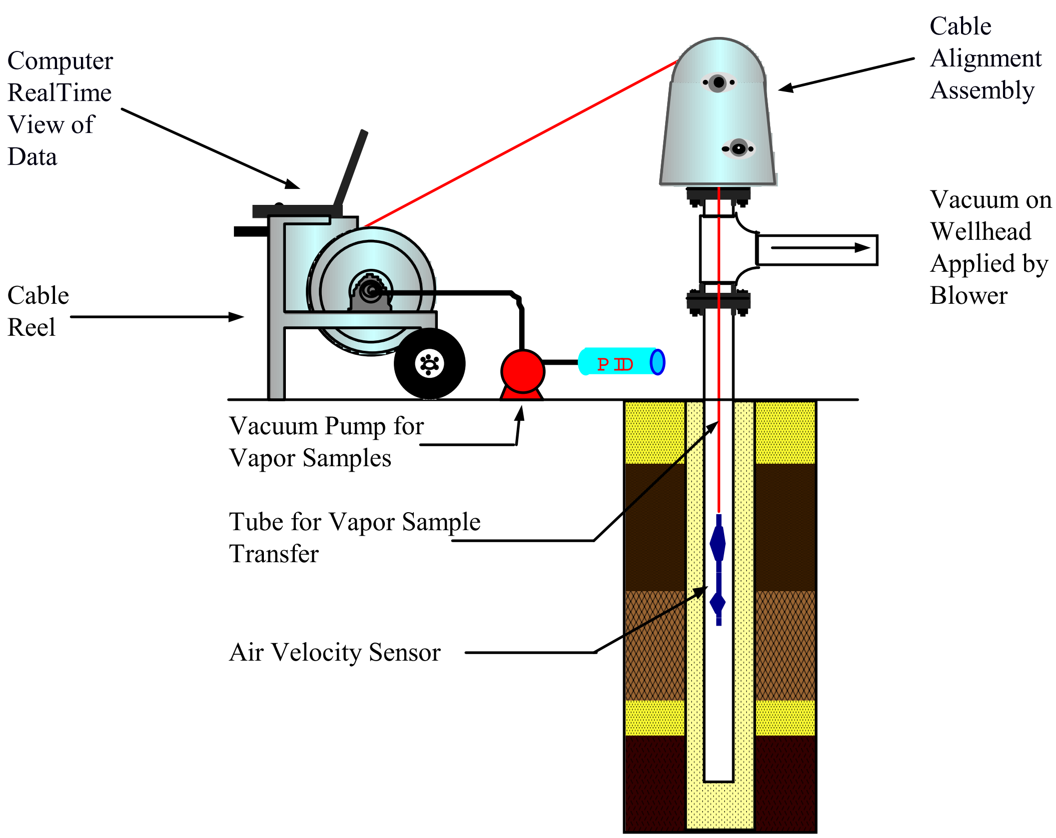
3.2 PNEUMATIC WELL LOGGING TECHNOLOGY

Pneumatic well logging is a technology developed by Praxis, which is designed to optimize SVE design and operation. Pneumatic well logging is performed by simultaneously measuring cumulative airflow and contaminant vapor concentrations vertically along the depth of an extraction well screen during active SVE. To record these measurements, a flow sensor is moved up through the well while vapor extraction and soil gas samples are continuously collected and analyzed. Collecting these measurements at a representative number of wells can yield a three-dimensional picture of the extent of soil contamination at a site as well as the distribution of soil permeability. These measurements, in conjunction with traditional sampling methods, can yield a more thorough understanding of a site and how an SVE system can be optimized. This more thorough understanding is possible because PneuLog technology provides information that other technologies cannot, such as soil permeability and mass loading of the vadose zone.

3.2.1 Equipment

The equipment used for PneuLog pneumatic well logging is illustrated in Exhibit 1. The PneuLog instrument is attached to a cable, which passes through alignment pulleys and a vacuum-tight fitting at the wellhead. The instrumentation is raised or lowered by a cable wound around a motorized reel. The logging proceeds at a rate of 8 feet per minute along the screen in the SVE extraction well. Sensors in the pulley assembly indicate the depth of the measurement. Electrical leads connect the flow sensor to a data acquisition system located on the motorized reel. A vapor sampling tube connects the sample port on the instrument to a vacuum pump, also located on the reel. The sampling pump draws a continuous stream of air through the sampling tube to the surface, where it is analyzed for VOCs and other compounds of interest (such as oxygen and carbon dioxide). A photoionization detector (PID) is used to provide a continuous reading of total VOC concentrations. Summa canister samples can be collected for off-site analysis by gas chromatography and mass spectrometry to estimate compound-specific concentrations at discrete depths and to calibrate the PID readings. Supplemental vapor samples can be collected in Tedlar bags and analyzed on-site with a field gas chromatograph.

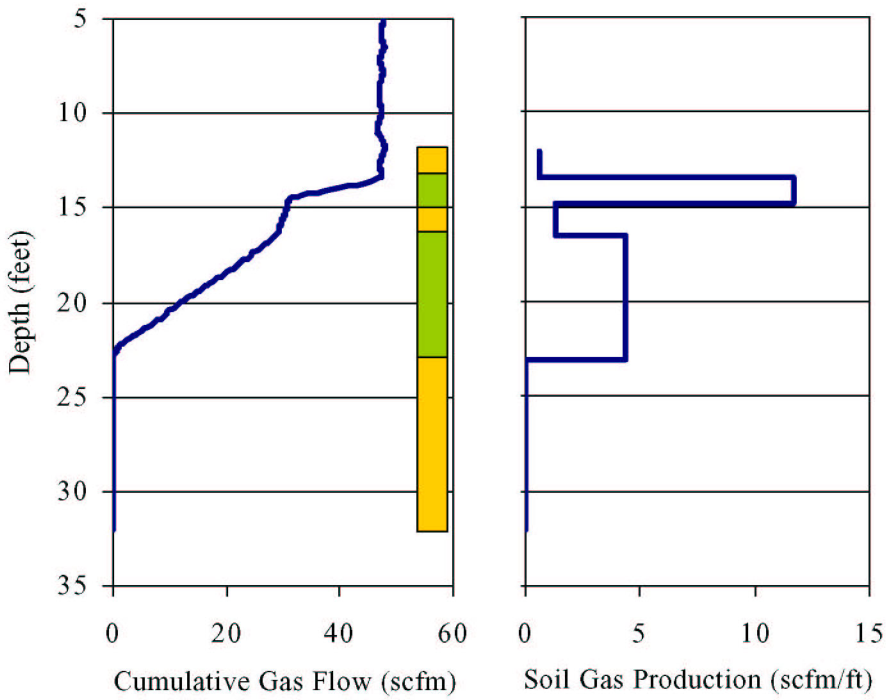
Exhibit 1: Schematic of Pneumatic Well Logging Equipment



3.2.2 Permeability Profiles

The airflow from each soil layer is related to the cumulative airflow by a simple mass balance. The cumulative airflow measured below the soil layer is subtracted from the cumulative airflow measured above the soil layer to calculate the airflow from a soil layer. The soil permeability of the interval is then determined from Darcy's law. The data and the analyses appear similar to output from borehole flowmeter testing in water wells. A typical cumulative gas flow measurement from PneuLog is provided in Part (a) of Exhibit 2, below. In this example, the well is screened from 12 to 32 feet bgs. As shown, the airflow from the bottom half of the well is essentially zero. The airflow increases steadily from 0 to 28 standard cubic feet per minute (scfm) between 23 and 16.5 feet bgs as the instrument is raised through the screen. The steady flow increase indicates this soil interval has a relatively uniform permeability to air. Only 2.5 scfm of soil gas are added from 16.5 to 15 feet. The volumetric flow increases by 15 scfm in the next 1.5-foot interval up to 13.5 feet. The top 1.5 feet of the screen adds only 1 scfm to the total.

Exhibit 2: Example Pneumatic Well Logging Results for Soil Permeability to Air



Part (a) Part (b)

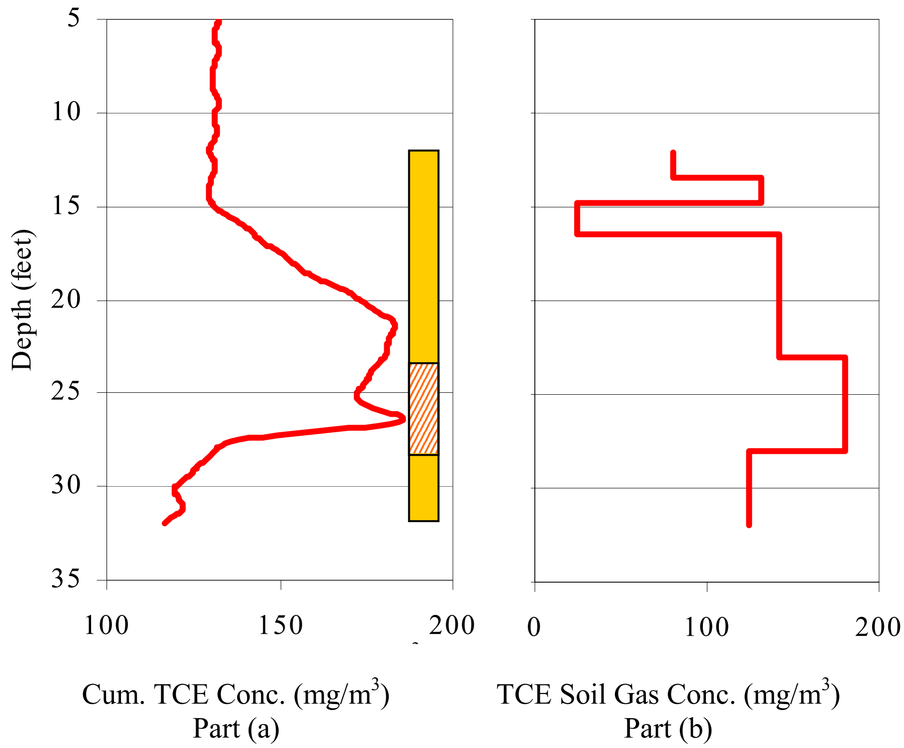
The diagrams present an interpretation of the cumulative flow measurements as soil gas production proceeded. An effective air permeability profile can be generated using the soil gas production profile with multi-dimensional analytical or numerical airflow models. The permeability of an interval is proportional to the change in flow across the interval, its thickness, its depth below the surface, and the well vacuum according to Darcy's law. Part (b) of Exhibit 2 reveals five soil strata along the screen. The permeability of the stratum intersected by the bottom half of the screen (yellow or light blocks) is relatively low since no measurable soil gas was produced. The geologist characterized the soil of this interval as silt. The air production rates for the soil intervals from 16.5 to 23 feet and 13.5 to 15 feet indicate coarse sand. These two sand intervals are separated by a 1.5-foot-thick silt interval. The soil at the top of the screen was also characterized as silt. This characterization of the physical properties is superior to a geological log and a typical air permeability test. The PneuLog results are usually consistent with the geologic observations; however, geologic logs provide little or no indication of potential air permeability. Without the pneumatic logging data, the permeability measured by typical testing is averaged over the screen interval and of the subsurface flow profile. It therefore cannot be quantified and well screens subsequently optimized.

3.2.3 Concentration Profiles

The measurement of VOC concentrations along the well screen indicates the distribution of VOCs in the screened interval. An example concentration log, which was collected simultaneously with the airflow log previously discussed, is presented in Part (a) of Exhibit 3, below. This concentration profile was obtained from a continuously reading PID that was calibrated to trichloroethylene (TCE) concentrations with on-site and off-site gas chromatographic analysis of vapor samples from discrete depths and the wellhead. The vapor concentration measured is lowest near the bottom of the screen and increases slightly up to a depth of about 28 feet. As the tool is raised higher in the well, the concentration increases sharply to a maximum at 26 feet and remains relatively high to a depth of 21 feet. The concentration then decreases steadily from 21 to 15 feet bgs. The concentration increases very slightly between 15 feet and the top of the screen.

The increases and decreases in concentration observed can be combined with the depth-specific air production in a mass balance to estimate depth-specific soil gas concentrations. The PneuLog device simultaneously measures the flow rate and concentration versus depth. The change in the product of these two variables over a specified depth interval divided by the flow change is equal to the contaminant vapor concentration in the soils of the depth interval. Application of this relationship to the data shown in Exhibit 3 Part (a) yields the contaminant vapor concentration profile presented in Exhibit 3, Part (b). The highest concentration occurs in the low-permeability material that underlies the deeper sand interval. This high concentration indicates that the low-permeability interval creates a mass transfer constraint to SVE.

Exhibit 3: Sample of Pneumatic Well Logging Results for Contaminant Product



Note: mg/m^3 = Milligrams per cubic meter

3.3 OPTIMIZING AN SVE SYSTEM AND IDENTIFYING SVE AS A VIABLE REMEDIAL ALTERNATIVE

As illustrated by this example, pneumatic well logging provides a more thorough and appropriate site characterization than will traditional methods alone. Repeating the process in a representative number of wells can generate a three-dimensional description of the physical and chemical subsurface by correlating between locations. The technique also provides higher-quality data that can be used to more effectively design and optimize an SVE system. Soil strata near or below cleanup goals are quickly identified, and the extraction flow rate can be reduced or terminated from these layers. The operation can then be focused on strata where contaminants remain at concentrations above cleanup goals. This optimization could lead to cost savings by accelerating cleanup and lowering operation and maintenance costs.

PneuLog can be used in conjunction with other new and improved methods of site characterization to build comprehensive data sets that can be used to evaluate when and if SVE is a viable alternative and even to decide when SVE is no longer needed. Real-time measurement technologies such as a MIP or laser induced fluorescence (LIF) provide contaminant distribution data that are independent of the permeability of the contaminated stratum. PneuLog, on the other hand, is biased by the permeability of the soil. Combining these two different types of data in a collaborative data set can provide practitioners with a better idea of whether SVE will be effective and the design specifications that are most appropriate.

3.3.1 Technology Assessment

Praxis developed the PneuLog technology to aid both site characterization and optimization of SVE systems. Tetra Tech's evaluation of this technology revealed several advantages and disadvantages. The primary advantages of this technology are as follows:

- A continuous vertical profile of contaminant concentration and soil permeability can be quickly developed for each SVE well on site. This profile represents average values for each major soil interval intersected by the vent well.
- The use of progressive extraction, vapor sampling, and pneumatic logging of the wells as they are installed will provide guidance for locating additional wells to more adequately characterize the Hartford site.
- The actual VOC concentrations in milligrams per cubic meter (mg/m^3) produced at specific intervals are measured.
- The permeability, flow rate, and total VOC production for a section of screened interval can be estimated. This information is useful in optimizing or modifying vent wells and for sizing blowers and vapor treatment equipment for new or modified SVE systems.
- The data are presented in a manner that is easy to interpret and highlights significant variations between intervals. When combined with other, more detailed, methods that can measure contaminant distribution regardless of permeability, the data can be used to decide when and if SVE will be effective or whether to modify the system.

The primary disadvantages are as follows:

- An SVE extraction well must be installed if one does not already exist. If SVE does not turn out to be appropriate for the Hartford site, then this site characterization method may be more expensive because installation of a well will generate soil cuttings and is labor intensive.
- Pneumatic logging provides limited data from soil intervals that are not within the screened interval of the well. The ideal screened depths cannot be identified before the vent well is installed. However, PneuLog testing in a single-well pilot test could be used to more effectively locate well screens in a full-scale, multi-well SVE system.
- Contamination from an overlying low-permeability layer may be detected at dilute concentrations in an underlying high-permeability layer. High levels of VOC contamination may be entering the vent well from one direction and be diluted by clean soil gas from other directions. The vent well tends to average VOC concentrations, and the PneuLog tool can measure only the average VOC concentration inside the well and the average permeability of the soil interval.

Overall, a technology such as PneuLog is warranted because of the size of the Hartford site and the need for efficiency in implementing a cleanup strategy. Additional information and design considerations should be evaluated in conjunction with Praxis or an equivalent vendor of a similar technology.

3.3.2 Monitoring the Effectiveness of a Cleanup Strategy

A direct measurement approach should be used to monitor the impact of any cleanup strategy for the Hartford site. Passive soil gas probes placed at regular intervals in and around treatment zones to measure relative changes in concentration can be an economical way to accomplish this task. Alternately, VMP samples can be collected over time using a focused analytical program. Any analytical program for monitoring the effectiveness of the remedy needs to include not only contaminant-specific analysis, but should also monitor for explosive levels of less toxic petroleum fuel-related constituents. Action levels in the vapor phase will need to be agreed upon by all stakeholders before a cleanup strategy can be implemented.

Real-time measurement tools such as a mobile gas chromatograph should be considered initially as a method to economically increase the density of vapor sampling. More sensitive vapor probe measurements such as Summa canisters may be required as concentrations decrease and vapors are mitigated. The PneuLog itself can also be used to evaluate yields and the benefit of continued operation of an SVE system.

3.4 GEOVIS VIDEO MICROPSCOPE ESTIMATES OF IN SITU NAPL SATURATIONS USING CPT TECHNOLOGY

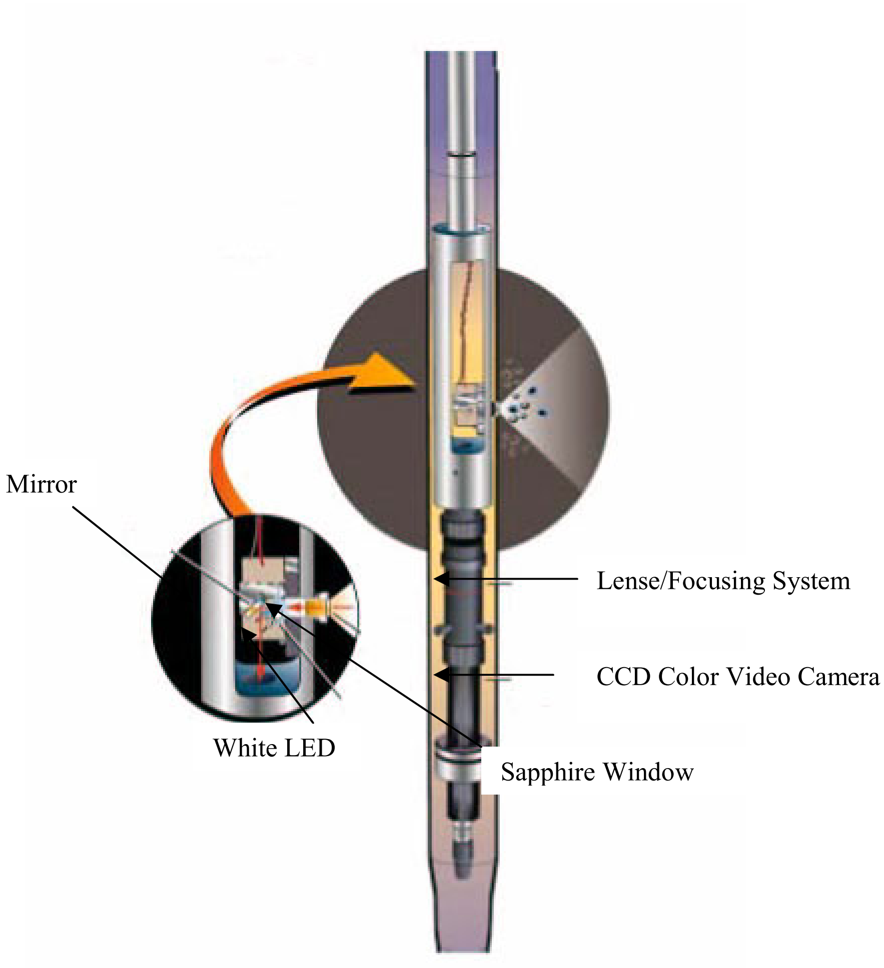
In addition to traditional methods for evaluating the potential for product removal at the site, Tetra Tech suggests that HWG consider GeoVIS as a method to increase the project team’s understanding of hydrocarbon saturations. Hydrocarbon saturations can be used to estimate where additional permeability and productivity testing using high-vacuum extraction may be warranted. Currently, the HWG proposes to base its product removal system design on one or two key locations where core data were collected and conditions were favorable for further testing (Clayton 2006c). Use of a limited set of results in the manner proposed could result in an ineffective remedial design and wasted project funds.

The GeoVIS video microscope has the capability for collecting real-time in situ images of the subsurface soil environment for use in estimating soil porosity and light NAPL saturations. The GeoVIS system uses a miniature digital video camera coupled with magnification and focusing lens systems integrated into a cone penetrometer probe. The soil environment is imaged through a window in the probe and the video signal from the camera is returned to the surface where it can be viewed in real-time on a video monitor, recorded on a video recorder, or digitized (or any combination). When combined with lithology information obtained from CPT probe data and soil contamination estimations from LIF data, GeoVIS provides the small-scale tools necessary to identify thin layers of highly permeable material that provide a potential pathway for contaminant transport and removal, which could be overlooked easily through conventional means. It also provides a direct means for locating contamination source zones that have been difficult to localize using traditional sampling approaches.

3.4.1 Equipment

The equipment used for GeoVIS is a direct push penetrometer mounted on a CPT platform. It is equipped with a vertically mounted charged-coupled device (CCD), a mirror to reflect a side view of the soil into the camera, and a sapphire viewing window (Exhibit 4). The GeoVIS uses light from four light-emitting diode (LED) light sources (Xenon lamps) to distribute diffused light evenly across a sapphire viewing window, resulting in even reflected light from the soil. The standard GeoVIS optics system provides a viewing field of approximately 2 by 3 millimeters and a magnification of 100 when viewed on a standard 13-inch monitor. Approximately eight unique (non-overlapping) photomicrographs can be collected per inch of soil or 96 unique images per foot of video push. All soil photomicrographs are collected using a frame capture device and can be saved as bitmap files. The pores between sand and gravel grains and contents of the pores (such as dense NAPL, or dense nonaqueous phase liquid [DNAPL]) are generally readily observable and easily definable from these soil microphotographs.

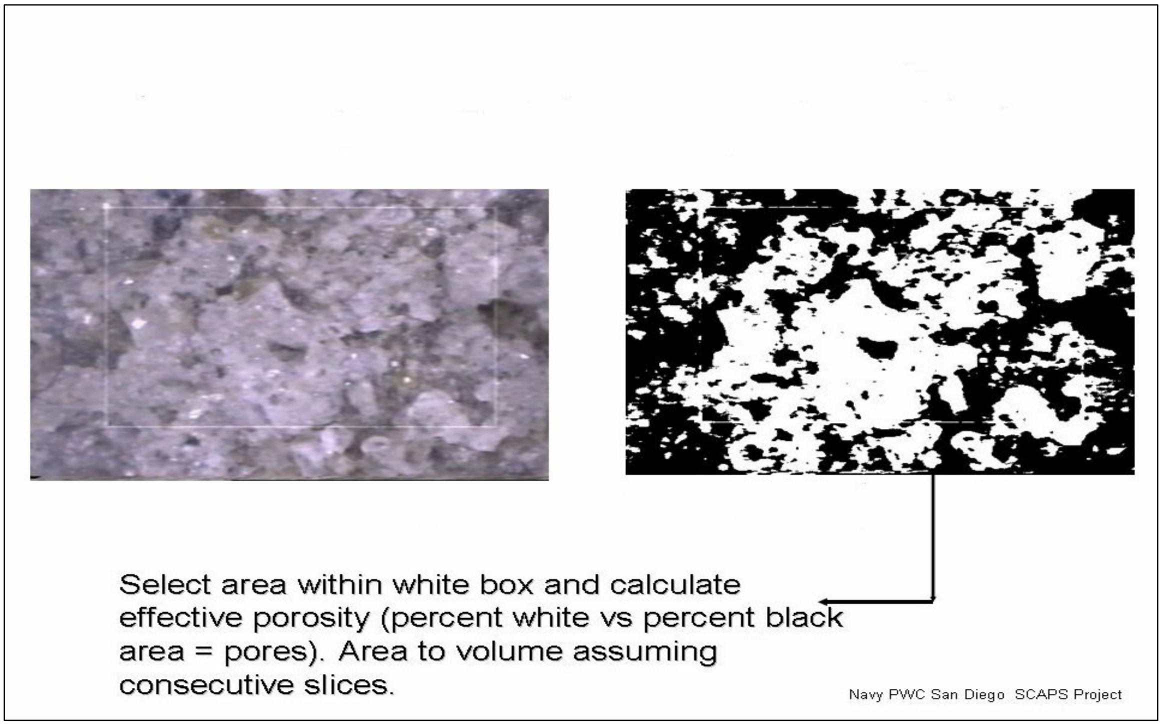
Exhibit 4: Schematic of GeoVIS Direct-Push Probe



3.4.2 Effective Porosity

Porosity between fine-grained materials is part of total porosity that cannot be observed within the photomicrographs; therefore, total porosity cannot be rendered. However, effective porosity as it relates to the specific yield of the soil is extracted and quantified since the large pores between granular materials can be observed. Pixels of grain and matrix materials are converted to pure white and pixels of pore space are converted to pure black. The number of white versus black pixels is used to estimate the percent pore space in the photomicrograph. Area percentages calculated from two-dimensional photomicrographs can be used to estimate porosity, saturation, and void volumes by the consecutive volume slice method. If a sufficient number of compositional determinations of two-dimensional slices are conducted on a three-dimensional volume, then the composition of the volume can be reliably estimated (Exhibit 5).

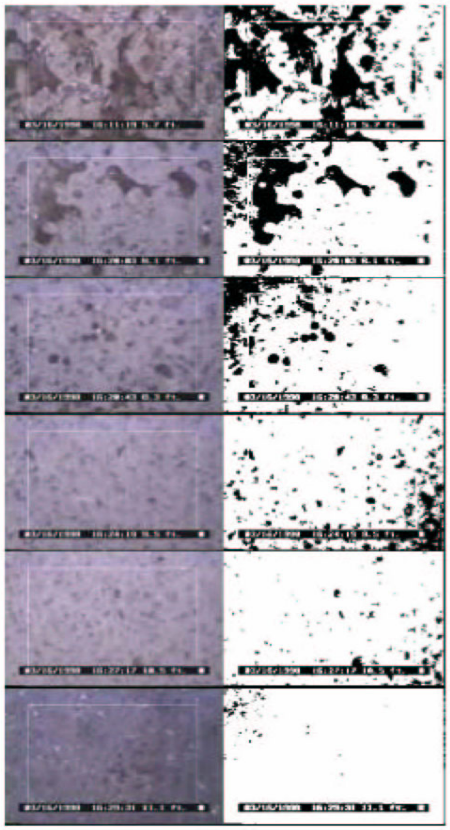
Exhibit 5: Estimated Soil Porosity (Vadose Zone) from GeoVIS Images



3.4.3 NAPL Saturation

Obtaining NAPL saturations is more problematic than processing GeoVIS outputs for porosity. NAPL color varies based on the thickness of the NAPL in the pores, the NAPL type, background reflectance, pore size, and soil type. Dark, globular DNAPLs are easily rendered, whereas lightly colored fuels and diesel are not rendered well. Another problem that may arise is that dark mica or other dark minerals can also be misinterpreted as free product; therefore, the percentage of dark minerals must be known before images can be processed for free product. It is recommended that images of fluorescing NAPL induced by LIF be collected to overcome the highly variable nature of NAPL colors and reflectance under most field conditions. After the NAPL areas are obtained from each photomicrograph, the areas can be converted to NAPL saturation by dividing the area by the effective porosity average for the push. Exhibit 6 shows the results of the DNAPL image processing for a soil video profile. Photomicrographs of DNAPL droplets are shown on the left. Results of the DNAPL image processing, presented in black and white, are shown adjacent to each photograph. Pixel counts as total image area and DNAPL saturation results are presented on the right. Saturation results are a percent within the pore space, assuming a consistent porosity of 43.1 percent. The photomicrographs and image processing results both show a large drop in DNAPL droplet numbers and sized and in DNAPL saturation with depth.

Exhibit 6: Vertical Profile of Soil Photomicrographs with DNAPL Droplets



Photomicrograph	DNAPL Rendering	Depth (ft)	DNAPL Area (%)	S_o
		5.7 ft	43.11%	100%
		8.1 ft	27.11%	62.9%
		8.3 ft	10.81%	25.1%
		9.5 ft	6.05%	14.0%
		10.5 ft	2.1%	4.9%
		11.1 ft	0%	0%

The information on this technology was adapted from *"Confirmation of CPT Video Microscope Estimates of In Situ Soil Porosity and NAPL Saturations"* (Sinfield, 2004).

3.5 ADDITIONAL SITE CHARACTERIZATION ACTIVITIES

In addition to the continued refinement of a CSM to support the evaluation of vapor intrusion issues at the Hartford site, information should also be gathered to support the evaluation of the nature and extent of dissolved- and free-phase contamination at depth and in off-site areas. The data available from the investigations conducted thus far have focused on the presence or absence of free product immediately beneath the Hartford site. Future investigations should also consider the engineering and characterization data needed to optimize the proposed remedies for the site.

As a first step in this process, the preliminary CSM should be expanded to include potential source areas north, east, and west of the Hartford site. Without any information on these potential source areas, it is difficult to provide detailed suggestions on delineation of dissolved-phase hydrocarbons at this time. The project team should consider the following activities:

- Compiling existing data from areas surrounding the Hartford site.
- Continued piezometer installation and monitoring real-time flow directions and water levels using pressure transducers in and around source areas where product recovery and SVE will likely be applied.
- Additional water sampling from small-gauge, multi-level wells both on and off site. Small-gauge wells should be installed with screened intervals within, and below, the identified boundaries of the free-phase and dissolved-phase plume to monitor product thicknesses and water levels.
- Additional source term characterization should be conducted such that mass loading can be estimated and the fate and transport of petroleum contaminants can be predicted.
- Fate and transport parameters such as groundwater flow velocities and directions should be mapped and calibrated using intrinsic tracers, or existing plume extents and characteristics, where possible.
- Natural attenuation parameters should be added to the set of monitoring parameters for wells in the distal fringe and surrounding the contaminant plumes.

Nested wells are needed throughout these areas for product removal, and monitoring wells should also extend to some depth below the plumes for monitoring.

The well network currently proposed should be augmented with small-gauge wells or temporary monitoring points whose locations are optimized based on the work products provided in this report. A dynamic approach is suggested to limit project cost and improve performance. As mentioned in the CSM portion of this report, there are obvious pathways for contaminant transport that will need to be refined and targeted.

4.0 INCORPORATING TRIAD-DRIVEN DYNAMIC WORK STRATEGIES

The general approach presented by Clayton and in the *"Technical Memorandum, Vapor Control System Upgrade Design"* (Clayton 2004c) and the utility and pipeline investigation is a traditional static or phased approach. Tetra Tech suggests that the project team instead consider adopting a dynamic work strategy to guide future activities. A dynamic work strategy explains how the decisions will be guided by field measurement results and how spatial uncertainties will be identified and addressed as the field activities proceed. Ideally, stakeholders build consensus on project objectives and key decisions that are based on agreed-on action levels before the new field activities are undertaken.

For example, if a sampling location is found to contain free product, the dynamic work strategy might discuss how its extent will be delineated and what type of data will be used to support delineation. Another example might include evaluating how headspace soil gas surveys, VMPs, PneuLog, or GeoVIS will be used to optimize treatment system design. Data from these types of evaluations then might be used to select specific VMP locations and locations where additional design data should be collected. These types of strategies should be laid out using a series of flow charts and diagrams before field crews mobilize.

Tetra Tech understands some of the basic reasons behind the phased approach Clayton proposed. However, Tetra Tech believes it is imperative for the project team to clearly state the specific rationale that will be used to select when and where various activities will be considered. The rationale should be based on a well established CSM and address every aspect of the project design, including installation of piezometers, direct-push soil borings, VMPs, soil and ambient air gas samples, full-size wells and vacuum monitoring probes. Establishing clear guidelines for decision-making should be the first step in the systematic planning process.

The revised CSM should be developed and used to select the most appropriate set of innovative technologies for use at the site. A data management and communication platform that operates in real time should be considered. Many three-dimensional data presentation tools are available. A web portal with a relational database should also be considered to expedite communication of results. This portal will facilitate project decision-making on a real-time basis and swift communication of results to all regulators and affected stakeholders.

4.1 SUMMARY OF SUGGESTIONS

The following summarizes the proposed dynamic work strategy to support the implementation of a vapor mitigation program and product removal design effort at the Hartford site. The activities are designed in a logical sequence such that the quality and utility of data that are collected is maximized. Maximizing the utility of data will also require that the CSM for the Hartford site be continually revised as new data are received. The CSM can communicate results to stakeholders as new data are received and can guide subsequent actions. The CSM should be used as the basis to scope additional work and establish contingencies and options that might need to be built into the removal strategy.

Suggested activities include, but are not necessarily limited to, the following:

- Hydrocarbon concentrations in near-surface preferential pathways such as sewers and utility corridors should be analyzed using ambient air methods. These data are particularly important because of the difficulty in using intrusive sampling methods near utility corridors, such as Rand Avenue. Real-time ambient air monitoring technologies for sampling from sewer manholes are the most promising method. A portable gas chromatograph or the equivalent with a mass selective detection system are suggested.
- The well network should be expanded north, east, and west to answer not only vapor-related issues, but also more long-range concerns related to impacts from the Hartford site to the surrounding environment. Downhole transducers should be placed in wells as practicable so that rapid fluctuations and changes in direction of flow can be monitored on a real-time basis. Upgradient sources will likely need to be addressed to assure the long-term effectiveness of the remedy. Technologies should be used that can increase well and screened interval density. Small gauge multiport wells, such as can be obtained from Precision Sampling Inc., should be used to reduce costs and improve the project team’s ability to monitor vertical and horizontal off-site migration of contaminants.
- In addition to lithologic descriptions, any contaminant-related features such as odor, staining, or unusual solid constituents should be noted on the logs. The visual observation of hydrocarbon contamination should be documented using the following standardized descriptions:
  - No Visible Evidence – No visible evidence of oil on soil sample;
  - Sheen – Any visible sheen in the water on soil particles as described by the sheen testing method presented later in this section;
  - Staining – Visible brown or black staining in soil. Can be visible as mottling or in bands. Typically associated with fine-grained soils;
  - Coating – Visible brown or black oil coating soil particles. Typically associated with coarse-grained soils such as coarse sand, gravels, and cobbles;

- Oil Wetted – Visible brown or black oil wetting the soil sample. Oil appears as a liquid and is not held by soil grains. Soils oozing petroleum typically contain 2 to 3 percent petroleum.

- These descriptions are general and may need to be modified to more accurately reflect actual site conditions and product characteristics.
- In addition to PID headspace and visual observations, the presence of free product in soil cores should also be evaluated periodically through direct application of a technology similar to ROST on the open core at ground surface. This evaluation is particularly important across the smear zone within the top of the Main Sand, where free product is most likely to be present. As the visual evidence of free product decreases, a water sheen test or SiteLAB total petroleum hydrocarbon ultraviolet fluorescence (UVF) field test kits or the equivalent might be considered to further understand the relationship between the measured concentration in soil, the presence of free product, and the ROST response.
- The water sheen test can be performed by placing soil in a small plastic bag or glass jar, adding distilled water, shaking the bag or jar, and observing the water's surface for signs of sheen. Sheen should be classified as follows:
  - No Sheen (NS) – No visible sheen on water surface;
  - Slight Sheen (SS) – Light colorless film; spotty to globular; spread is irregular, not rapid; areas of no sheen on water surface remain; film dissipates rapidly;
  - Moderate Sheen (MS) – Light to heavy film; may have some color or iridescence; globular to stringy; spread is irregular to flowing; few remaining areas of no sheen on water surface;
  - Heavy Sheen (HS) – Heavy colorful film with iridescence; stringy in appearance; spread is rapid; sheen flows of the sample; most of water surface may be covered with sheen.
  - Additional multiport VMP and well designs should be optimized using PneuLog. Petroleum vapors invading sewer lines should be collected before the final SVE system is designed and tested. Specific areas for testing should be identified through the use of the CSM as it is revised based on the products developed during this effort and subsequent data collection efforts.
- A near-surface monitoring network that might rely on VMP data and or headspace soil gas should be used to evaluate the impact of free product removal and vadose zone SVE or other methods for reducing vapors during remedy testing and before full-scale implementation. The performance of the system should be checked against well-defined decision criteria before full-scale implementation is considered.
- GeoVIS should be used along with other types of physical and empirical testing to evaluate and map zones beneath the village where product removal should be considered. This type of evaluation will improve the potential for the effective removal of product beneath the village.

4.2 SUMMARY

The work products generated in support of the refinement of a CSM for the Hartford site are encouraging. Tetra Tech hopes that the additional work products provided in this report will continue to expand the project team's understanding of the Hartford site. Tetra Tech also hopes that the project team will continue to refine and clearly state the decision logic that guides the activities in future work plans. The project schedule should be sequenced to assure that field activities and remedial efforts are optimized. Once optimized, locations where actions will be considered should be further tested using empirical methods. As systems come on line, the HWG should continue to refine operating conditions and parameters.

The Hartford site is complex, and implementation of an efficient remedy can be supported by all elements of the Triad approach. Real-time measurement techniques can be used to make maximum use of data as it is collected. The aggressive use of a systematic plan designed around the refinement of the CSM and efficient communication of results is needed. Well-documented dynamic work strategies, which clearly define how data will be used to support decision-making, will limit project delays. The collaborative use of differing sources of information is needed to improve project efficiency.

Current data are not sufficient to address many of the principal study questions for the project. As the project progresses, Tetra Tech suggests that the project team begin to consider ways to address as many of the objectives as efficiently as possible through a dynamic approach designed around innovative technologies and strategies.

Tetra Tech would be pleased to provide related available data sources on the products presented in this report to the Hartford Working Group. If you have any questions or comments on this document, please contact Mr. Robert A. Howe at (303) 441-7911 or via e-mail at Robert.Howe@ttemi.com.

5.0 REFERENCES

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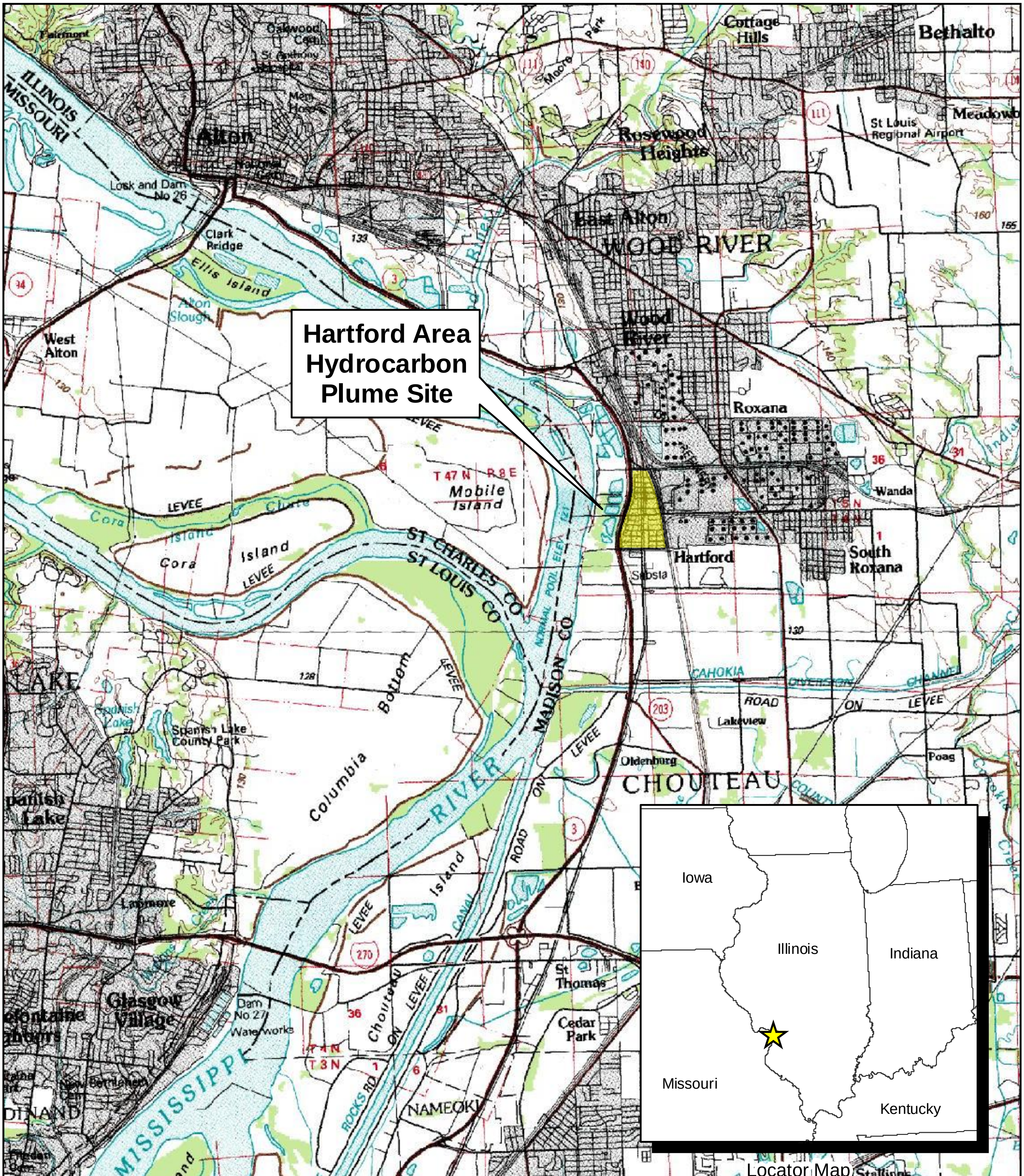
FIGURES



Legend

Site Boundary

N W E S

0 1.5

Miles

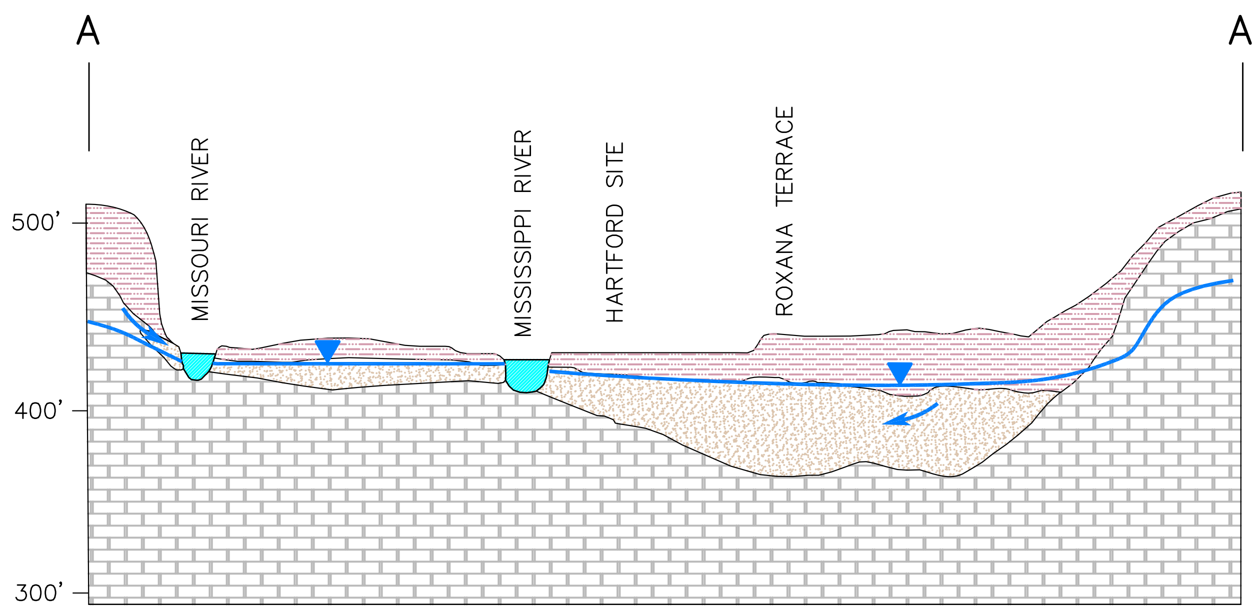
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 1

LOCATION MAP

TETRA TECH EM INC.

2007/07/23 O:\DOJ\Fig1_Location_Map1.mxd TtEMI-DN Kurt.Cholak



LEGEND

- CAHOKIA ALLUVIUM
- MAIN SAND
- RENAULT LIMESTONE – MISSISSIPPIAN BEDROCK
- WATER
- WATER TABLE SURFACE
- GROUNDWATER FLOW DIRECTION

100'
50'
0

VERTICAL SCALE:
1" = 100'
APPROX.

1 0 1 2

SCALE: 1" = 2 MILES
HORIZONTAL

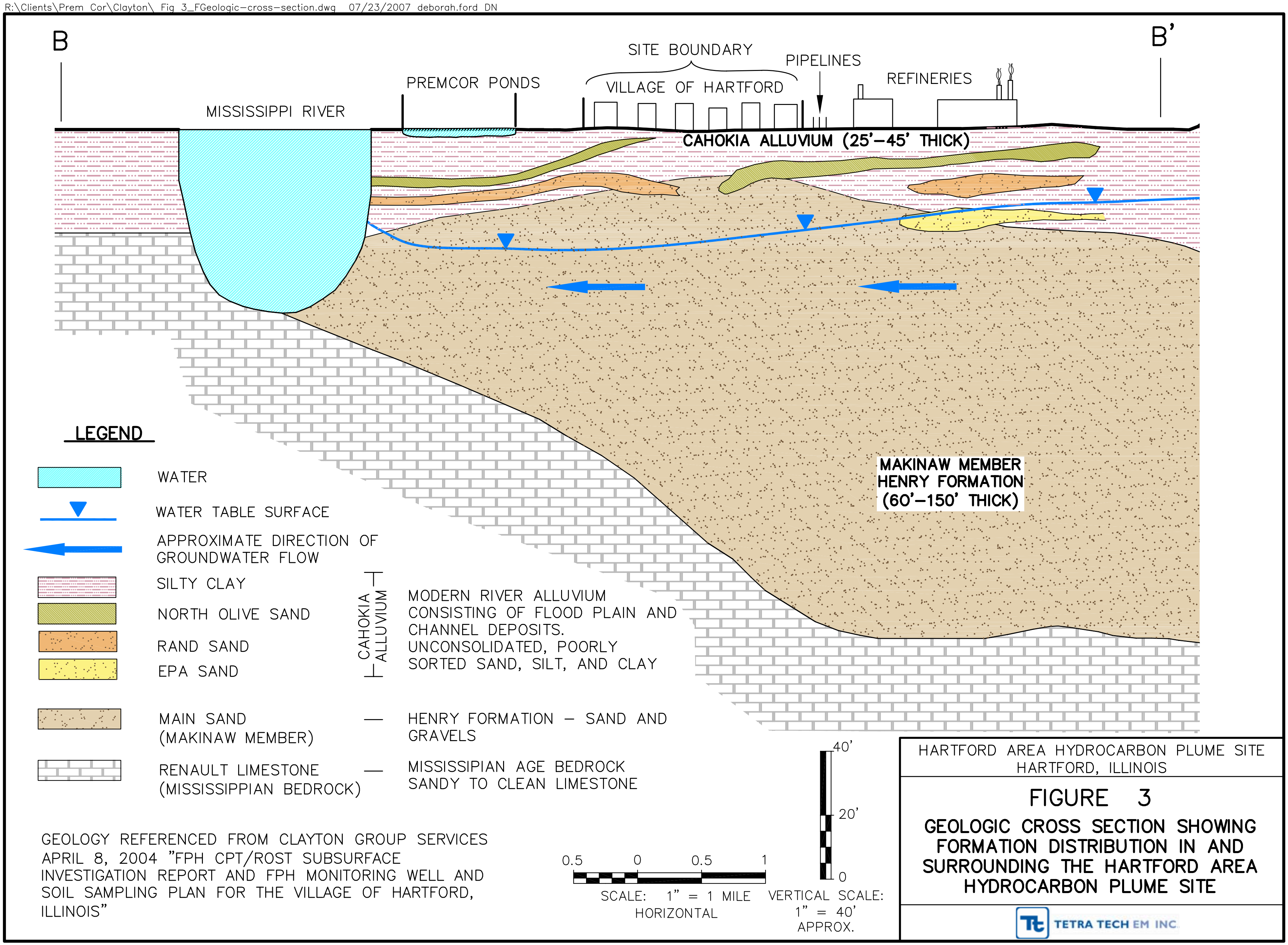
HARTFORD AREA
HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 2

REGIONAL GEOLOGIC CROSS SECTION

TETRA TECH EM INC.

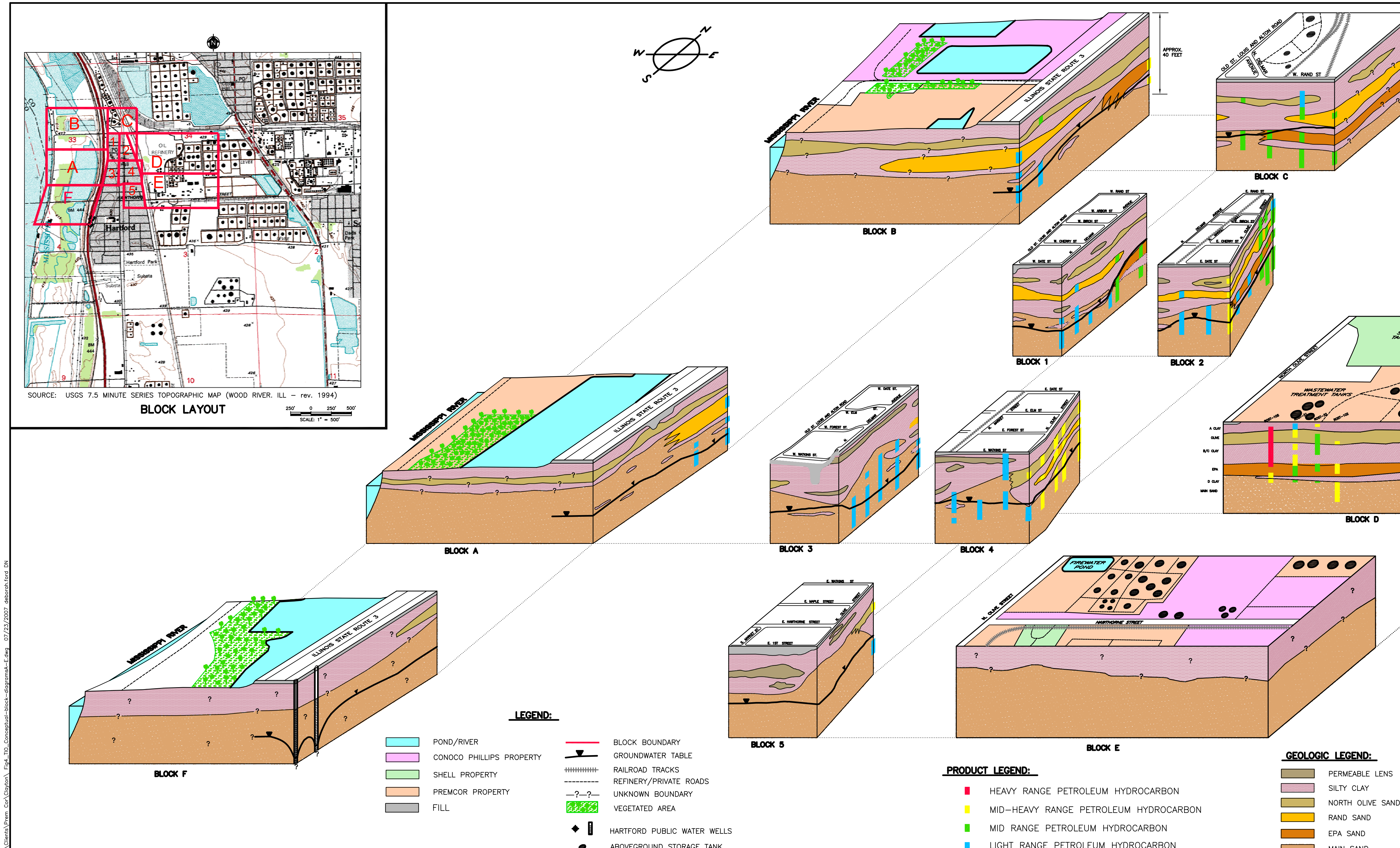
R:\Clients\Prem Cor\Clayton\ Fig 3_FGeologic-cross-section.dwg 07/23/2007 deborah.ford DN



HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 3

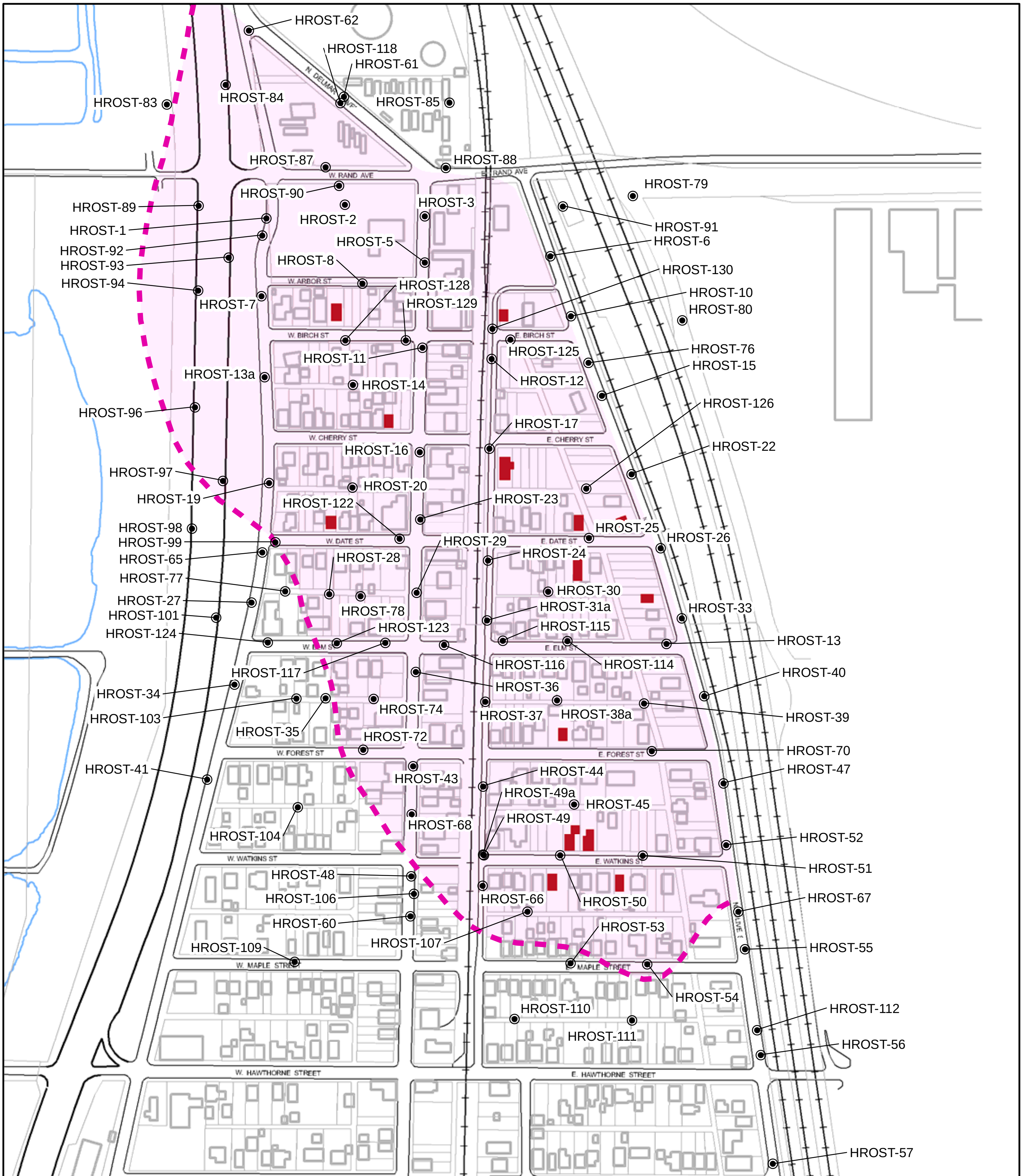
GEOLOGIC CROSS SECTION SHOWING FORMATION DISTRIBUTION IN AND SURROUNDING THE HARTFORD AREA HYDROCARBON PLUME SITE



Hartford Area
Hydrocarbon Plume Site
Hartford, Illinois

FIGURE 4
PRELIMINARY GEOLOGICAL CONCEPTUAL SITE MODEL

TETRA TECH EM INC.



Legend

- ROST Sample Location
- ROST Response Boundary
- Pond
- Railroad
- Parcel
- Extent of Free Product Plume
- Building
- Building with Reported Fire

N
W E
S

0 400
Feet

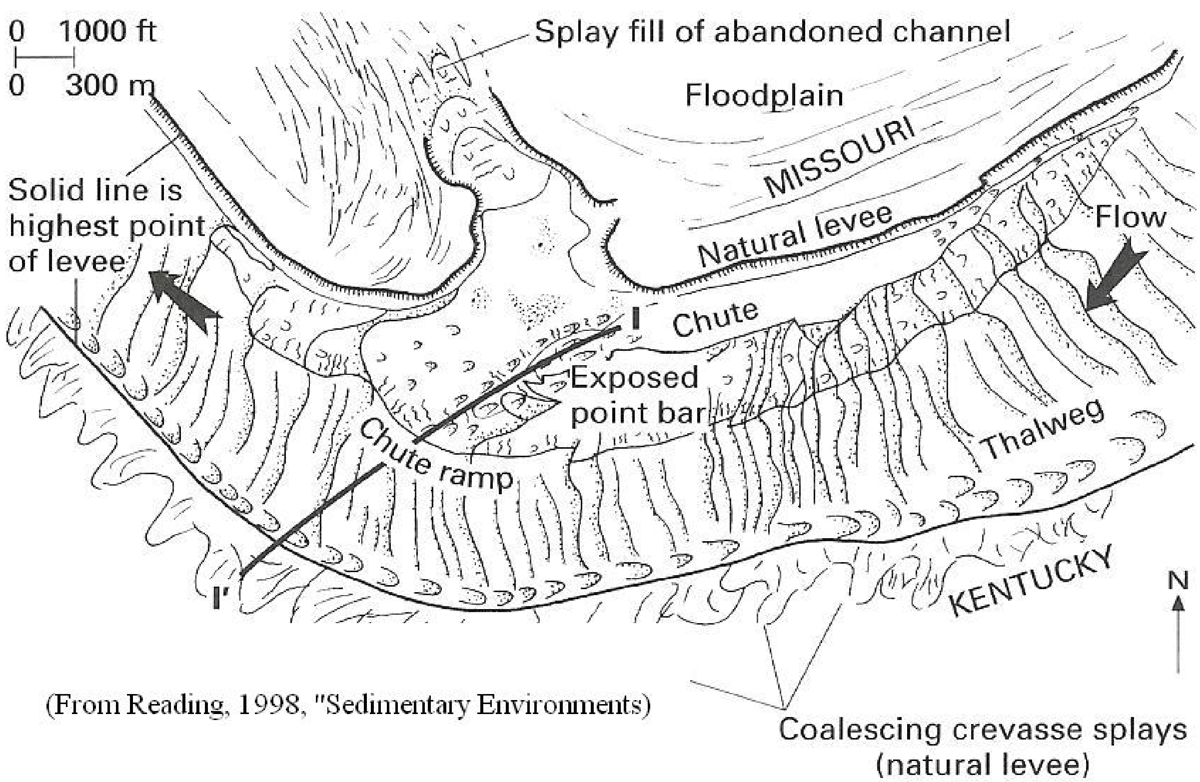
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 5

ROST APPROXIMATE
EXTENT OF HYDROCARBON MAP

TETRA TECH EM INC.

07/24/07 O:\DOJ\FigA5_Plume.mxd TtEMI-DN Kurt.Cholak



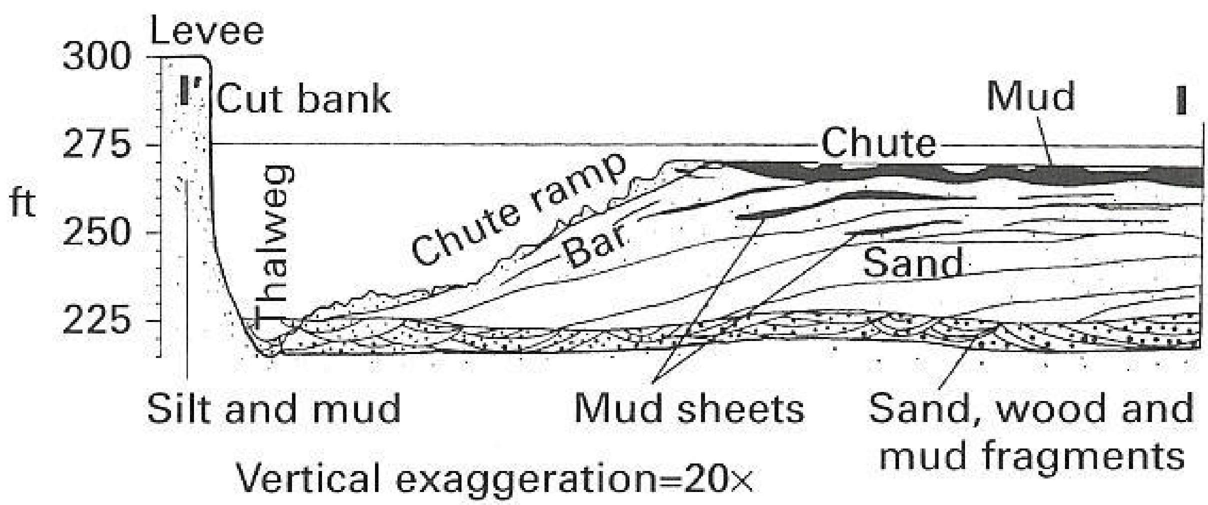
(From Reading, 1998, "Sedimentary Environments)

HARTFORD AREA
HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 6

AVULSION OF A SEDIMENTARY SEQUENCE

TETRA TECH EM INC.



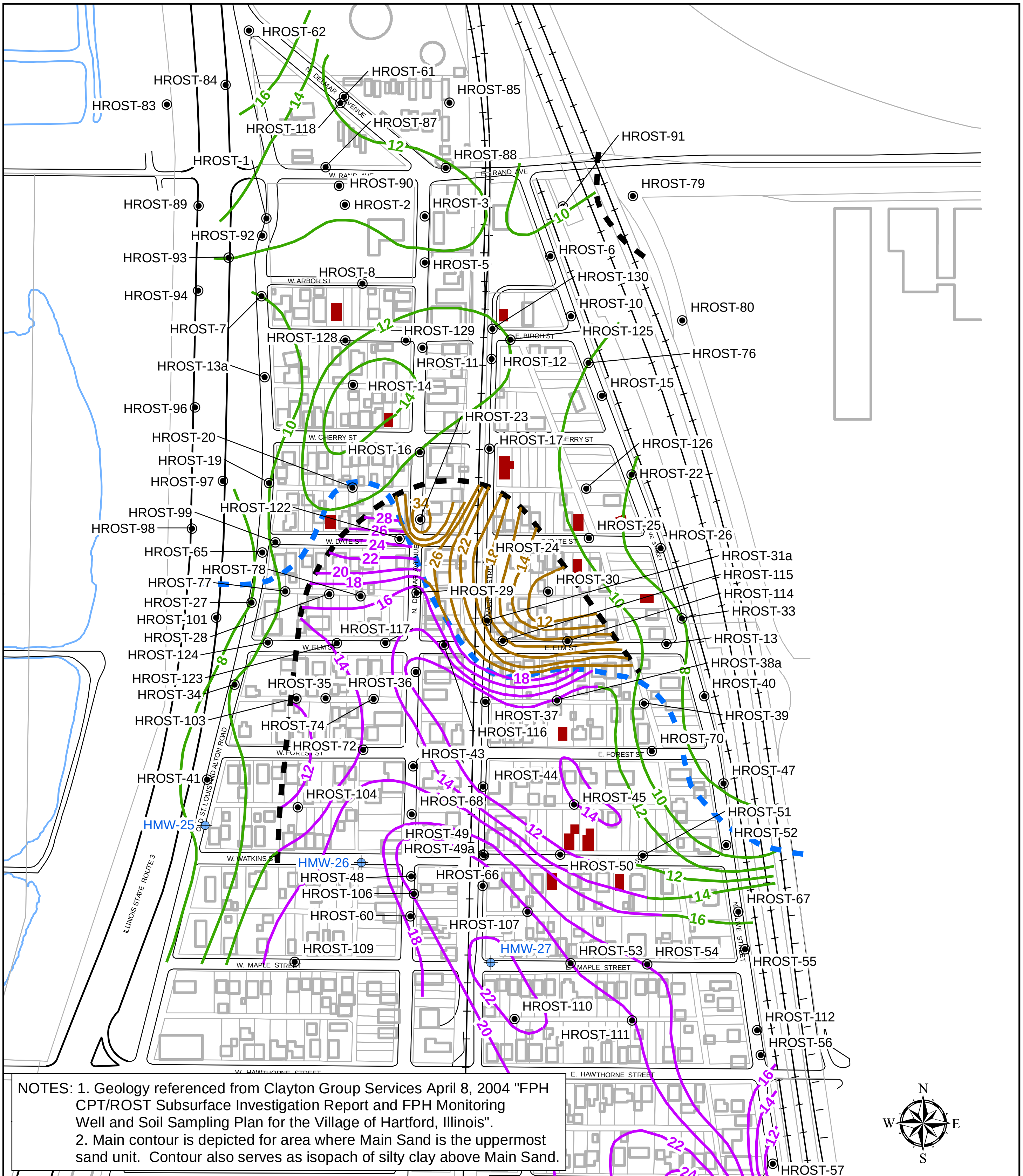
(From Reading, 1998, "Sedimentary Environments)

HARTFORD AREA
HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 7

CROSS SECTION OF A MIXED LOAD RIVER

TETRA TECH EM INC.



NOTES: 1. Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".
2. Main contour is depicted for area where Main Sand is the uppermost sand unit. Contour also serves as isopach of silty clay above Main Sand.

Legend

- ROST Sample Location
- HMW Well
- Contour of Thickness of A-Clay above North Olive (feet - depth from surface)
- Contour of Thickness of A-Clay above Main (feet - depth from surface)
- Contour of Thickness of A-Clay above Rand (feet - depth from surface)
- Extent of Rand Sand
- Pinched-out Boundary for North Olive
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

0 400
Feet

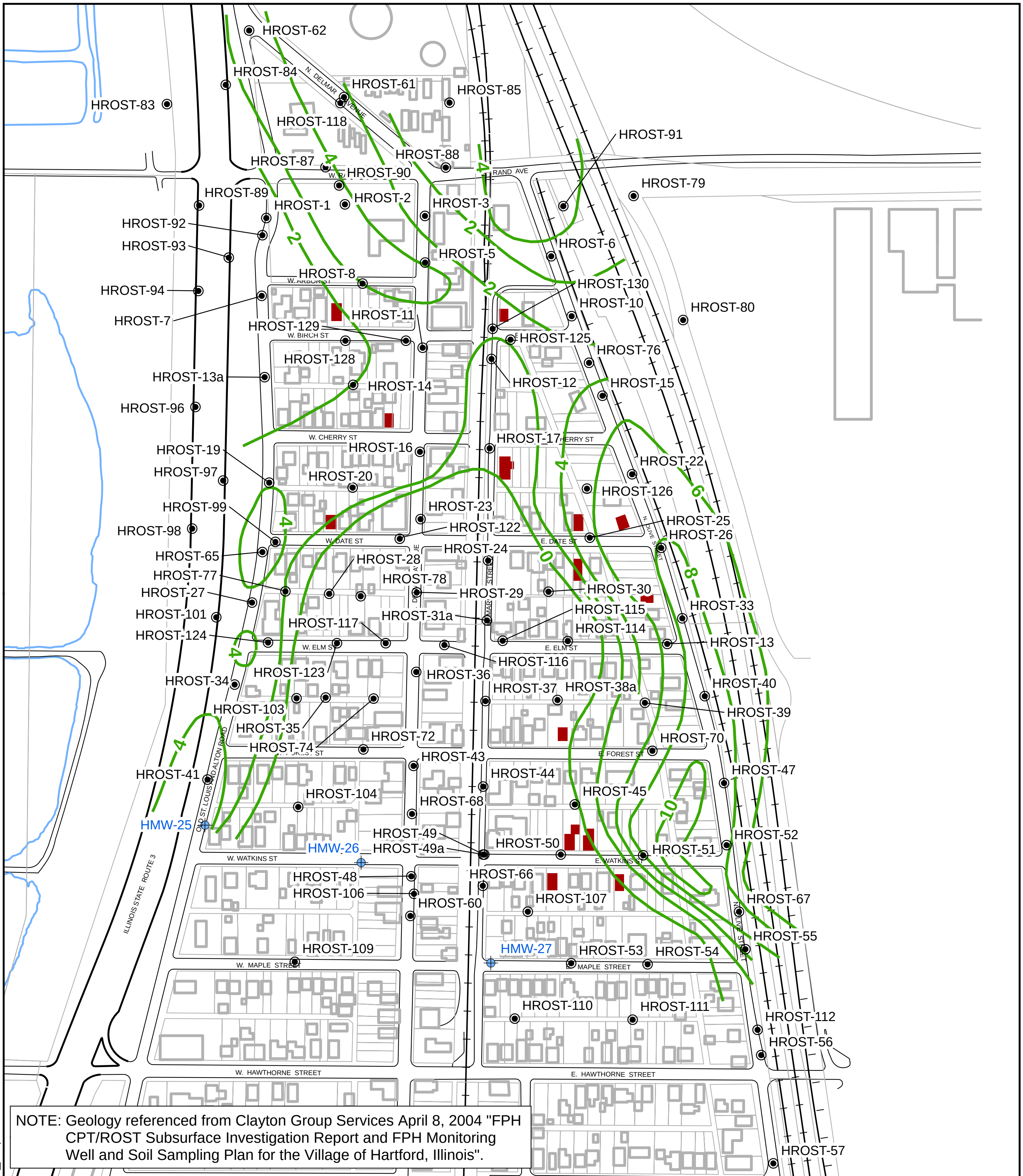
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 8

ISOPACH OF A-CLAY ABOVE STRATUMS INDICATED

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA8_TopA_Clay.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- North Olive Thickness (feet)
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N
W E
S

0 400
Feet

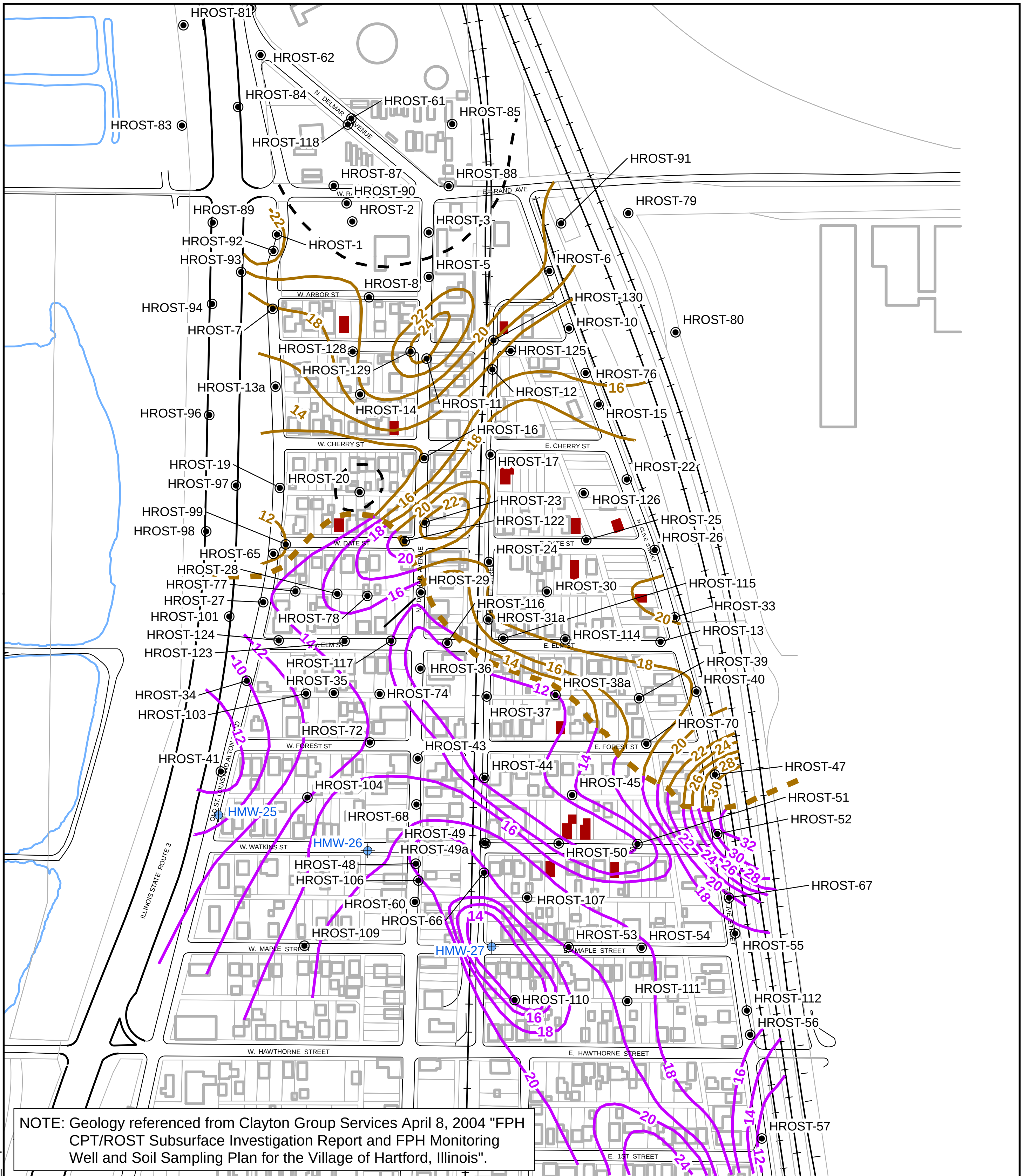
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 9

NORTH OLIVE STRATUM ISOPACH

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA9_N_Olive_Sand_Isopach.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- Rand Contour (feet - depth from surface)
- Main Contour (feet - depth from surface)
- Pinched-out Boundary for Rand
- Boundary of Rand Conjoining Main
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N
W E
S

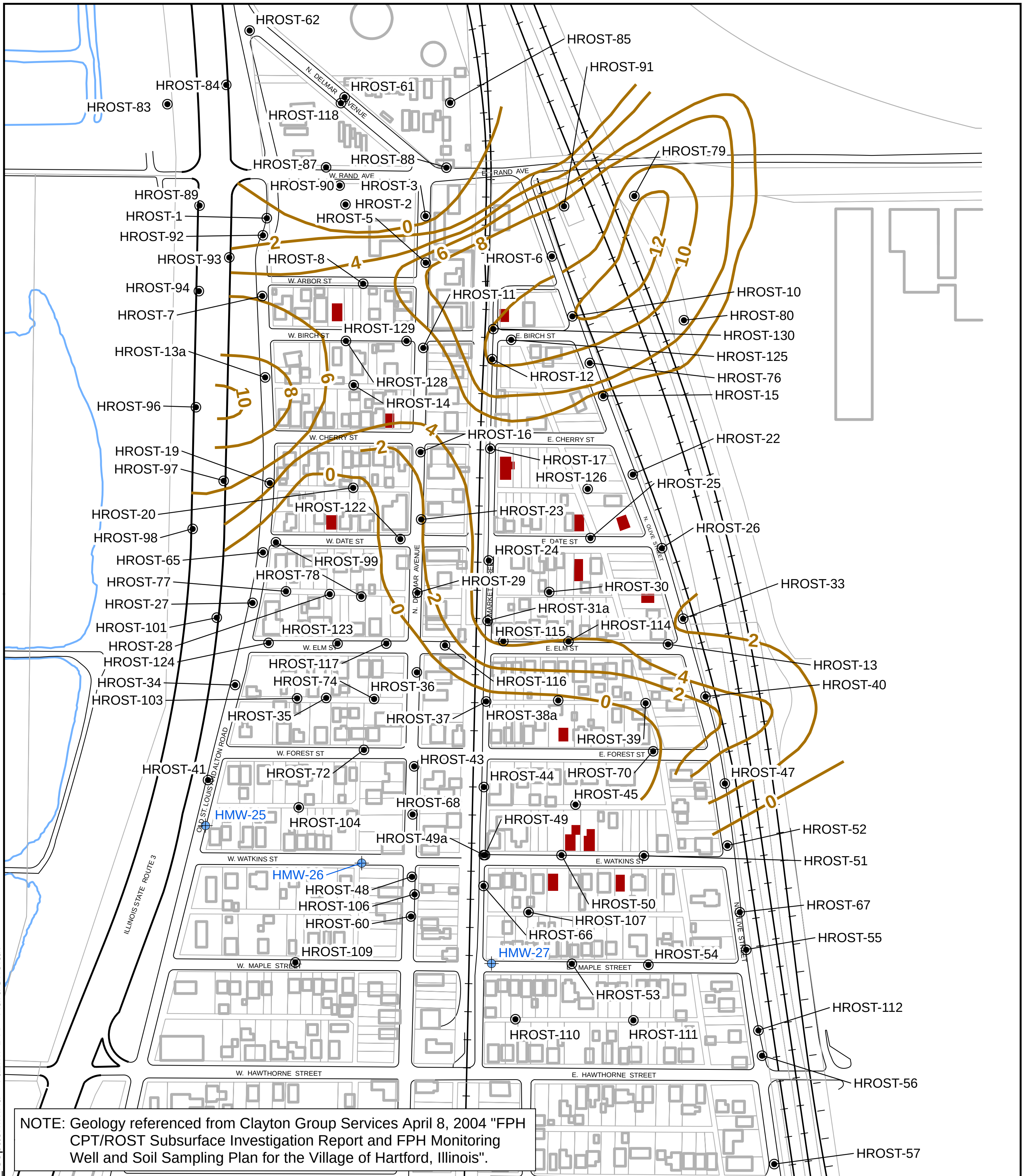
0 400
Feet

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 10
TOP OF RAND AND
MAIN STRATUM

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA10_Rand_Sand_Top.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- Thickness of Rand in feet
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N W E S

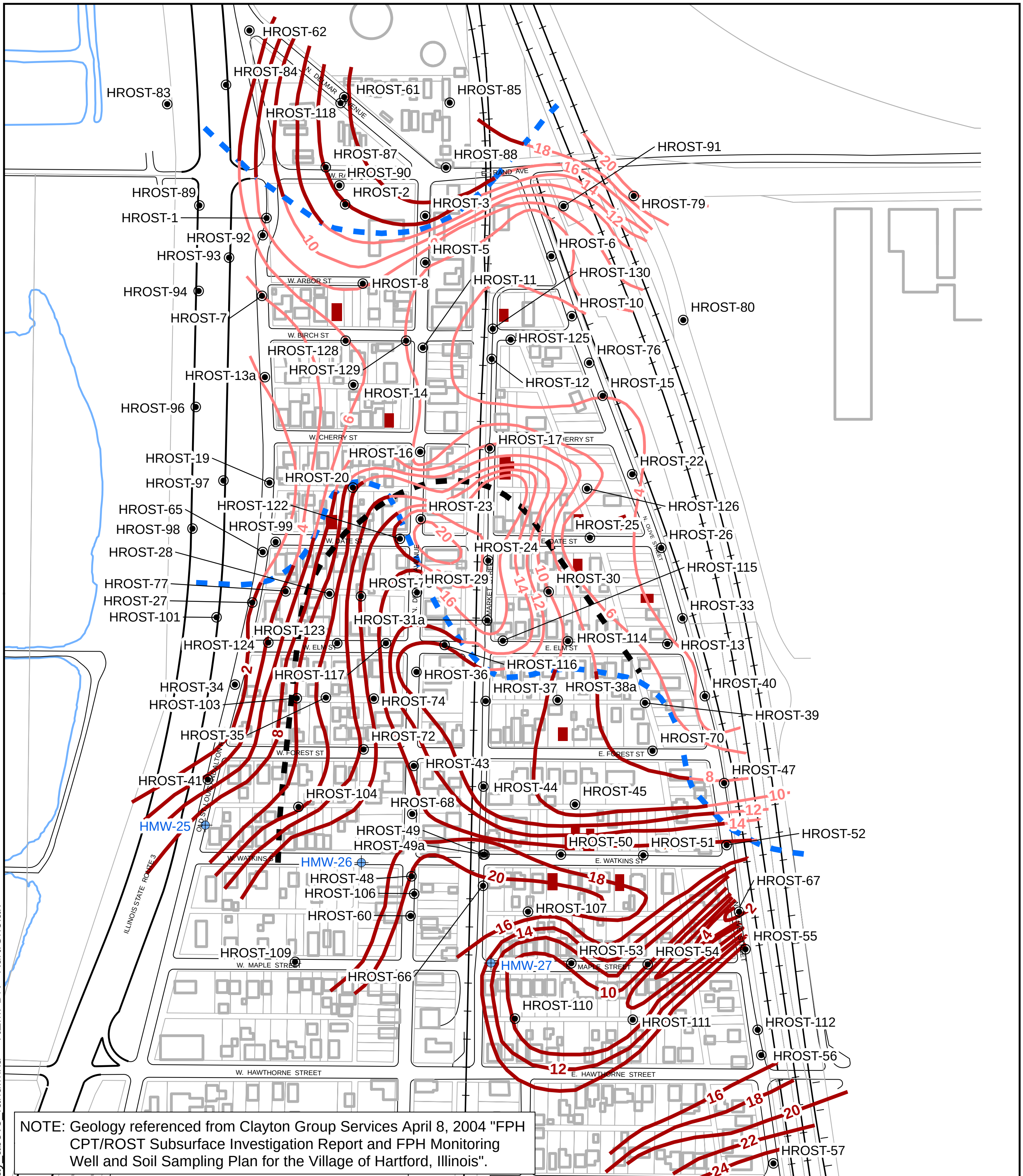
0 400
Feet

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 11
THICKNESS OF RAND STRATUM IN FEET

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA11_Rand_Sand_Isopach.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- Isopach Silty Clay Contour in feet
- Isopach Silty Clay Contour above Main in feet
- Extent of Rand Sand
- Pinched-out Boundary for North Olive
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N
W E
S

0 400
Feet

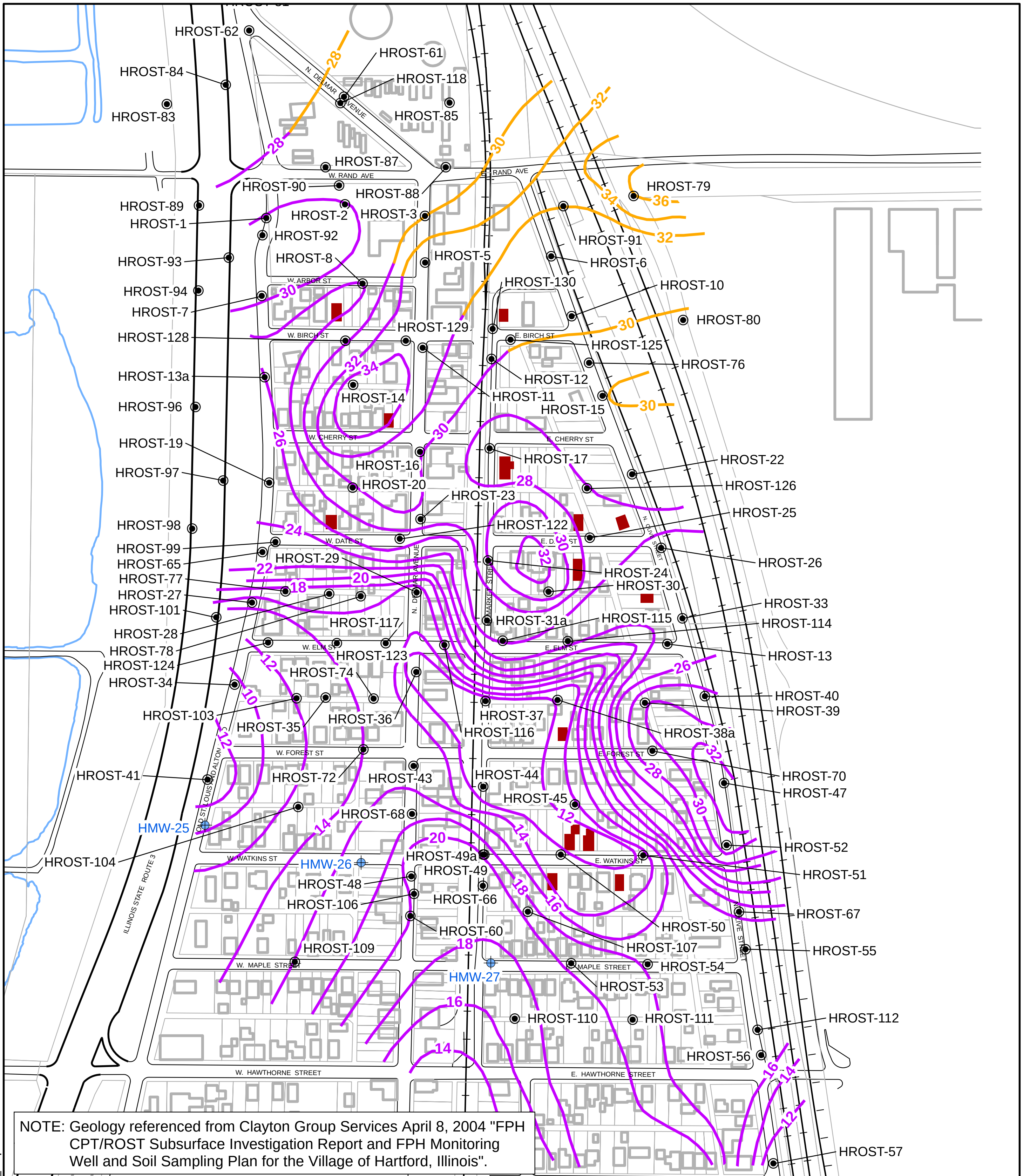
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 12

ISOPACH OF SILTY CLAY BETWEEN RAND STRATUM OR MAIN SAND AND THE NORTH OLIVE STRATUM OR GROUND SURFACE

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA12_isopach_clay_above_rand.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- EPA Contour (feet - depth from surface)
- Main Contour (feet - depth from surface)
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N W E S

0 400

Feet

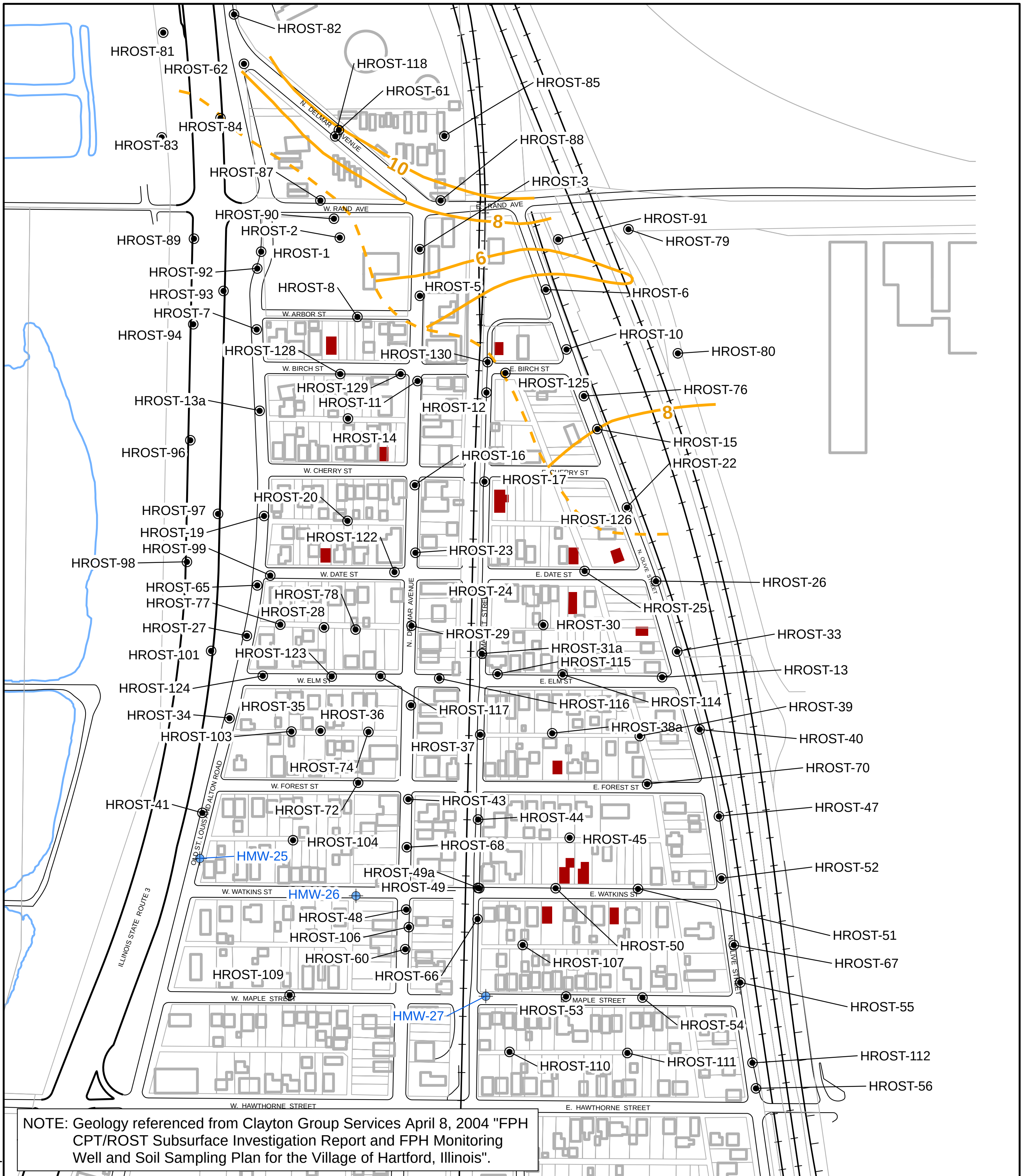
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 13

TOP OF EPA STRATUM

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA13_Epa_Sand_Top.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- EPA Merges with Main Boundary
- EPA Thickness (Feet)
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N
W E
S

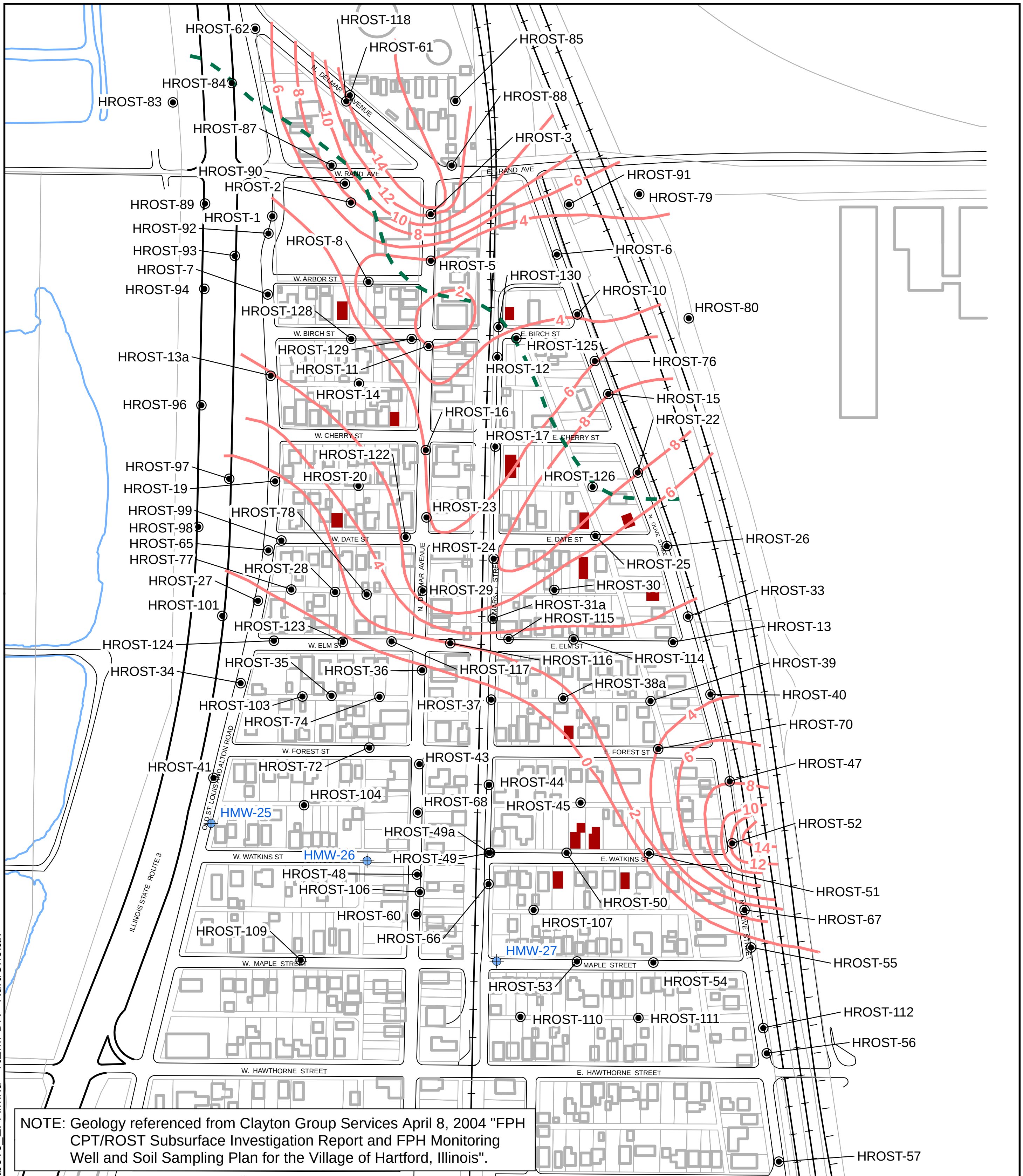
0 400
Feet

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 14
EPA STRATUM ISOPACH

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA14_Epa_Sand_Isopach.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- Silty Clay Thickness (feet)
- Extent of EPA Sand
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

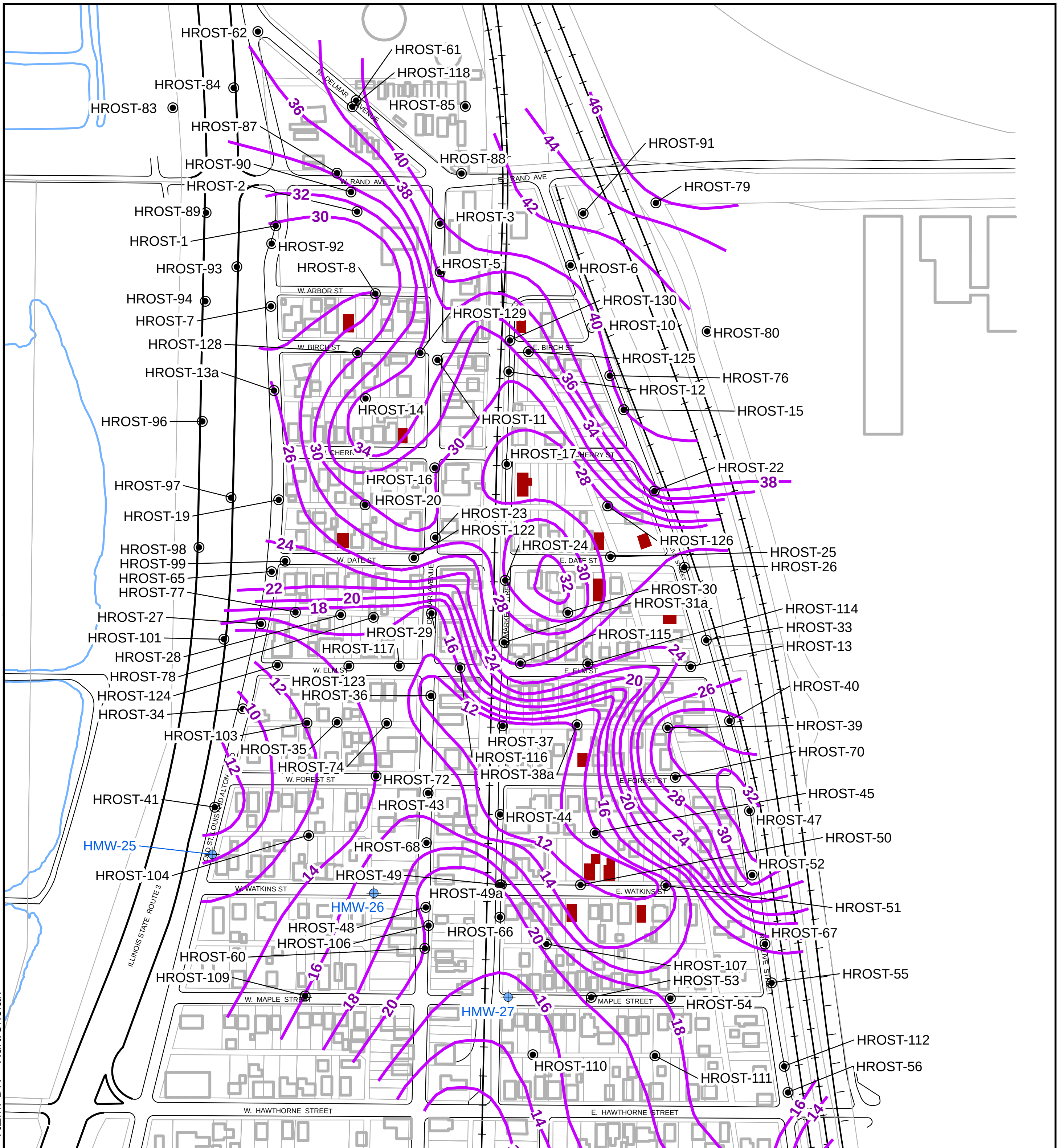
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 15

ISOPACH OF SILTY CLAY BETWEEN EPA STRATUM OR MAIN SAND AND THE RAND STRATUM OR NORTH OLIVE STRATUM

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA15_Silty_Clay_above_EPA.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- ROST Sample Location
- HMW Well
- Main Contour in feet
- Pond
- Railroad
- Parcel
- Building
- Building with Reported Fire

N
W E
S

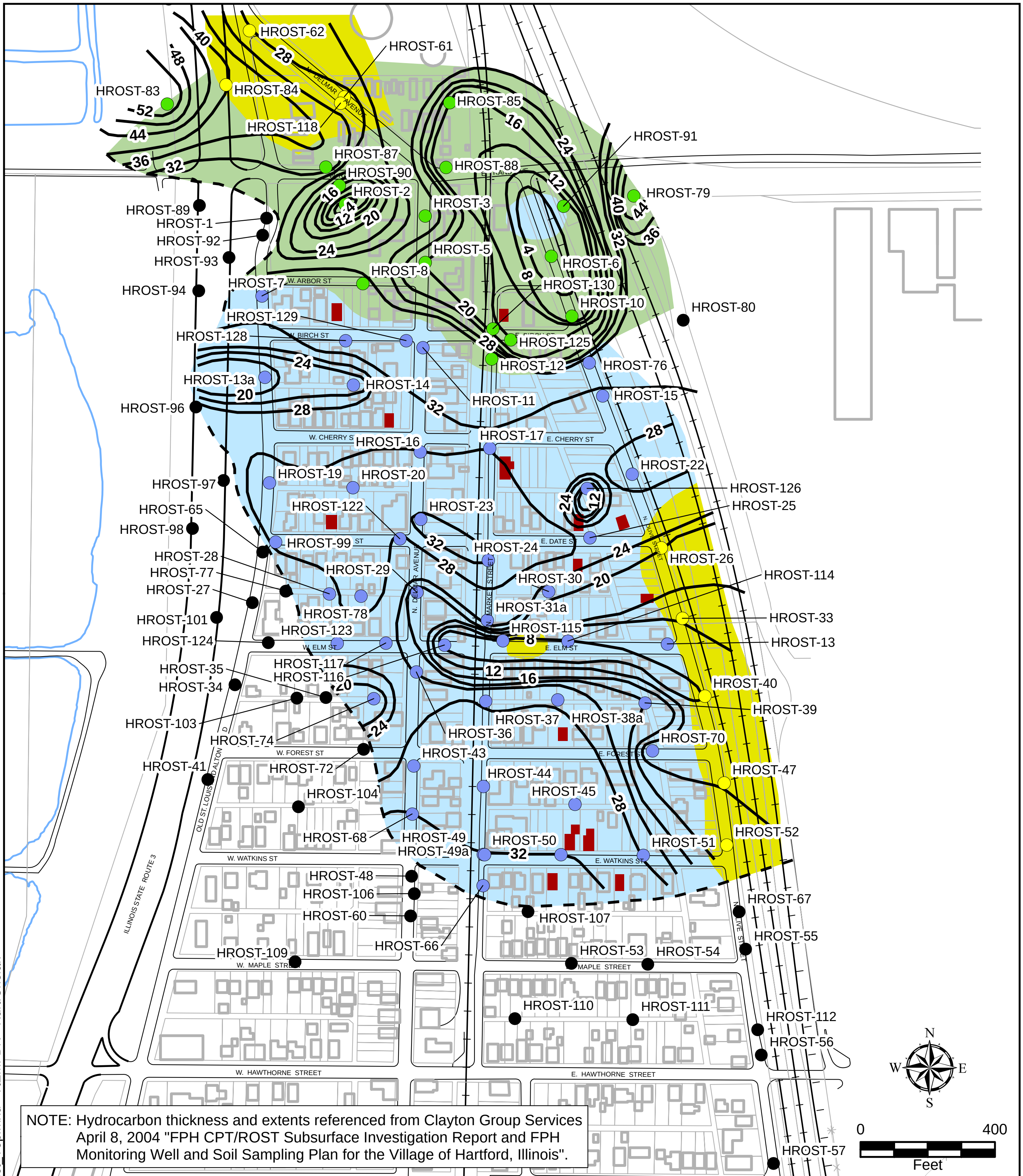
0 400
Feet

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 16
TOP OF MAIN SAND

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA16_Main_Sand_Top.mxd TtEMI-DN Kurt.Cholak



NOTE: Hydrocarbon thickness and extents referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

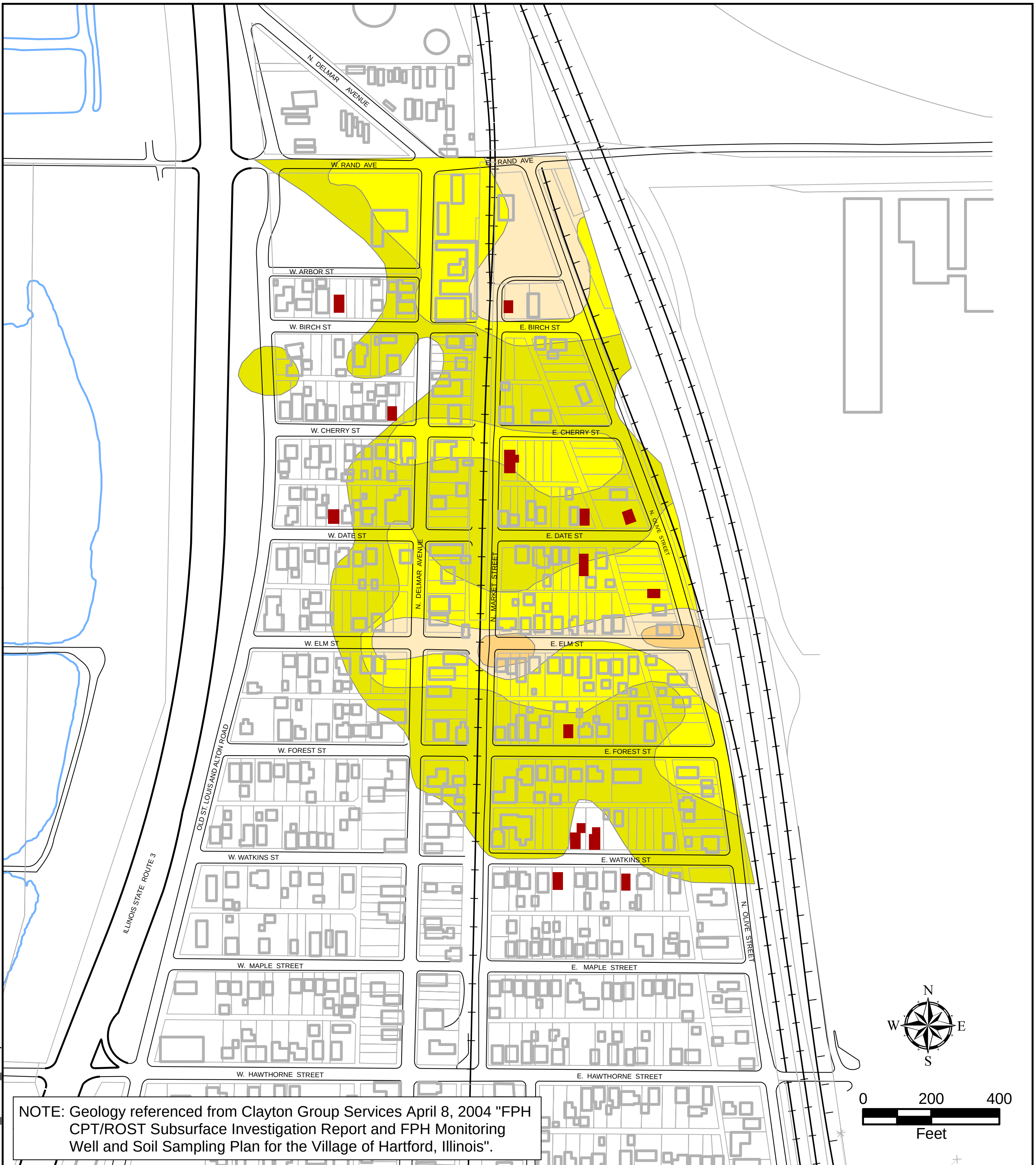
- ROST Sample Location - no apparent product
- ROST Sample Location - Light Range Product
- ROST Sample Location - Mid Range Product
- ROST Sample Location - Heavy Range Product
- Product Boundary
- Product Contour in feet, depth below surface
- Building
- Building with Reported Fire
- Light Range Product Boundary
- Mid Range Product Boundary
- Heavy Range Product Boundary
- Pond
- Railroad
- Parcel

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 17
TOP OF TOTAL PETROLEUM HYDROCARBON ROST RESPONSE

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA17_Total_Product_Top.mxd TtEMI-DN Kurt.Cholak



NOTE: Geology referenced from Clayton Group Services April 8, 2004 "FPH CPT/ROST Subsurface Investigation Report and FPH Monitoring Well and Soil Sampling Plan for the Village of Hartford, Illinois".

Legend

- 5 to < 10 Feet of total ROST Response
- 10 to < 20 Feet of total ROST Response
- 20 to < 30 Feet of total ROST Response
- 30 to < 40 Feet of total ROST Response
- Building
- Building with Reported Fire
- Pond
- Railroad
- Parcel

Note: < Less Than

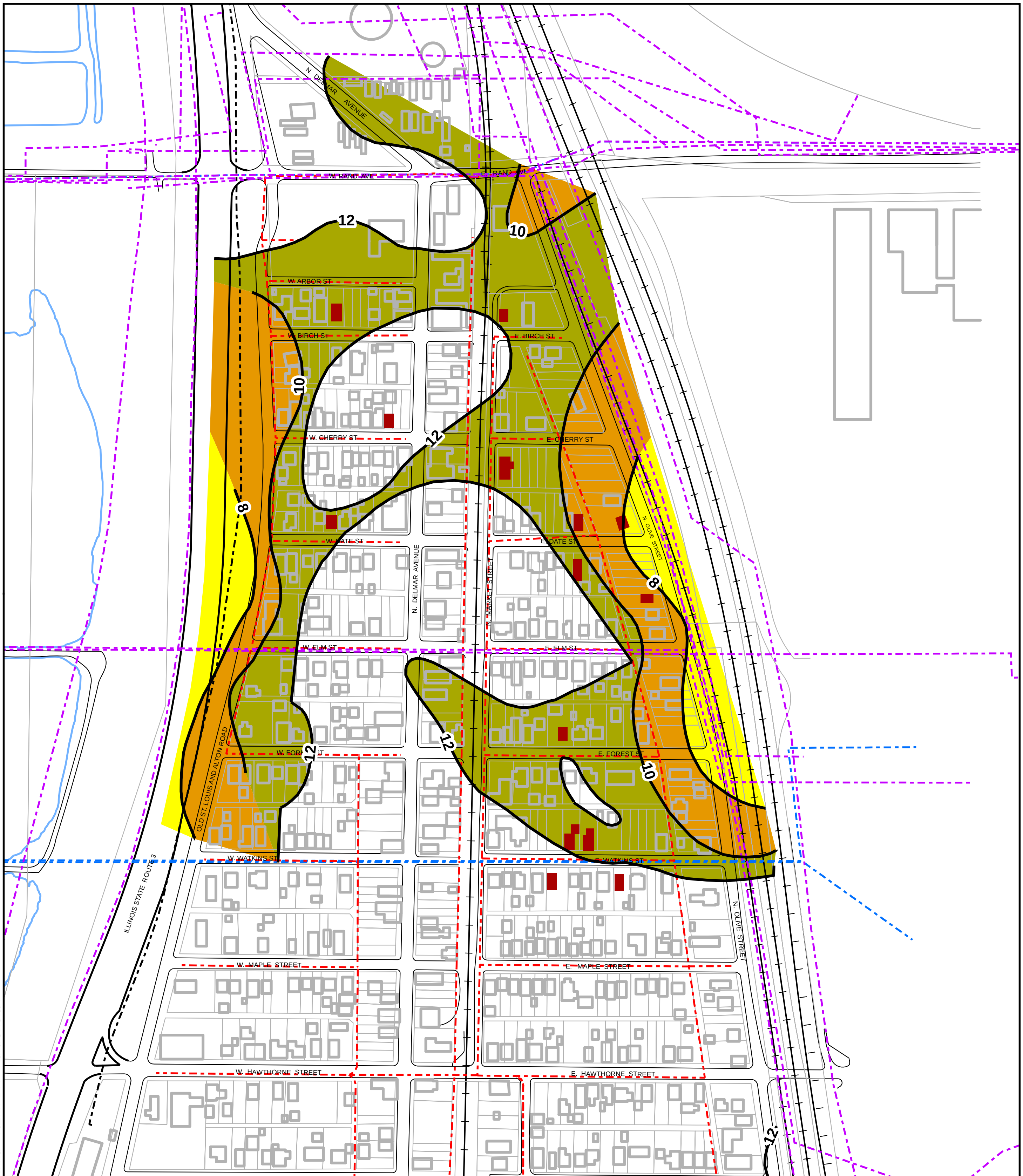
Sources:
Clayton Group Services, Inc. 2006a.,
Clayton Group Services, Inc. 2004b.,
Clayton Group Services, Inc. 2006c.

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 18

TOTAL PETROLEUM HYDROCARBON ROST RESPONSE THICKNESS

TETRA TECH EM INC.



Legend

Top of Sand
(feet - depth from surface)

Product Pipeline

Municipal Sewer

Industrial Sewer

Forced Main

Pond

Railroad

Parcel

Less than 8 Feet Below Ground Surface

8-10 Feet Below Ground Surface

10-12 Feet Below Ground Surface

Building

Building with Reported Fire

N S W E

0 400

Feet

HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS

FIGURE 19

LOCATIONS WHERE POROUS STRATUM (SAND UNITS) ARE POTENTIALLY IN CONTACT WITH PRODUCT PIPELINES AND MUNICIPAL SEWERS

TETRA TECH EM INC.

2007-07-24 O:\DOJ\FigA19_Sewer_Map.mxd TtEMI-DN Kurt.Cholak

Considerations for Applying
the Triad Approach
Hartford Area Hydrocarbon Plume Site

Office of Solid Waste and
Emergency Response

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United States
Environmental Protection Agency
(5102G)
Washington, DC 20460