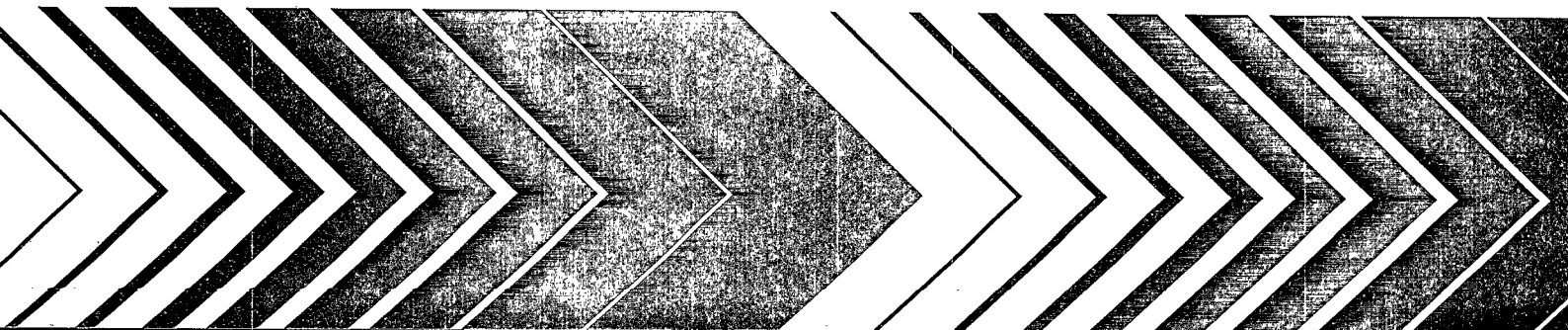
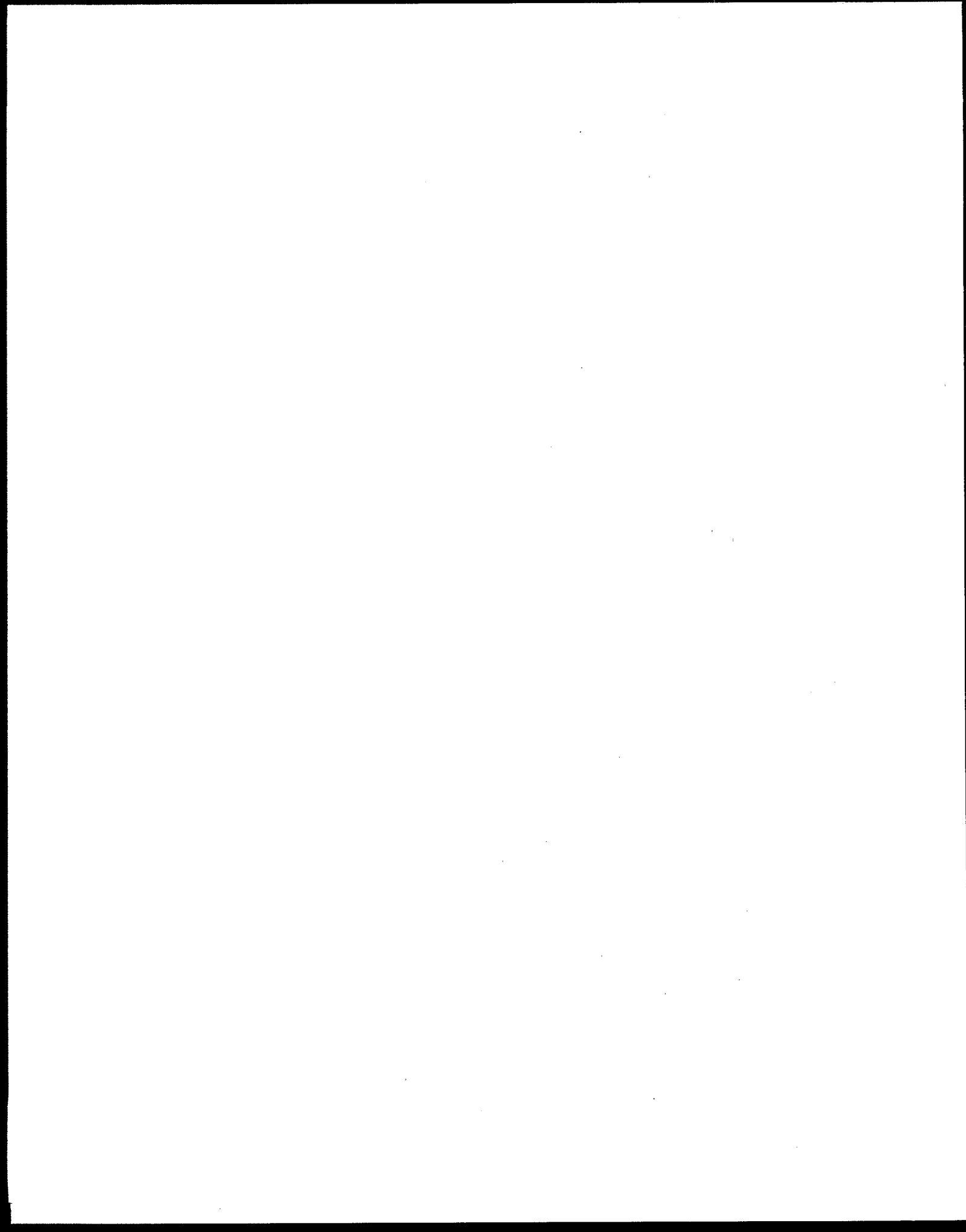




# **Monitoring and Assessment of In-Situ Biocontainment of Petroleum Contaminated Ground-Water Plumes**





# **Monitoring and Assessment of In-Situ Biocontainment of Petroleum Contaminated Ground-Water Plumes**

by

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## Notice

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## Abstract

This two-year field research project was conducted to assess the potential for natural attenuation of gasoline contaminated groundwater plumes at two underground storage tank (UST) sites in northern Utah. An evaluation of rapid site assessment techniques for plume delineation and subsurface site characterization was carried out using cone penetrometer and ambient temperature headspace (ATH) analysis techniques. An approach was developed for the collection and evaluation of initial site contaminant soil concentration and routine ground-water quality monitoring data for the determination of the efficacy of in situ biocontainment and "stabilization" of fuel-impacted groundwater plumes to provide guidance regarding implementation of an intrinsic remediation, monitoring-only alternative at UST sites. A screening-level Natural Attenuation Decision Support System (NADSS) was developed to provide guidance to regulatory personnel on data collection, data reduction, data interpretation, and decision-making efforts to evaluate the nature and potential extent of intrinsic plume bioattenuation taking place under a given set of site conditions. This screening-level NADSS is described in detail, and IBM PC compatible software is provided in a companion EPA document: *A Screening Level Natural Attenuation Decision Support System for the Assessment of Biocontainment of Hydrocarbon Contaminated Plumes*. Data collected from the two field sites are presented and evaluated in detail in the report, and the rate and extent of the natural attenuation of ground-water plumes at these two sites are quantified.

This report was submitted in fulfillment of CR 818835-01 by Utah Water Research Laboratory, Utah State University, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 24, 1991, to August 15, 1995, and work was completed as of January 15, 1995.



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## Abbreviations and Symbols

ADE	Advection-dispersion equation
ATH	Ambient Temperature Headspace technique
BTEX	Benzene, toluene, ethylbenzene, xylenes
CEC	Cation exchange capacity
CPT	Cone penetrometer testing
DDW	Distilled deionized water
DEQ	Department of Environmental Quality
EQL	Environmental Quality Laboratory, UWRL
FID	Flame ionization detector
GC	Gas chromatography
HAFB	Hill Air Force Base, Utah
HC(s)	Hydrocarbon(s)
IC	Ion chromatography
ICP	Inductively coupled plasma arc spectrophotometer
LIB	Lab-In-A-Bag ATH method
MSE	Mean square error
OVN	Organic vapor monitor
PID	Photoionization detector
MCL	Maximum contaminant level
NADSS	Natural Attenuation Decision Support System
TCD	Thermal conductivity detector
TDS	Total dissolved solids
UST	Underground storage tank
UWRL	Utah Water Research Laboratory
VOA	Volatile organic analysis

### SYMBOLS

H	Henry's law constant
K <sub>d</sub>	Soil/water partitioning coefficient

---

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# Chapter 1

## Introduction

### General Problem Statement

Potential groundwater quality impacts from leaking underground petroleum storage tanks are a significant environmental concern due to the sheer number of such tanks ( $\approx 1.2$  million (NWWA, 1985; U.S. EPA 1984a, 1986a)) and the extent of possible environmental contamination when they leak. Hinchee et al. (1987) estimated that 130,000 gallons of groundwater, 2,300 yd<sup>3</sup> soil, and 800 yd<sup>3</sup> of soil vapor could be contaminated from 1,000 gallons of gasoline. Compounding the problem is the fact that many tanks have reached or exceeded their design life; many are not adequately protected against corrosion; and many do not have adequate overfill and spill containment systems.

Many of these petroleum storage tanks are currently being removed and replaced or upgraded to eliminate the source of possible petroleum contamination to underlying aquifers. However, there remains a large number of sites with groundwater contamination above existing water quality limits (300,000 confirmed releases as of June 1995, with an additional 100,000 releases expected by 2000 (e.g., Hal White, U.S. EPA, Office of Underground Storage Tanks (OUST), personal communication, 1995)). While contamination from petroleum storage tank releases can have a significant impact on public health and the environment, active remediation of each of these contaminated sites represents a significant resource burden to the independent tank owners, the petroleum industry, and the public. Historically, however, expectations of having to apply active remediation at all sites has generally not allowed focusing resources on those sites which represent the greatest threat to public health and the environment.

When released into the subsurface environment, gasoline distributes among the soil, gas, and water phases that make up this environment. As the gasoline moves through the unsaturated zone, it leaves behind vapors containing volatile gasoline components and residual liquid hydrocarbons retained within the soil matrix. A large fraction of gasoline components are

water soluble and migrate to underlying groundwater with infiltrating water. Plumes of groundwater hydrocarbon contamination spread within the soil environment by groundwater advection and diffusion. These contaminants are generally not conservative, but are degraded and transformed through a variety of biotic and abiotic processes which actively take place in the subsurface environment (Dragun, 1988; Lyman et al., 1991; U.S. EPA, 1991). Many gasoline components are biodegradable, and a primary mechanism for their transformation in the subsurface is via biodegradation. During biodegradation, these components provide a carbon and energy source for the growth of soil microorganisms, resulting in a demand for terminal electron acceptors that are necessary if energy is to be extracted from these hydrocarbon contaminants. These biodegradation reactions take place under a variety of soil pH and oxidation reduction potential (redox) conditions and involve various terminal electron acceptors (oxygen, nitrate, manganese, iron, sulfate, carbon dioxide, carbon). Also, these reactions take place at various rates, each affecting, to a different degree, the ultimate migration and effective containment of contamination in both the unsaturated and saturated zones.

Due to dispersion and diffusion, concentrations of contaminants are relatively low near the fringes of the plume. Slow advective rates and low contaminant concentrations near the plume boundaries provide an opportunity for microbial communities to become enriched with contaminant degraders. This enrichment results in microbial populations capable of decomposing the advancing plume. If biodegradation of the contaminant proceeds at a rate greater than or equal to the rate of advance of the contaminant front, the plume will be effectively contained, and it can eventually be completely remediated if the source of contamination is removed.

This biocontainment proceeds at a rate limited by the overall limiting reaction, e.g., oxygen transfer to the plume, contaminant solubilization, nutrient availability, etc. It can be hypothesized then, that under certain

conditions, intrinsic biodegradation processes can prevent significant migration of contaminants away from the source of contamination, i.e., degradation rate  $\geq$  transport rate away from source. Once the source of contamination is removed, e.g., following tank repair/removal, intrinsic biodegradation mechanisms may eventually result in complete contaminant removal from the affected soil/groundwater.

The only costs associated with site clean-up under these intrinsic biocontainment conditions are related to costs for source removal and for the necessary, ongoing monitoring of contaminant distribution and movement over the lifetime of the dissolved contaminant plume. This low-cost management option is attractive to both the regulatory and regulated communities. It becomes necessary, however, to quantitatively describe such degradation reactions unambiguously so that reliance on passive methods can be assured for long-term contaminant control and protection of public health and the environment. Without reliable containment information, contamination may continue to spread, worsening existing conditions, posing increased public health risk, and increasing final cleanup costs.

Knowledge of intrinsic degradation process rates for contaminants at fuel release sites has been limited. This lack of information has been primarily due to the lack of standard, well-tested methodologies for the monitoring and quantification of in situ degradation rates in subsurface soil and groundwater environments. To obtain this type of information, chemical/biological parameters in an aquifer and the overlying vadose zone indicative of in-situ biodegradation processes taking place in these environments must be well understood and documented. Once this is accomplished, routine measurements of these parameters, or a subset of these parameters, would allow identification of conditions under which in-situ biodegradation could be relied upon to provide natural attenuation of a contaminant plume. These measurements would also provide a methodology for monitoring the progress of contaminant degradation in response to efforts to enhance intrinsic plume biocontainment.

Ideally, measurements to identify hydrocarbon contaminated groundwater conditions that would result in effective plume biocontainment, and measurements used to monitor the progress of these biodegradation reactions, would be made on-site using simple and low-cost methods. This would allow inexpensive determinations to be made rapidly and routinely at many locations throughout a site, without the need for costly and delayed laboratory support. This would facilitate sound environmental management of the many thousands of leaking underground storage tank sites that exist throughout the country.

Although this simple field-based approach is not entirely feasible, rapid field measurements, supported by inexpensive laboratory determinations of critical groundwater quality variables, provide sufficient information to assess the potential for in-situ biocontainment of a groundwater plume. This also allows the monitoring of the progress of these attenuation reactions over time.

This project involved the evaluation of simple on-site instruments (headspace hydrocarbon analyzer, pH meter, dissolved oxygen (DO) meter, commercially available chemical kits for analysis of alkalinity,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  in groundwater, and a hand-held  $\text{O}_2/\text{CO}_2$ /total hydrocarbon meter for gas analysis. These on-site measurements were supported by laboratory analyses ( $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  in groundwater) to evaluate the effectiveness of field screening measurements. These measurements were made to quantitatively describe significant bioprocesses controlling the fate and movement of dissolved hydrocarbon plumes at a site. The total suite of water quality data could not be reliably determined from field analyses. However, a combination of field-determined parameter values (headspace hydrocarbon analysis, pH, alkalinity and DO in groundwater and an  $\text{O}_2/\text{CO}_2$ /total hydrocarbon analysis for the soil gas) and laboratory-determined properties ( $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ ,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$  in groundwater) were found to be a low-cost approach to quantitatively describe intrinsic remediation reactions occurring at the two study sites. With these low-cost, routine measurements, it is hoped that more frequent data can be obtained, to allow improved, more cost-effective, protective management of UST sites.

Environmental hazards from leaking underground storage tanks are significant. Active, intensive remediation of all of the estimated 300,000 to 400,000 potential sites is neither technically practical, nor economically feasible. The dilemma facing the regulatory community is the requirement to protect public health and environmental quality with limited manpower and a shrinking resource base. The goal of this project was to identify and validate field monitoring, data reduction, and reporting techniques that can be utilized to rapidly and conclusively demonstrate the existence of intrinsic biodegradation reactions at leaking UST sites. With this demonstration of natural containment of a hydrocarbon plume, rational decisions can be made regarding the need for active remediation to ensure protection of public health and the environment. Based on an evaluation of field and laboratory water-quality and soil-core measurements, and companion modeling results, recommendations regarding the selection of process variables, monitoring procedures, and data reduction and reporting methods needed at hydrocarbon contaminated sites to document intrinsic bioremediation of groundwater plumes have been made.

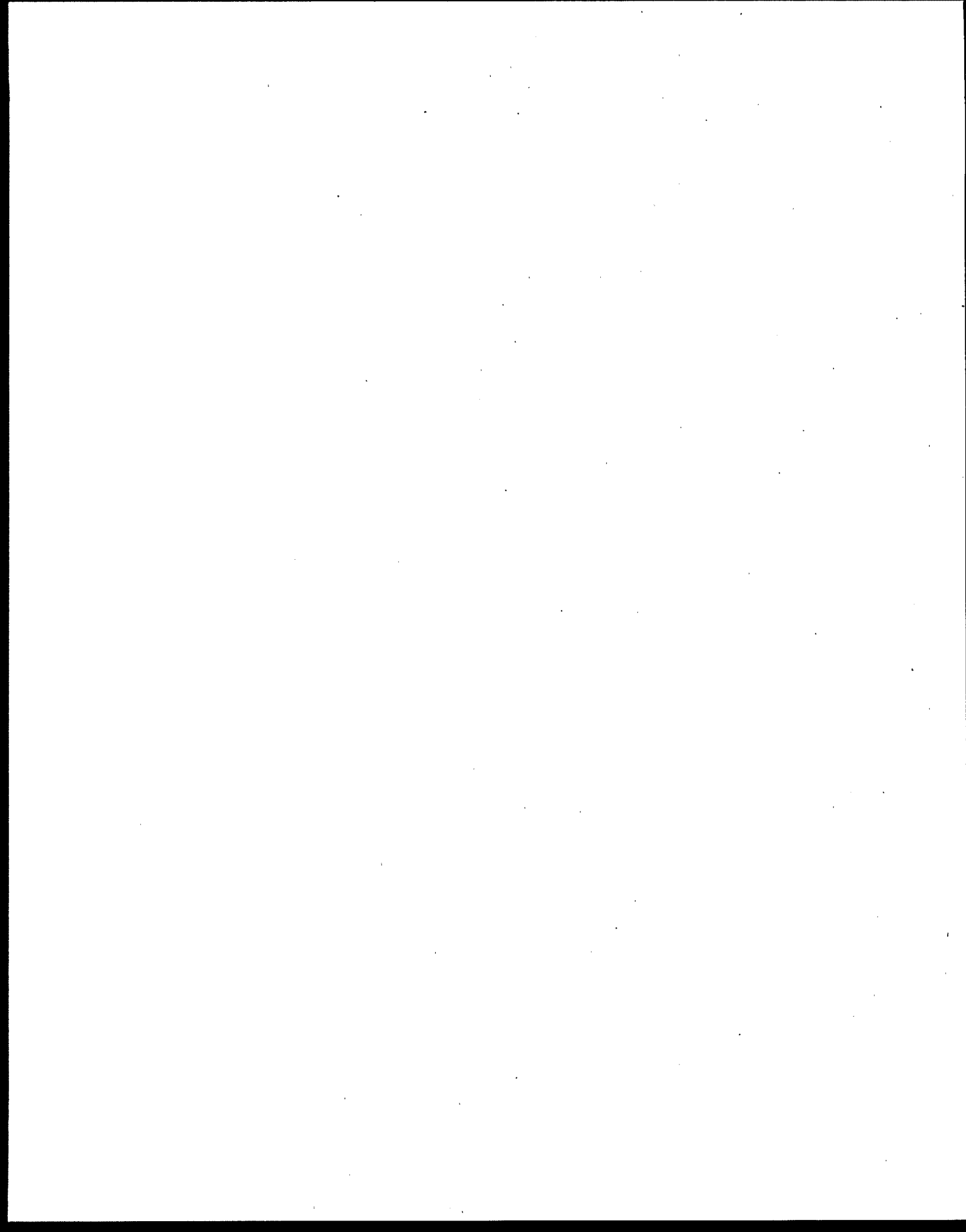
These recommendations form the foundations of a screening-level Natural Attenuation Decision Support System (NADSS) described in a companion document, *A Screening Level Natural Attenuation Decision Support System for the Assessment of Biocontainment of Hydrocarbon Contaminated Plumes*. In this decision support system, site-specific soil, site, and contaminant characteristics are utilized to aid site remediation personnel in: 1) the design of data-gathering programs, 2) the analysis, verification, and interpretation of field data, 3) the use of a screening-level contaminant fate and transport model, 4) the assessment of the impact of source removal on accelerating overall plume stabilization and site remediation, 5) the determination of the reliability of intrinsic biocontainment for site management to assure the protection of public health and the environment, and 6) the need for further evaluation of natural attenuation mechanisms occurring at a particular site through long-term monitoring and advanced-level natural attenuation modeling.

### Objectives

This work was conducted because of the need for prudent investment of environmental cleanup funds, because of the containment/treatment potential of intrinsic biodegradation processes occurring at fuel contamination sites, and because of the perceived need for a standard methodology for developing and interpreting site characterization data to quantify these

intrinsic biodegradation reactions. Specific objectives of this research project were to:

1. Assess intrinsic biodegradation reactions occurring at two well-defined fuel spill sites.
2. Assess and select practical field sampling and analytical methods which best quantify the observed biodegradation reactions. This assessment was based on a comparison of field methods with rigorous laboratory analyses. It was also used to identify which parameters are best quantified with standard laboratory techniques.
3. Develop a data reduction and analysis methodology that could be used to quantify intrinsic remediation processes occurring at a UST site based on field and laboratory-determined soil and groundwater quality data.
4. Develop a screening-level decision support system which would guide site managers through the site assessment and biocontainment prediction process to determine whether an intrinsic remediation approach is protective, or whether a more aggressive corrective action approach is required at a given site.





## Chapter 2

### Conclusions

The research was conducted in four phases. The first was a site assessment/characterization phase in which contaminant distribution and site hydraulic characteristics were determined using field and laboratory methods. The second phase involved process monitoring, in which field and laboratory analyses were used to monitor ground-water and soil gas characteristics that reflected in-situ biodegradation reactions taking place throughout the field sites. The third phase was the reduction of field data to yield quantitative estimates of plume mass, plume migration, and source lifetime. The final phase involved the use of a three-dimensional analytical model to provide in-situ biodegradation process verification and long-term predictions of the fate of the plumes as they were attenuated by natural biodegradation reactions. Based on the results of the study, the following conclusions can be made for each phase of investigation.

#### Site Assessment Techniques

##### *Cone Penetrometer Testing (CPT) Techniques*

1. Results from the Hill Air Force Base (AFB) site indicate that conventional site assessment techniques based on small numbers of large diameter ground-water monitoring wells and limited soil core and shallow soil gas survey data can be severely limited in their ability to provide a detailed understanding of subsurface soil conditions at a site.
2. The CPT techniques used in this study allowed the delineation of subsurface conditions that greatly impacted local ground-water flow and contaminant transport below the Hill AFB site. This resulted in a significant modification to the conceptual model of contaminant distribution and migration observed at the site.
3. The CPT approach, coupled with placement of small diameter ground-water monitoring probes and field ambient temperature headspace (ATH) measurements, enabled the collection of cost-

effective data for accurate plume delineation on nearly a real-time basis.

##### *Ambient Temperature Headspace Measurements*

1. Literature findings suggest that for reproducible, temperature-insensitive ATH measurements, headspace-to-liquid volume ratios should be as high as possible without compromising contaminant sensitivity. Values between 10:1 and 20:1 should be sufficient to yield robust measurements, with acceptably low method detection limits.
2. The use of a detector that provides a linear response to organics over a wide range of contaminant concentrations is critical in obtaining representative ATH measurements. The flame ionization detector (FID) has this characteristic (Perry, 1981), and is generally preferred over photoionization detector (PID) systems which are more sensitive to moisture and have a narrower linear range than the FID (U.S. EPA, 1990b; Holbrook, 1987).
3. The use of ATH methods must be based on a general knowledge of the nature of the contamination being screened for. For a given contaminant distribution, the ATH method provides consistent and representative indications of the level of contamination in a given sample. However, when contaminant composition varies significantly between sites or within a given site, this contaminant level/ATH relationship begins to lose its validity.

##### *Field Versus Laboratory Generated Data*

1. The data obtained for the Hill AFB and Layton sites support the findings of Robbins et al. (1989) which suggest that, for a given distribution of contamination, field ATH measurements provide a consistent and representative indication of the level of

contamination in a given sample. Based on a comparison of data from each of the field sites, specific laboratory versus field concentrations relationships were site dependent.

2. Field ATH measurements appeared more sensitive to the contaminant distribution found at the Layton site (where a hydrocarbon sheen on a number of ground-water samples was observed) compared to that observed at the Hill AFB site. This was based on the slope of the laboratory purge and trap versus field ATH ground-water concentration relationships observed at each site. The slope of this relationship was less than one at the Hill AFB site, while it was nearly two at the Layton site.
3. The field ATH measurement method appears, as expected from theory, to be more sensitive in field situations with free product or high levels of residual saturation than at those sites where weathered fuel contamination exists.
4. Based on the combined data set's normalized residuals, it was shown that the combined regression loses its accuracy at high ground-water concentrations. This suggests that site-specific relationships between laboratory and field hydrocarbon measurements will be more valid than general relationships developed from a range of site conditions.
5. Field ATH measurements can be used to effectively guide initial ground-water quality investigations and to optimize ground-water monitoring probe and monitoring well placement for long-term site monitoring. However, field screening data should not be used as a substitute for laboratory-determined ground-water hydrocarbon data.

### **Site-Specific Intrinsic Remediation Mechanisms**

The intrinsic remediation evaluation protocol developed in this study was used to evaluate the potential for plume containment and to quantify intrinsic attenuation mechanisms taking place at the two field sites. This seven-step protocol involved: 1) determining whether a plume has reached steady-state conditions; 2) quantifying contaminant degradation rates; 3) estimating the mass of contaminant remaining in the source area; 4) estimating the length of time the source area will continue to act as a source of ground-water contamination; 5) predicting the long-term behavior of the plume; 6) making decisions regarding the acceptability of an intrinsic remediation management approach at a given site; and 7) developing a long-term monitoring strategy for compliance and intrinsic remediation process monitoring. Based on the

application of this protocol to the two field sites investigated in this study, the following conclusions can be reached.

### **Hill AFB Site**

1. A centerline concentration profile analysis of specific compound and total petroleum hydrocarbon (TPH) plumes existing at the Hill AFB site indicated that a significant decline in all contaminant concentrations took place within the dissolved plume over the course of the study.
2. Dissolved contaminant mass data also showed a significant decline in plume mass for all specific compounds and TPH by the end of the two-year study. Center of mass calculations indicated a movement of all mass centers 17 to 106 ft downgradient of the source area. This suggested that the plume was responding to a pulse source with contaminant attenuation.
3. Dissolved plume mass changes over time were used to estimate zero and first order degradation rates for benzene, toluene, ethylbenzene, and xylene (BTEX), naphthalene, and TPH contaminants.
4. The BTEX components followed zero order degradation with rates ranging from 0.06 g/d for ethylbenzene and p-xylene to approximately 0.1 g/d for benzene and toluene. Naphthalene and TPH followed first order kinetics with rates of approximately 0.03 and 0.009/d, respectively.
5. Based on the dissolved contaminant masses evident in the plume at the end of the study period, the lifetime of the BTEX compounds within the plume was short (less than two weeks). Approximately 270 days was predicted for 99.9 percent naphthalene removal. More than two years was estimated for the same removal efficiency of TPH components under existing site conditions.
6. The decision to apply intrinsic remediation at this site is warranted based on: 1) the contaminant degradation rates and plume attenuation observed; 2) the lack of an impacted downgradient receptor; and 3) the potential aquifer assimilative capacity that is more than 90 times greater than that required for the assimilation of the TPH and BTEX remaining in the dissolved plume.
7. A long-term monitoring scheme for both compliance and process monitoring purposes can be carried out using the existing monitoring network. Annual monitoring until 1997 should

provide adequate data to validate complete plume assimilation to permit site closure.

### **Layton Site**

1. Centerline concentration profile analysis of specific compound and TPH plumes existing at the Layton site indicated that, despite variations in concentrations, the plume appeared to be at steady-state conditions during the course of the study and through February 1995.
2. Plume steady-state conditions were confirmed using dissolved contaminant mass and center of mass calculations. Center of mass data indicated that only TPH showed any actual downgradient movement, and its mass center showed only a net movement of 10 ft over the two-and-a-half year study period. These results suggest that the Layton plume was acting as a continuous source which was stabilized by ongoing intrinsic attenuation mechanisms.
3. Changes in contaminant plume centerline concentrations with distance from the source area were used to estimate contaminant first order degradation rates for BTEX and naphthalene. Contaminant retardation factors were used to convert downgradient distances to contaminant travel times so that these rates could be expressed in the conventional units of 1/time.
4. The contaminant fate and transport model described in this study was also used to estimate contaminant degradation rates through model calibration to measured field data. Field data from March 1993 were used for the BTEX components to generate first order degradation rates. These calibrated rates account for dispersion, dilution, and site-specific sorption and transport characteristics that control the movement and degradation of contaminants at the Layton site. Degradation rates generated from the plume centerline concentration method were statistically equivalent to those developed from the model calibration effort at the 95 percent confidence level.
5. Naphthalene concentrations, observed along most of the March 1993 plume centerline transect, were above 1 mg/L and exceeded the expected naphthalene aqueous equilibrium concentration which was based on the known composition of automotive gasoline. Consequently, a time-averaged naphthalene concentration was used for model calibration. A portion of the naphthalene transect, with time-averaged concentrations below the known equilibrium water concentration, was selected for model calibration. This yielded a first order naphthalene degradation rate that was statistically equivalent to the rate generated from the centerline concentration method.
6. Comparison of results from the centerline concentration and model calibration methods for degradation rate estimates for continuous sources suggest that the simpler degradation rate approach can be used to provide representative contaminant degradation rates when a plume has reached steady-state conditions.
7. The soil-core data available from the Layton site were limited and provided residual phase source area mass values that were underestimated based on masses dissolved in the ground-water plume in February 1995. Residual product volume estimates were based on gasoline residual saturation values reported in the literature for silty clay soils similar to those at the Layton site.
8. From these residual mass estimates, the lifetime of the total mass of BTEX and naphthalene at the Layton site, based on reaching their maximum contaminant level (MCL) values in the plume, ranged from approximately 30 years for toluene to over 100 years for ethylbenzene. Due to MCL concerns for ethylbenzene, the projected site management time frame without source removal was approximately 100 years.
9. With 100 percent source removal, the required site management time frame, based on the ethylbenzene MCL, was reduced to approximately 14 years. Under these site conditions, however, benzene becomes the contaminant with the greatest duration of concern, requiring approximately 22 years to reach its MCL value of 5 µg/L.
10. The time to reach ground-water MCL values for the BTEX components was also estimated using the field calibrated fate-and-transport model. Results from these simulations indicated that site management would be controlled by the benzene plume since it was projected to require approximately 18 years to reach an MCL of 5 µg/L everywhere within the plume following 100 percent source removal or source depletion. The time to reach the MCL values for all other components was projected to be seven-and-a-half years or less.
11. The decision to apply only an intrinsic remediation plume management approach at the Layton site should be made with caution.

Despite apparent plume stabilization and the lack of an impacted downgradient receptor, low contaminant degradation rates (approximately one order of magnitude lower than at the Hill AFB site), large residual masses of contaminant within the source area and a marginal potential aquifer assimilative capacity will require long-term monitoring and site management estimated to last more than 100 years.

12. Active source removal and residual mass remediation are warranted at the Layton site to accelerate the rate of contaminant removal from the site and shorten the length of time required for plume management.
13. A long-term monitoring scheme for both compliance and process monitoring purposes can be carried out using the existing monitoring network. An annual monitoring frequency should provide adequate data to validate plume assimilation and to refine estimates of plume lifetime and contaminant removal rates.

## **Overall Methodology**

### ***Improvements in Field Screening/Plume Delineation***

1. The combined CPT/ATH procedures used in this field investigation for initial plume delineation proved to be rapid and cost effective. These procedures led to a significantly improved understanding of subsurface conditions at both of the field sites.
2. These procedures enabled the use of densely spaced sampling networks that provided a detailed picture of contaminant distribution at these sites. This network spacing produced detailed quantification of dissolved contaminant mass and center of mass migration and allowed a detailed assessment of contaminant

degradation and plume attenuation not possible with a more conventional monitoring approach.

### ***Implementation of the Intrinsic Remediation Protocol***

1. The intrinsic remediation protocol developed in this study provides a logical, quantitative approach for evaluating the presence and rates of contaminant assimilation within an aquifer system.
2. The protocol provides improvements over conventional assessment methods for plume containment through its use of multiple approaches to evaluate intrinsic remediation processes occurring under field conditions. Plume centerline concentration analysis is used, along with plume mass and center of mass analysis, to incorporate the aerial aspects of plume containment that have not normally been incorporated into field evaluations of intrinsic remediation processes.

### ***Utility of the Fate-and-Transport Modeling Approach***

1. The modeling approach used to describe intrinsic remediation processes occurring at the two UST field sites allowed the quantitative assessment of contaminant migration and degradation using data from the field screening and plume delineation approaches developed in this study.
2. The model was easy to implement in a spreadsheet environment and appeared to provide a quantitative description of contaminant plume profiles that were observed at the two distinctly different field sites evaluated in this study. The model provided independent verification of plume steady-state conditions and allowed the rapid assessment of the impact of various source removal options on the duration of contaminant plumes produced from hydrocarbon releases at these sites.

## Chapter 3

### Recommendations

An evaluation of rapid site screening/plume delineation techniques and a quantitative assessment of natural attenuation mechanisms taking place at two field sites were carried out in this study. Based on these results, the following recommendations can be made regarding site assessment/plume delineation and the evaluation of intrinsic remediation mechanisms for plume containment at UST sites.

#### Site Assessment Techniques

##### ***Cone Penetrometer Testing (CPT) Techniques***

Rapid plume delineation techniques (i.e., CPT, Geoprobe) offer the complete elimination of soil cuttings and large volumes of contaminated ground water that are often costly and regulatorily challenging to manage. This makes the screening techniques used in this study ideal for application at many sites. Due to the effectiveness of the CPT techniques used in this study to accurately delineate localized site characteristics, it is recommended that some form of rapid plume delineation and field screening be implemented at most UST sites. The importance of additional insights into local ground-water flow conditions that can be provided by these CPT techniques, as in the Hill AFB case, is invaluable especially when considering an intrinsic remediation management option at a site. Accurate and representative plume delineation that can cost-effectively be provided by these rapid plume delineation techniques are essential if successful intrinsic remediation monitoring and modeling are to occur.

##### ***Ambient Temperature Headspace Measurements***

1. Literature findings suggest that for reproducible, temperature-insensitive ambient temperature headspace (ATH) measurements, headspace-to-liquid volume ratios should be as high as possible without compromising contaminant sensitivity. Values between 10:1 and 20:1 should be sufficient to yield robust measurements, with acceptable low method detection limits.

2. Use of a detector that provides a linear response to organics over a wide range of contaminant concentrations is critical in obtaining representative ATH measurements. The flame ionization detector (FID) has this characteristic (Perry, 1981), and it is generally preferred over photo ionization detector (PID) systems which are more sensitive to moisture and have a narrower linear range than an FID (U.S. EPA, 1990b; Holbrook, 1987).
3. The use of ATH methods must be based on a general knowledge of the nature of the contamination being screened for. For a given contaminant distribution, the ATH method provides consistent and representative indications of the level of contamination in a given sample. However, when contaminant composition varies significantly between sites or within a given site, this contaminant level/ATH relationship begins to lose its validity.

##### ***Field Versus Laboratory Generated Data***

1. The primary use of field ATH measurements appears to be in the initial site assessment phase, which was done in this study, where rapid, semi-quantitative results generated from the method are used for detailed plume delineation efforts.
2. Once this initial screening is completed, it is recommended that laboratory groundwater hydrocarbon concentration analyses be conducted to provide accurate ground-water quality data for further site fate-and-transport and intrinsic remediation evaluation.

##### ***Site-Specific Intrinsic Remediation Mechanisms***

###### ***Hill AFB Site***

Based on the results of this research project, ample evidence exists to suggest that intrinsic remediation

processes have successfully attenuated petroleum contaminants released at the Hill AFB site. The following recommendations for the site can be made based on these findings.

1. An intrinsic remediation management approach should be applied at this site. This approach suggests that the monitoring of ongoing processes should take place to ensure that aquifer conditions which have resulted in plume containment persist there over time.
2. Since the plume at the Hill AFB site appears to be responding as a pulse source, site management activities should focus on long-term monitoring. An annual monitoring frequency is recommended, with sample collection and analysis as presented in Chapter 6.
3. Site closure actions should be initiated when this annual monitoring indicates that contaminant assimilation (i.e., ground-water concentrations below contaminant MCLs throughout the site) has been accomplished. This process is projected to be complete by 1997.

### ***Layton Site***

Based on the results of this research project, ample evidence exists to suggest that intrinsic remediation processes have successfully attenuated petroleum contaminants released at the Layton site. The following recommendations for the site can be made based on these findings.

1. An intrinsic remediation management approach can be applied at this site. This approach is limited by the mass of contaminant that remains at the site, however. With the large mass of contaminant

remaining at the site, 30 to over 100 years was projected before source depletion and site restoration is complete if only accomplished by intrinsic remediation processes.

2. Since the plume at the Layton site is reflective of a continuous source, site management activities should focus on source removal and long-term monitoring. Source removal is prudent at this site to reduce the length of time the aquifer remains impacted. Monitoring of ongoing intrinsic processes should take place to ensure that aquifer conditions which have resulted in plume containment persist there over time. If source removal is not implemented, a three-to five-year monitoring frequency is recommended. If source removal activities are carried out, the time for site restoration is expected to be significantly reduced and a two- to three-year monitoring frequency is recommended. Sample collection and analysis should be carried out as described in Chapter 6.
3. The effectiveness of residual phase source removal at the Layton site should be investigated over the near term using field scale treatability assessments. Potentially applicable technologies include bioventing for residual contamination at and above the capillary fringe, and some form of air injection ground-water treatment, i.e., air sparging or preferably in-well aeration, for contaminant removal in the saturated zone. Application of these technologies for the removal of residual mass can greatly reduce the time required for plume management at the site. Application of these technologies may also reduce the overall site management costs if they can be implemented in a cost-effective manner.

## Chapter 4

### Materials and Methods

#### Research Approach

The research was conducted in four phases. The first was a site assessment/characterization phase in which contaminant distribution and site hydraulic characteristics were determined using rapid field characterization methods. The second phase involved process monitoring, in which field techniques were used to monitor ground-water and soil-gas characteristics that reflect in-situ biodegradation reactions taking place throughout the field sites. The third phase was the reduction of field data to yield estimates of total dissolved plume contaminant mass, center of mass, mass center trajectory, contaminant degradation rates, and estimated source lifetime. The final phase involved the use of a three-dimensional analytical model to provide in-situ biodegradation process verification and long-term predictions of the fate of the plume as attenuated by natural biodegradation reactions. This research effort was carried out by performing the following tasks.

1. Two field sites with known contamination from gasoline storage tanks were selected. These sites were former gasoline filling stations and were accessible to the research team. Both sites were "aged" with "constant" source terms where it was reasonable to hypothesize that natural biodegradation reactions, and subsequent plume containment, had developed and were quantifiable.
2. At both sites, single and multilevel ground-water monitoring probes were placed within and around the area of the contaminant plume. These wells included upgradient "background" wells, and wells within the area of contamination, allowing the definition of the boundaries of the plumes with some certainty. A gradient of chemical and biological conditions was observed throughout each plume so that transformation/degradation rates, mass transfer rates, etc., could be estimated. Plume characterization was carried out using cone penetrometry and 5/8-in diameter piezometer ground-water sampling wells to rapidly and inexpensively collect soil textural information and ground-water data from sampling locations throughout each plume. Following initial plume characterization, multilevel monitoring points were installed with three monitoring points placed within a 15-in radius of each other. Soil samples were collected from three locations within the vadose zone and three locations within the saturated zone during the construction of each well to provide soil core data for the initial site characterization phase of the study. During long-term monitoring, site characterization information was collected using all of the ground-water sampling points.
3. Multilevel unsaturated zone sampling wells were located throughout the site to allow monitoring of biodegradation processes taking place within the zone of contamination. Unsaturated zone sampling probes were placed using three monitoring positions per well, and were located based on ground-water hydrocarbon concentrations measured throughout the site. An attempt was made to provide a three-dimensional description of the unsaturated zone lying above the contaminated aquifer during the long-term monitoring phase of the project using these sampling locations.
4. The following data were collected throughout the site during the initial site characterization phase of the project.
  - pH (soil & ground-water)
  - O<sub>2</sub> (ground-water)
  - Fe<sup>2+</sup>, Mn<sup>2+</sup> (ground-water)
  - NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> (ground-water)
  - Aromatic hydrocarbons, TPH (soil, soil-gas, and ground-water)
5. The following data were collected throughout the site six times during the process monitoring phase of the project.
  - pH (ground-water)
  - O<sub>2</sub>, CO<sub>2</sub> (soil-gas)
  - O<sub>2</sub> (ground-water)

- $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$  (ground-water)
  - $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  (ground-water)
  - Aromatic hydrocarbons, TPH (soil-gas, and ground-water)
6. Field data were reduced to generate estimates of total dissolved mass of contaminant and the migration of this contaminant mass using the following techniques.
- Total dissolved plume mass was estimated using the Thiessen area method (Chow et al., 1988) to assign a specific plume area to each ground-water monitoring point. Total dissolved plume mass was estimated for each sampling event used in the study.
  - The center of the dissolved plume mass was estimated by taking the first moment about a defined axis at each site. The dissolved plume center of mass (centroid) was determined for each sampling event used in the study.
  - The movement of the plume centroid over time was described based on the changes in its absolute position. Contaminant plume velocities were calculated between each sampling interval.
  - Contaminant degradation rates were estimated based on the change in total dissolved plume mass between each sampling interval.
  - Aquifer assimilation capacity was estimated based on the change in terminal electron acceptor concentration and mass within versus outside the plume.
7. Finally, an analytical, three-dimensional ground-water fate-and-transport model which accounts for advection, dispersion, contaminant sorption, and contaminant degradation was applied to both field sites to validate the observation of intrinsic biodegradation at these sites. The use of this model involved the following steps.
- Hydraulic properties for the aquifer were selected based on measured field data and information regarding the nature of soil below each site.
  - A source configuration was established for each site. Model input variables for measured source concentrations, contaminant properties, and time since the release were varied to evaluate the sensitivity of the model to these parameter values and to determine those combinations of parameters producing the best model fit of centerline contaminant concentrations for a tester data set.

- Once the model was calibrated to centerline concentrations, the contaminant degradation rates and source configurations were further refined to calibrate the model to the measured total dissolved contaminant mass for the tester data set.
- With a degradation rate set to zero, the mass of contaminant degraded over the calibrated lifetime of the plume was determined by the difference from the calibrated non-zero degradation rate model results as an independent estimate of contaminant assimilation rate in the plume.
- Finally, the effects of source removal on the lifetime of the plume and the maximum plume travel distance were assessed using the site-specific, field-data calibrated model.

### Site Selection

The major thrust of the research was to develop a methodology that could be used to demonstrate bio-containment of soluble hydrocarbon plumes under a variety of hydrogeologic conditions. It is important that the application of this methodology to hydrocarbon-contaminated sites is simple and that the required chemical, biological, and hydrogeological data are easy to collect or estimate. In general, two types of contamination scenarios could have been considered depending on the behavior of the contamination source. In one case, the source of contamination has been exhausted. Here only a soluble plume persists and, while it is being transported by ground-water, it is subjected to a variety of degradation reactions (abiotic degradation, aerobic and anaerobic degradation/transformation, sorption, etc.). A release of hydrocarbon-contaminated water from a disposal pit where little or no residual saturation persists within the vadose zone is an example of such a case. In the second scenario, the source of ground-water contamination persists for a long period of time due to residual-phase hydrocarbon existing in the subsurface either above or below the ground-water table.

Conceptually, the first scenario is easier to investigate than the second. To demonstrate that the soluble plume is degrading, it is sufficient to monitor the changes of the total mass of plume over time. If the data indicate that the mass decreases with time at a significant rate, and that hydrocarbon concentrations are reduced below a level of concern, no additional analyses or modeling are necessary. Although, from the conceptual view point this is a simpler case, in reality such a demonstration may prove difficult due to the problems and costs associated with monitoring a traveling soluble plume. In particular, it may be difficult to prove, without proper controls, that the observed decrease in mass is real and not due to the always present uncertainties



related to ground-water monitoring systems. In addition, this scenario is less important from a practical point of view. After the source of contamination is removed, the remaining soluble plume can be dealt with in a number of ways, including removal by pump and treat techniques. However, in many situations, it is prohibitively expensive to remove hydrocarbon-contaminated soil from the vadose and saturated zones. Simple mass balance calculations, as well as limited field data, indicate that if this residual hydrocarbon is left in place it could serve as a source of local ground-water contamination for decades. It is therefore of utmost importance to be able to estimate the long-term effects of residual saturation on ground-water resources. For these reasons, this research effort was focused on the evaluation of the fate of soluble hydrocarbon plumes originating from "continuous" sources. Both sites investigated were of this "continuous" source-type at the initiation of the study, although the complete dissolution of the mass in the source area was observed at one site (i.e., a "continuous" source becoming a "pulse" source for all contaminants of concern) during the two-year study period. The specific characteristics of each site are described in Chapters 5 and 6 which follow.

## Field Methods

### *Conceptual Approach to Process Monitoring*

The field investigation program reported here was closely related to the data interpretation effort, keeping

in mind that data were collected which were both necessary and sufficient to analyze the behavior and fate of the soluble hydrocarbon plumes under investigation. In order to define what data were needed, it was instructive to first analyze the processes involved in a typical hydrocarbon release to the soil environment.

In a typical gasoline spill, a separate-phase product is released and migrates in the subsurface toward the water table as indicated in Figure 4-1. This movement is driven by gravity and capillary forces. After the product reaches the capillary fringe, it spreads horizontally above it and depresses the ground-water table. At this point, the presence of the product is usually detected in monitoring wells, and a product recovery effort is put into place. As a result, some of the mobile product is removed. However, a significant portion of the product may remain in the unsaturated zone in the form of residual saturation (discontinuous blobs of hydrocarbon trapped in small pores and pore throats). The amount of this residual phase depends on the soil type and the presence of other phases; in dry sand the residual saturation may be as low as three to 10 percent of the pore space, while the residual saturation of hydrocarbon trapped below the water table may reach 50 percent of the pore volume.

All of the residual phase cannot be practically removed by pumping or soil flushing. The only practical way to remove it is through subsurface air stripping, known commonly as soil vapor extraction (SVE), through in-situ

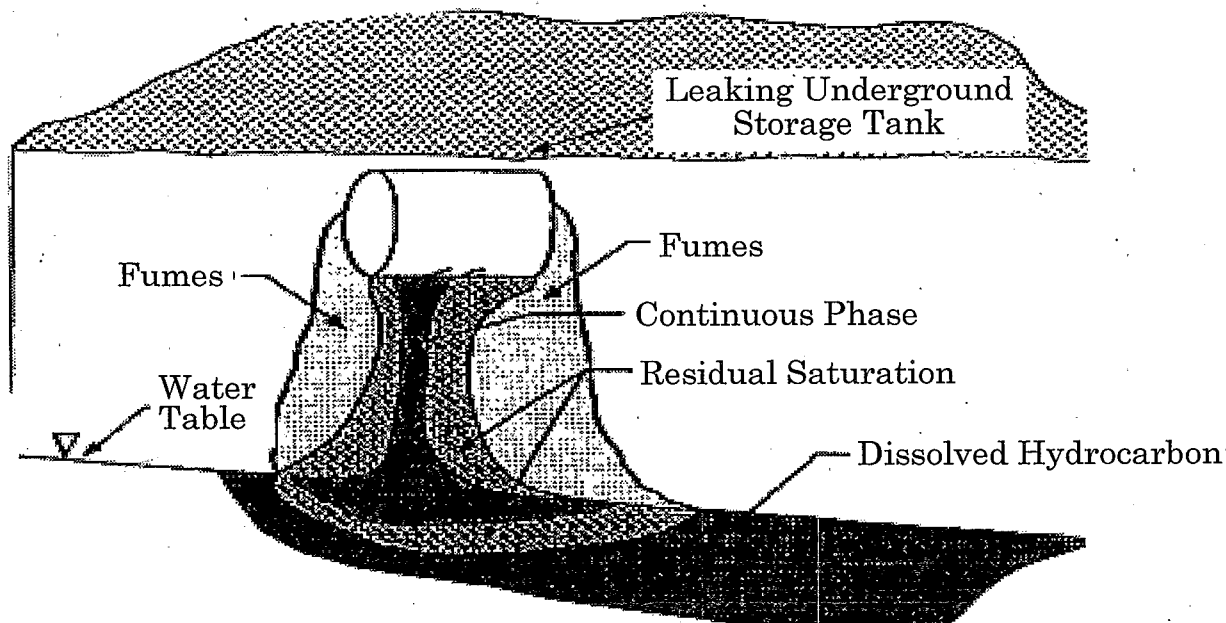


Figure 4-1. Conceptual model of the distribution of contaminants released from a leaking UST into the subsurface environment.

biodegradation via bioventing, or by physical removal of the soil through excavation. SVE is ineffective in low permeability soils and for low volatility compounds. Neither SVE nor bioventing remove hydrocarbon trapped below the water table, and soil excavation is expensive and requires further treatment of the excavated soil before final disposal. In cases where the hydrocarbon cannot be efficiently removed from the subsurface, the residual phase acts as a long-term source of ground-water contamination due to slow hydrocarbon dissolution into the aqueous phase. The local rate of dissolution depends on two factors: (1) the composition of the residual saturation and (2) the ground-water velocity. The rate at which the source term is diminished depends on the initial mass of hydrocarbons present, and thus depends on the total concentration of hydrocarbons in soil.

As the hydrocarbon plume is transported in ground-water by advection and hydrodynamic dispersion, it mixes with the surrounding ground-water. If the surrounding ground-water contains oxygen, and if there are appropriate bacteria present in the subsurface, then aerobic biodegradation will occur at the fringes of the plume. The oxygen used in these biodegradation reactions comes both from the ground-water and from the vapor phase in the vadose zone via molecular diffusion. If alternative metabolic processes are important at the site, i.e., degradation under denitrifying, sulfate reducing, iron reducing or methanogenic conditions, then the availability of these terminal electron acceptors to the indigenous microorganisms, in addition to oxygen, dictates the overall rate and extent of hydrocarbon degradation in the contaminated aquifer. The overall rate of degradation will depend then on the rate of mixing of hydrocarbons and terminal electron acceptors in the ground-water.

It should be noted that the advective transport of hydrocarbons in ground-water is retarded due to the distribution of constituents between the aqueous and soil phases. This retardation should enhance the mixing process since the electron acceptors approaching the hydrocarbon plume from the upstream direction will have a velocity essentially that of the ground-water, which is greater than that of the retarded hydrocarbon plume.

Fuel hydrocarbons from leaking storage tanks represent potential sources of carbon and energy for soil microorganisms. Given this potential, it is likely that a community of microorganisms will develop in most ground-water systems that will degrade dissolved hydrocarbons where concentrations are not toxic and requisite nutrients and electron acceptors are not limiting overall metabolic reaction rates. It is possible then, that microbial degradation of hydrocarbon contaminants in ground-water and the vadose zone may proceed fast enough to effectively stop the spread and/or movement of the contaminant plume.

Respiratory metabolism will generally lead to much more rapid transformation and mineralization of hydrocarbons than will anaerobic, fermentative processes (Dragun, 1988; Downey et al., 1988). In areas of high hydrocarbon concentration, one or more reactants necessary for microbial utilization and mineralization of the hydrocarbons may become limiting. For respiratory metabolism to proceed, the availability of respiratory electron acceptors (e.g.,  $O_2$ ,  $Mn^{4+}$ ,  $NO_3^-$ ,  $Fe^{3+}$ ,  $SO_4^{2-}$ ,  $CO_3^{2-}$ ) is critical. Nutrients (especially N and P) must also be available to the microorganisms if their metabolism, leading to hydrocarbon degradation, is to occur unhindered.

Ground-water is often anaerobic due to the utilization of oxygen in the decomposition of organic matter. This is especially frequent when ground-water is contaminated with petroleum hydrocarbons (Lovely et al. 1989). In these situations, respiratory electron acceptors other than oxygen may be used for hydrocarbon degradation. Evidence of respiratory mineralization of hydrocarbons in contaminated ground-water can be gathered by monitoring changes in ground-water chemistry and overlying gases that reflect the utilization of respiratory electron acceptors. For example, Lovely et al. (1989) showed that  $Fe^{3+}$  reduction, evidenced by the accumulation of the  $Fe^{2+}$ , could be linked to the microbial oxidation of petroleum aromatic compounds in an anaerobic aquifer. Similarly,  $NO_3^-$  or  $SO_4^{2-}$  reduction and methanogenesis ( $CO_3^{2-}$  reduction) supports anaerobic microbial respiratory degradation of ground-water contaminants (Lovely and Phillips, 1987b). Observations of the changes in petroleum hydrocarbon concentrations, the disappearance of  $O_2$ , the accumulation of  $CO_2$ , the accumulation of  $Fe^{2+}$ , the disappearance of  $SO_4^{2-}$ , and/or the accumulation of  $H_2S$  and  $CH_4$  in a hydrocarbon-contaminated aquifer system, coupled with observations and modeling of ground-water movement and contaminant plume migration, allow calculations of mass balances for these materials. The mass balance calculations then allow the quantitative assessment of the rate of biodegradation of hydrocarbon contaminants based on the rates of change of electron acceptors and respiration products observed at the field site.

In summary, there are two major hydrocarbon-producing and hydrocarbon-degrading mechanisms which occur within a contaminated ground-water plume, hydrocarbon dissolution and respiratory microbial degradation. At some point in time, these two processes reach steady-state. This will happen when the rate of contaminant dissolution is equal to the overall rate of contaminant biodegradation. Under these conditions, contaminants within the soluble hydrocarbon plume will reach a steady-state distribution, i.e., the spatial hydrocarbon concentration distribution will remain constant in time. It should be noted that this conceptual model does not

take into account the depletion of source mass over time. However, the source depletion time scale may be on the order of decades, while plume equilibrium is expected to occur within months to several years from the beginning of plume development.

#### **Site Assessment/Characterization Phase**

Reconnaissance sampling of ground-water was conducted in the initial phase of the project to define the spatial, three-dimensional distribution of the contaminated zone. In addition, characterization of site hydrogeology was developed to define, as completely as possible, the nature of ground-water flow and mixing below each site.

#### **Contaminant Plume Delineation**

Initial saturated zone characterization was conducted using cone penetrometry techniques (Blegen et al., 1988; Smythe et al., 1988). All cone penetrometer work was conducted by Terra Technologies (Houston, TX) using field procedures and quality assurance/quality control (QA/QC) methods specified in Appendix A through a subcontract arrangement with the Utah Water Research Laboratory (UWRL). Specific procedures and data interpretation methods are provided in the paper by Klopp et al. (1988), among others. In what is termed the position mode, the point is continuously pushed through the soil and resistance data are recorded with a resolution of approximately 10 in. If the soil texture allows, once the tip reaches the desired depth and is removed from the soil, temporary or permanent sampling points can be placed in the remaining hole without the expense and effort necessary for the placement of a conventional sampling well. The placement of temporary and permanent monitoring points at both field sites was made possible using this method.

For initial plume delineation, samples drawn from the 5/8-in diameter temporary piezometer wells were analyzed on-site using ambient temperature headspace (ATH) analysis techniques. Duplicate ground-water samples were collected, with headspace analyses being run on one duplicate using field screening techniques. The second sample was transported to the UWRL and analyzed using laboratory purge-and-trap procedures. This comparison allowed the evaluation of the representativeness of field screening techniques for hydrocarbon delineation during site screening activities.

Subsequent to initial site plume delineation, 44 permanent ground-water monitoring points were placed throughout the plume at the Hill AFB site, while 21 permanent points were placed at the Layton, UT, field site to provide point measurements of saturated zone conditions upstream, within, and surrounding the contaminant plume.

Aromatic hydrocarbon, boiling point splits and total petroleum hydrocarbon measurements provided the

primary information regarding the spatial distribution and composition of the soluble contaminant source term. Associated soluble electron acceptors ( $O_2$ ,  $NO_3^-$ ,  $SO_4^{2-}$ ), microbial respiration products ( $Fe^{2+}$ ,  $Mn^{2+}$ ), and ground-water pH were also used to define reaction zone boundaries of various types which have developed within and surrounding the dissolved hydrocarbon plumes. Table 4-1 summarizes the analyses that were conducted. The geological/ hydrogeologic stratification of the aquifer and vadose zone was also described, based on cone penetrometer resistance and slug test measurements.

#### **Soil-Gas Sampling**

Soil-gas samples from the vadose zone above the contaminant plume at the study sites were collected with push probes to aid in the delineation of areas of biological activity. Soil-gas sampling techniques have been used by a number of authors for the delineation of subsurface contamination from both residual saturation and ground-water plumes (Glaccum et al., 1983; Kreamer, 1983; Schmidt and Balfour, 1983; Evans and Schweitzer, 1984; Eklund, 1985; Morgan and Klingler, 1987; Zdeb, 1987) with varied success. Current recommendations are to utilize soil-gas sampling with care, especially if site surficial geology is not well defined, and to obtain soil-gas samples as close to suspected ground-water contamination as possible.

Soil-gas data were collected and analyzed on site for total hydrocarbons,  $O_2$ , and  $CO_2$  to provide support data for site assessment samples. In addition, soil-gas  $O_2$ ,  $CO_2$ ,  $CH_4$ , total hydrocarbon, aromatic hydrocarbon, and boiling point split samples, collected via stainless steel canisters, were analyzed using laboratory instruments to assess the accuracy and representativeness of field measurements for hydrocarbon, respiration product, and reactant gas detection. These soil-gas data can provide insights into the nature and extent of gas production and utilization in the unsaturated zone. The data also allow the estimation of  $O_2$  and  $CO_2$  flux into and out of the contaminant plume to estimate in-situ biodegradation rates (Dupont et al., 1991; Hinchey et al., 1991). Soil-gas data provided rapid feedback regarding general subsurface hydrocarbon and bioprocess conditions. Data were also evaluated as to their efficacy in identifying plume boundaries and in detecting significant respiration reactions that were occurring in the contaminant plume at the two field sites investigated in this study.

#### **Soil Sampling**

A soil core sampling site was selected and named to correspond with the nearest water sampling point (SS-well name). The cone penetrometer truck was maneuvered into position and a steel probe was used to push a hole to the top of each sampling depth. The probe was then removed from the hole and replaced

**Table 4-1. Analyses Conducted on Reconnaissance Samples Collected During the Site Assessment/Characterization Phase**

Sample Type	Measurement	Method	Purpose
Ground-water	O <sub>2</sub>	Membrane Probe	Electron Acceptor
	Fe <sup>2+</sup> , Mn <sup>2+</sup>	Colorimetry	Electron Acceptor
	pH	Glass electrode	CO <sub>2</sub> , Eh
	Aromatic HCs*	Lab GC†	Substrate
	Total HCs	Field/Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate
Soil-gas	O <sub>2</sub>	O <sub>2</sub> Meter	Electron acceptor
	CO <sub>2</sub>	CO <sub>2</sub> Meter	Mineralization product
			Electron acceptor
			Redox couple
	CH <sub>4</sub>	GC	Mineralization product
			Redox couple
	Aromatic HCs	Lab GC	Substrate
	Total HCs	Field/Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate

\*HCs = Hydrocarbons

†GC = Gas Chromatography

with a steel collar attached to an 18- to 30-in long section of 1.5-in O.D. galvanized steel conduit. The conduit was then pushed into the hole to the appropriate sampling depth, filling the conduit with soil. The conduit was pulled out of the hole, cut into 6-in long pieces, sealed with aluminum foil and duct tape, and placed on ice for transport to the UWRL Environmental Quality Laboratory (EQL). Single sampling events varied in sampled depth from 6 in to 2 ft depending upon soil conditions. Samples were stored at the EQL in an anaerobic chamber, filled with 8 percent hydrogen and 92 percent nitrogen at 10°C to mimic subsurface conditions, prior to analysis.

#### Water Sampling

Water samples were collected either with a hand operated peristaltic pump or, for the conventional two- to four-in monitoring wells existing at the field sites, using a submersible centrifugal pump. All sampling equipment was decontaminated with soap and water wash, a water rinse, and a final distilled water rinse between sampling locations. Three casing volumes were removed from the monitoring wells and gravel points before sampling. Samples were collected into two 140-mL syringes to minimize loss of volatile compounds and to minimize oxygenation of the sample. One syringe was used for laboratory volatile organic analysis (VOA) samples and

on-site ATH analysis for volatile hydrocarbons. The second syringe was used for ATH, nutrients, and metals analyses. For metal and nutrient analysis, the suspended solids in the sample were allowed to settle up to one hour, then the sample was filtered through a 0.45-μm syringe filter and a 1-g C-18 sorbent filter to remove dissolved organic materials. Samples for metal analysis were preserved by field adjusting the pH to < 2.0 with several drops of a solution of 50 percent nitric acid. The VOA and nutrient samples were transported in coolers on ice and stored at less than or equal to 4°C until the appropriate analyses were conducted.

The soil core, soil-gas, and ground-water samples were analyzed for physical and chemical characteristics important in fate-and-transport assessment as shown in Table 4-2.

#### Ambient Temperature Headspace Technique

Traditionally, water and soil samples from a leaking UST site are taken to a laboratory for extraction of hydrocarbons and chromatographic analysis of individual hydrocarbon contaminants. Reliable field techniques are desirable to supplement laboratory analyses because they are inherently less expensive and faster than conventional methods. A less expensive analysis will allow more samples to be analyzed on a fixed budget for

**Table 4-2. Analyses Conducted on Samples Collected During the Installation of Soil-Gas and Ground-water Monitoring Points**

Sample Type	Measurement	Method	Purpose
Ground-water	O <sub>2</sub>	Membrane Probe	Electron acceptor
	Fe <sup>2+</sup> , Mn <sup>2+</sup>	Colorimetry	Electron acceptor
	Cl, SO <sub>4</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup> , CO <sub>3</sub> <sup>2-</sup>	IC*	Ionic strength/ electron acceptor
	NO <sub>3</sub> <sup>-</sup>	IC	Electron acceptor nutrient
	pH	Glass electrode	CO <sub>2</sub> , Eh
	Aromatic HCs†	Lab GC‡	Substrate
	Total HCs	Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate
Soil-Gas	O <sub>2</sub>	O <sub>2</sub> Meter	Electron acceptor
	CO <sub>2</sub>	CO <sub>2</sub> Meter	Mineralization product electron acceptor
			redox couple
	CH <sub>4</sub>	Lab GC	Mineralization product redox couple
Soil core	Aromatic HCs	Lab GC	Substrate
	Total HCs	Field/Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate
	Available Fe	Extraction/color	Electron acceptor
	Available Mn	Extraction/AA	Electron acceptor
	Carbonate	Inorganic Carbon	Source/sink of CO <sub>2</sub>
	Organic carbon	Acid chromate Oxidation	Substrate/absorption
	pH	1:1/glass electrode	Redox/metals activity
	Kjeldahl-N	Digestion/distillation	Nutrient
	Extractable P	Extraction/color	Nutrient
	Texture	% sand/silt/clay	Sorption/hydraulics
	Aromatic HCs†	Lab GC	Substrate
	Total HCs	Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate

\*IC = Ion chromatography

†HCs = Hydrocarbons

‡GC = Gas chromatography

a more complete assessment of site conditions. Having a rapid analysis on site can also reduce expensive down-time of sampling and drilling equipment during plume delineation.

In this project, several field ATH techniques for determining hydrocarbon contamination of water and soil were evaluated. These techniques used detector response to headspace total hydrocarbons generated in a polyethylene bag as the quantitation method for contaminated soil and ground-water. One of these techniques was developed for water samples at the UWRL, while the other technique was developed for water and soil samples and is commercially available as

Lab-In-A-Bag (LIB) (In-Situ Inc., 1991). Per these techniques, the sample was put into a polyethylene bag and air was added to create a headspace above the samples. When soil samples were being analyzed, water was added to the sample before the headspace was introduced. After contaminants were allowed to equilibrate between or among phases, the headspace was routed to a detector. Detailed procedures for both ATH methods are provided in Appendix B.

A Summit Instruments SIP-1000 portable gas analyzer with a flame ionization detector was used in this study for field determinations of hydrocarbon headspace concentrations. In this instrument, samples are routed

to the detector through the line which carries air to the detector. Since there is no GC column in this line, the detector responds to the entire sample without separation of individual compounds in the gas matrix.

One-quart Ziplock® polyethylene freezer bags were typically used in field headspace measurements in this study. The sample was introduced through the zipper closure, and the bag was sealed so that headspace gases were isolated within the bag and sample train. One of the problems with these bags is that fatty acids are incorporated into the bags as a slip agent to keep them from sticking together (Gerber, personal communication, 1994). Experience in the field has shown that, on hot days, these fatty acids can interfere with headspace analyses. The bags should be refrigerated if the ambient temperature is more than 80°F to minimize this interference.

Stock solutions for calibration standards for the field methods were made by saturating tap water with the contaminant of interest. The stock solutions were made into calibration standards by serial dilution with distilled deionized water (DDW) in syringes. Sixty-mL syringes were used for the UWRL method, while 140-mL syringes were used for the Lab-In-A-Bag ATH (LIB) method.

Readings from samples and standards were taken directly off the SIP-1000. The net detector response to headspace gases was determined for each by subtracting the background response from these values. Net, background-corrected detector response values were used for all further data analysis of ATH samples.

These field ATH techniques are fundamentally different from laboratory procedures in two important respects: (1) the contaminants which reach the detector are in equilibrium with the original sample matrix rather than being a more complete extraction of that matrix; and, (2) the hydrocarbon constituents are not separated from one another before they arrive at the detector. In order for the field techniques to be truly useful, TPH determinations from laboratory and field techniques must be well correlated. The field/laboratory hydrocarbon concentration relationship determined in this field study is presented and discussed in Chapter 5.

### Site Hydrogeology

Characterization of site hydrogeologic conditions began with a review of existing geologic and hydrogeologic information available for the sites. The geologic data related to the site subsurface structure and depositional environment were reviewed and analyzed, along with available regional and site-specific ground-water flow data. This initial data review was followed by a more detailed investigation of subsurface hydrogeologic

conditions using cone penetrometer techniques described above.

In order to quantify advective and dispersive soluble plume transport at the site, the average pore-water velocity was determined. This required the estimation of average hydraulic gradient, average hydraulic conductivity, and average porosity throughout the site. The average hydraulic gradient was estimated using ground-water table elevation data measured in the ground-water monitoring wells. The hydraulic conductivity was determined from multiple slug tests conducted at various locations throughout each site (U.S. EPA 1990a). Total and air-filled porosity measurements were determined using bulk density and soil moisture content data developed from the soil cores collected during ground-water and soil-gas monitoring well placement. This information is crucial to understanding soluble plume dispersion and transport at the field scale.

Finally, to evaluate the attenuation of soluble hydrocarbons in the ground-water plume, organic carbon normalized soil/water distribution coefficients,  $K_{oc}$ , were estimated for the range of soils represented in the subsurface.  $K_{oc}$  values were estimated using organic matter content analyses of the soil cores and the distribution coefficients available from literature sources for the contaminants of concern.

### Process Monitoring Phase

Once the ground-water and soil-gas monitoring wells were placed throughout the site, they were used to provide detailed information regarding the three-dimensional characteristics of the contaminant plume and the changes in its characteristics over time. The initial process monitoring phase of the project consisted of collecting ground-water and soil-gas samples from all monitoring well points during months 10, 13, 16, 19, and 23 of the study.

Aromatic hydrocarbon, boiling point splits, and total petroleum hydrocarbon measurements in ground-water and soil-gas samples collected during this phase of the study (Table 4-3) provided the primary information regarding the spatial distribution and composition of the soluble contaminant source term and resulting dissolved plume as they were affected by seasonal ground-water table elevation, and temperature fluctuations. Associated electron acceptors, microbial respiration products, and other water quality parameters affecting microbial reactions were also used to define reaction zone stability over time (Table 4-3).

### Analytical Methods

Table 4-4 provides a summary of parameters measured and analytical methods used throughout the field study. Procedures that are not common or standardized are briefly described below.

The bioavailability of  $\text{Fe}^{3+}$  and  $\text{Mn}^{4+}$  as electron acceptors was determined during the site assessment/characterization phase of the study. To determine the concentration of amorphous  $\text{Fe}^{3+}$  that was available in aquifer material, the method of Lovely and Phillips (1987a) was used. Ferrous iron present in aquifer sediment samples (0.1 g) was extracted with 5 mL of cold 0.5 M HCl. The extract was treated with ferrozine in a buffer (50 nM HEPES, pH=7) prior to being filtered through a 0.2- $\mu\text{m}$  polycarbonate filter. The concentration of  $\text{Fe}^{2+}$  in the extract was determined by measuring the absorbance of the filtrate at 562 nm. This method does not oxidize  $\text{Fe}^{2+}$  nor reduce  $\text{Fe}^{3+}$  (Lovely and Phillips, 1986). The same procedure was repeated with another aquifer sediment sample using 5 mL of 0.25 M hydroxylamine hydrochloride in 0.25 M HCl as the extractant. Under acidic conditions, hydroxylamine reduces  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$ . The amount of hydroxylamine-reducible  $\text{Fe}^{3+}$  is calculated as the difference between the  $\text{Fe}^{2+}$  measured in the hydroxylamine and HCl extracts. This concentration of  $\text{Fe}^{3+}$  indicates the capacity of the aquifer material to provide  $\text{Fe}^{3+}$  as a terminal electron acceptor. Lovely and Phillips (1987a)

showed a strong correlation ( $r^2 = 0.94$ ) between the extent of reduction of various synthetic  $\text{Fe}^{3+}$  forms with hydroxylamine and the capacity of an  $\text{Fe}^{3+}$ -reducing acetate enrichment culture to reduce the  $\text{Fe}^{3+}$  forms. This indicated the validity of the method for quantifying electron acceptor in aquifer materials. Once initial site characterization was completed, subsequent analyses for iron consisted of analysis for reduced iron ( $\text{Fe}^{2+}$ ) only in ground-water samples.

The concentration of amorphous  $\text{Mn}^{4+}$  that was bioavailable as an electron acceptor was determined using the method of Lovely and Phillips (1988). This method involved dissolving the  $\text{Mn}^{4+}$  in a 0.1 g wet aquifer sediment sample into a solution (5 mL) of 0.25 N hydroxylamine hydrochloride in 0.25 N HCl. The manganese content was then measured by atomic absorption spectrophotometry with an acetylene flame. Production of  $\text{Mn}^{2+}$  was determined by cold extraction of a 0.1 g sample with 5 mL of 0.5 N HCl for 10 min. The sample was then filtered using a 0.2- $\mu\text{m}$  pore filter and manganese concentration in the filtrate was analyzed as noted above.

**Table 4-3. Analyses Conducted on Ground-Water and Soil-Gas Samples Collected During the Process Monitoring Phase of the Project**

Sample Type	Measurement	Method	Purpose
Ground-water	$\text{O}_2$	Membrane probe	Electron acceptor
	$\text{Fe}^{2+}$ , $\text{Mn}^{2+}$	Colorimetry	Electron acceptor
	$\text{SO}_4^{2-}$	IC*	Electron acceptor
	$\text{NO}_3^-$	IC	Electron acceptor nutrient
	pH	Glass electrode	$\text{CO}_2$ , Eh
	Aromatic HCs†	Lab GC‡	Substrate
	Total HCs	Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate
Soil-gas	$\text{O}_2$	$\text{O}_2$ Meter	Electron acceptor
	$\text{CO}_2$	$\text{CO}_2$ Meter	Mineralization product
			electron acceptor
			redox couple
	Aromatic HCs	Lab GC	Substrate
	Total HCs	Field/Lab GC	Substrate
	Boiling point splits	Lab GC	Substrate

\*IC = Ion chromatography

†HCs = Hydrocarbons

‡GC = Gas chromatography

**Table 4-4. Analytical Methods Used for Ground-Water, Soil-Gas, and Soil Core Samples Collected During the Study**

Sample Type	Measurement	Method Type	Reference Method
Ground-water	O <sub>2</sub>	Membrane Probe	4500-O G, APHA (1989)*
	CH <sub>4</sub>	Lab GC†	TCD‡
			Alltech column (36254L)
	Fe <sup>2+</sup>	Colorimetry	Lovely & Phillips (1987)*
	Mn <sup>2+</sup>	Colorimetry	Lovely & Phillips (1988)*
	Major cations		
	Cl, SO <sub>4</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup>	IC§	300.0, U.S. EPA (1989)
	CO <sub>3</sub> <sup>2-</sup> , NO <sub>3</sub> <sup>-</sup>		
	pH	Glass electrode	4500-H + B, APHA (1989)*
	Aromatic HCs#	Lab GC	5030, Modified 8020
	Total HCs	Lab GC	Using FID• & Petrocol
	Boiling point splits	Lab GC	column, U.S. EPA (1986e)
Soil-gas	O <sub>2</sub>	O <sub>2</sub> Meter	Gastechtor
	CO <sub>2</sub>	CO <sub>2</sub> Meter	Model 3250X
	O <sub>2</sub>	Lab GC	TCD
	CO <sub>2</sub>	Lab GC	Alltech column (36254L)
	CH <sub>4</sub>	Lab GC	TCD
	Aromatic HCs	Lab GC	5030, Modified 8020
	Total HCs	Lab GC	using FID & Petrocol
	Boiling point splits	Lab GC	column, U.S. EPA (1986e)
Soil core	Available Fe	Extraction/color	Lovely & Phillips (1987)*
	Available Mn	Extraction/AA	Lovely & Phillips (1988)*
	Carbonate	Inorganic Carbon	Nelson (1982)
	Organic carbon	Acid chromate oxidation	Nelson & Sommers (1982)
	pH	1:1/glass electrode	4500-H+ B, APHA (1989)*
	Kjeldahl-N	Digestion/distillation	4500-Norg B, APHA (1989)*
	Extractable P	Extraction/color	Olsen & Sommers (1982)
	Texture	% sand/silt/clay	Gee & Bauder (1986)
	Aromatic HCs	Lab GC	5030, Modified 8020
	Total HCs	Lab GC	Using FID & Petrocol
	Boiling point splits	Lab GC	Column, U.S. EPA (1986e)

\*Method utilizing a Hach field kit

†GC = Gas Chromatography

‡TCD = Thermal conductivity detector

§IC = Ion chromatography

#HCs = Hydrocarbons

•FID = Flame ionization detector



### Assessment of Intrinsic Remediation

Intrinsic remediation assessment as used in this study, and incorporated into the Natural Attenuation Decision Support System (NADSS) accompanying this report, involves a seven-step process outlined in Figure 4-2. These steps include the following: 1) determining whether steady-state plume conditions have developed during the monitoring period; 2) estimating contaminant degradation rates from plume centerline concentrations or model calibration for tracer compounds versus reactive compounds detected within the plume; 3) estimating the source mass term; 4) estimating the source lifetime based on degradation rates estimated in Step 2; 5) predicting long-term plume behavior from a calibrated fate-and-transport model with and without source removal efforts implemented at the site; 6) decision making regarding the use of intrinsic remediation at a given site and the impact and desirability of source removal there; and 7) developing a long-term monitoring strategy if intrinsic remediation is selected as the preferred alternative for plume management at a given site. Each of these steps is discussed in more detail below and highlighted in the site-specific results presented in Chapters 6 and 7.

### Determination of Steady-State Plume Conditions

Verifying that steady-state conditions exist for a contaminant plume at a given site is critical in establishing that intrinsic remediation processes are likely taking place there and are likely to provide continued plume containment under current site conditions. Steady-state plume conditions occur when the rate of contaminant release from the source area is equivalent to the rate of contaminant assimilation by biotic and abiotic processes taking place within the aquifer. These steady-state conditions can be identified by observing the time course of contaminant concentration at a specific ground-water monitoring location. A more desirable approach is to investigate contaminant concentration and contaminant mass distribution throughout the entire plume. This latter approach involves the collection of centerline contaminant concentration data at various time intervals to determine if the entire plume has reached steady-state concentrations or through a determination of the total integrated mass and center of mass of contaminant within the delineated plume.

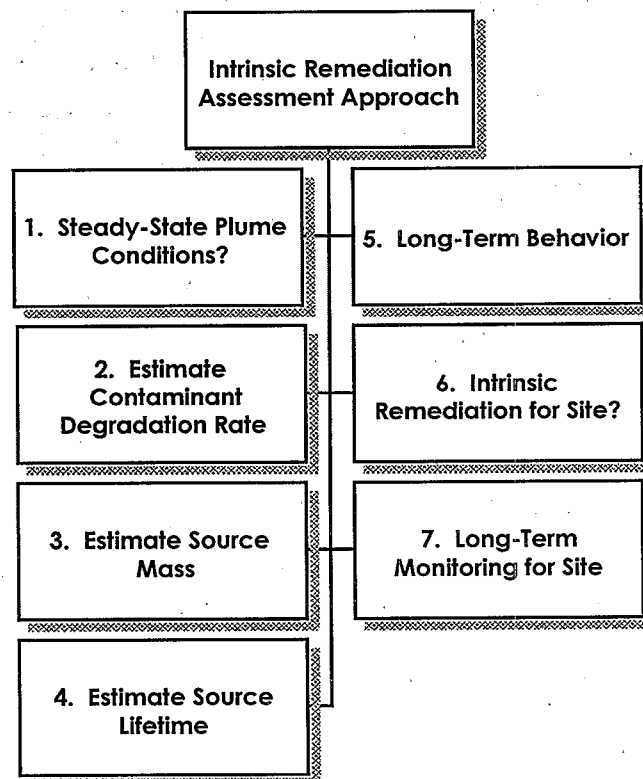


Figure 4-2. The Intrinsic Remediation Assessment Approach developed and applied in this field study to identify and quantify intrinsic remediation processes taking place at a given field site.

### Contaminant Centerline Concentrations

Plume centerline concentrations which are consistent from one sampling interval to the next are indicative of steady-state plume conditions. Comparison of data from specific sampling intervals should be done carefully, however. The distribution of contaminant mass between the vadose zone and ground-water can have a significant impact on the mass of dissolved contaminant in the ground-water plume at a given ground-water table elevation. If ground-water table elevations fluctuate widely, significantly different volumes of contaminated soil can be below the ground-water table, producing significantly different dissolved plumes from one sampling time to the next. While these variations in ground-water plume characteristics are important in understanding the overall risk posed by a given site, they tend to confuse the issue of steady-state plume evaluation. It is recommended then that if ground-water table fluctuations can be expected to produce highly variable contaminant plume profiles on a seasonal basis, the steady-state evaluation should be based on comparison of data with comparable ground-water elevation values. This is recommended although these data sets may be six months to one year apart in time.

If comparable data sets are collected based on ground-water elevation consideration, a plume centerline response indicated in Figure 4-3 should result. Figure 4-3 shows ground-water plume centerline concentration data collected at four distinct points in time. As indicated in this figure, the BTEX plume is shown to be growing between Times 1 and 2 (based on increased concentrations over time at fixed sampling locations),

appears stable between Times 2 and 3 (based on comparable plume centerline concentrations at these two sampling intervals), and has decreased between Times 3 and 4.

Figure 4-4 summarizes the logic involved in the interpretation of contaminant centerline concentration relationships observed for a given plume. If steady-state or receding plume conditions are indicated based on three to four sets of comparable monitoring data, the plume can be considered to be stable under existing aquifer conditions. The intrinsic remediation management option should then be evaluated for the site. If the plume is observed to be growing, either monitoring should be continued, or aggressive containment and source removal activities should be carried out if a sensitive receptor has already been impacted by ground-water contamination.

### Dissolved Contaminant Plume Mass and Center of Mass Calculations

A more rigorous evaluation of plume steady-state conditions involves the estimation of the total dissolved mass and the location of the centroid of this mass for the entire plume. In order to develop an estimate of the dissolved contaminant mass within the entire plume, an aquifer volume associated with each monitoring point must first be determined. Once an aquifer volume is associated with each monitoring point, the product of contaminant concentration and aquifer volume for each monitoring point is summed to yield a total dissolved mass for the plume.

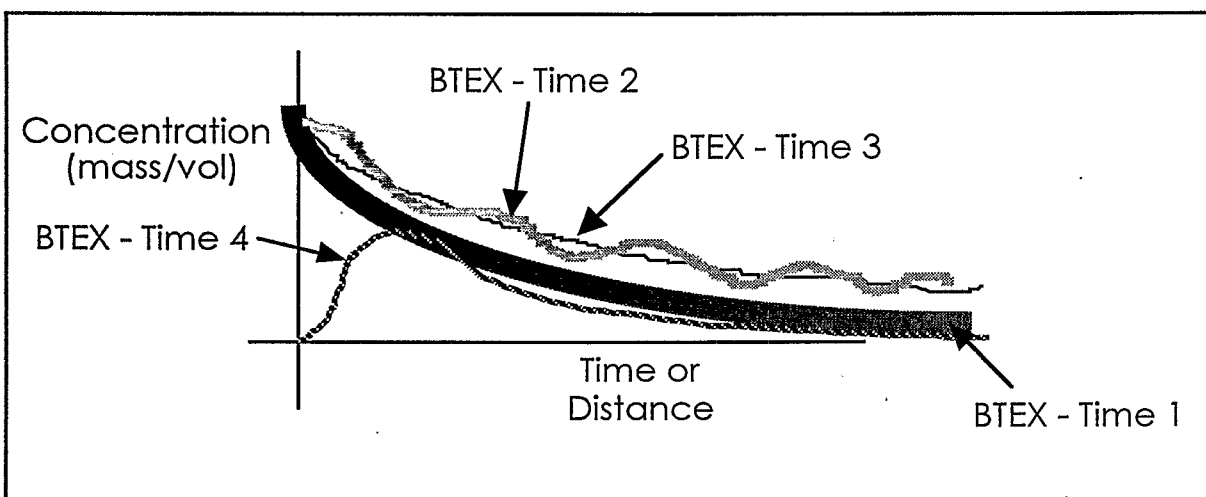
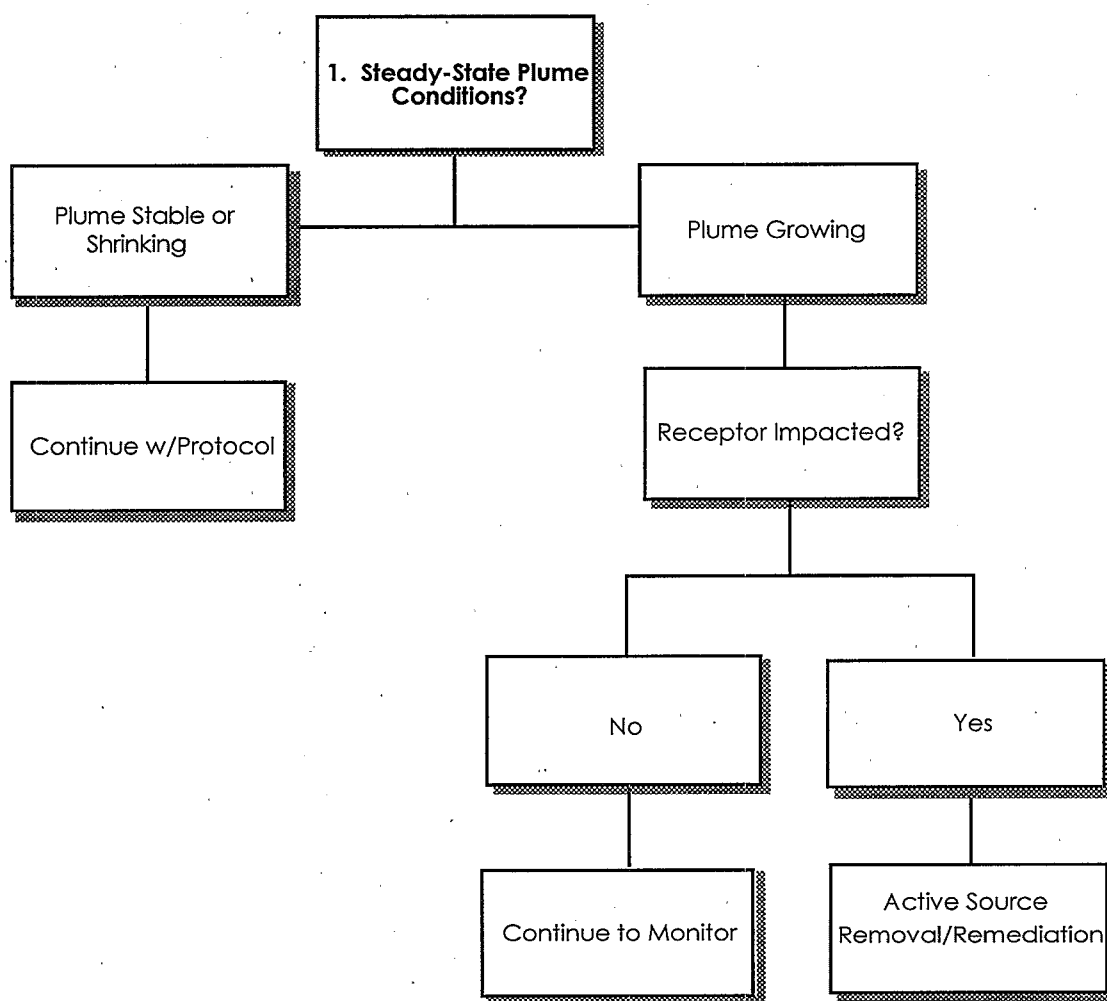


Figure 4-3. Plume contaminant centerline concentration profiles during the growth (Time 1 to 2), steady-state (Time 2 to 3), and receding periods (Time 3 to 4) of a contaminant release.

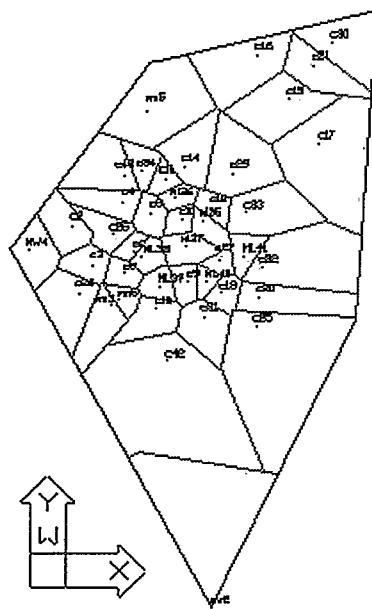


**Figure 4-4. Decision logic in response to outcome from analysis of steady-state plume conditions.**

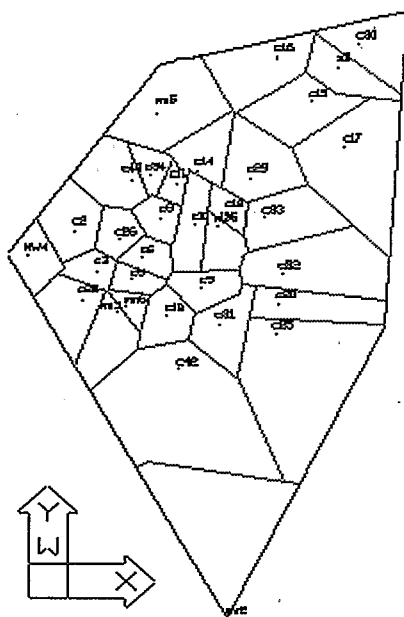
Aquifer volume is determined from the product of the aquifer porosity, the average aquifer thickness (generally the length of the largest sampling interval used within the monitoring network at a given sampling time), and a plume surface area associated with each sampling point. The method used in this study to obtain an estimate of sampling point areas is the Thiessen polygon method. This method was developed in the field of hydrology for use in estimating areas associated with point rainfall measurements within rain gage networks. The Thiessen method assumes that the concentration measured at a given sampling point is equal out to a distance halfway to the sampling points located next to it in all directions. The relative weights (areas) represented by each sampling point are determined by the construction of a Thiessen polygon network, the boundaries of which are formed by the perpendicular bisectors of lines connecting adjacent points (Chow et al., 1988). Appendix C provides a

summary with examples of the application of the Thiessen polygon method for ground-water plume mass estimates at the two sites under investigation in this study.

The outer boundary of the Thiessen polygon network is estimated based on the outermost well locations. It is important to be consistent with boundary definition if mass calculations for different sampling events are to be compared. An example of the boundary area used for the Hill AFB site is shown in Figure 4-5, which summarizes the areas used for total mass and mass center calculations for the June 1993 and January 1994 data sets. Consistent plume boundaries were used for all data reduction and analyses conducted in this study. Refer to Appendix C for a summary of plume areas used in all mass/mass center calculations.



a) Thiessen areas for June 1993.



b) Thiessen areas for January 1994.

Figure 4-5. An example of Thiessen area boundaries identified for the Hill AFB site in: a) June 1993, and b) January 1994. Note the consistent outer plume boundary and the variable internal area distribution between sampling times.

Once areas associated with each sampling point are determined, a thickness of contamination must be estimated so that contaminated volume and total mass calculations can be carried out. The estimation of this thickness is only important if "absolute" masses are desired. Without an estimation of contaminant thickness, mass per unit thickness (M/L) comparisons would result in trends identical to those of "absolute" mass. In the case of both the Hill AFB and Layton sites, the actual thickness of contamination was estimated to be the maximum depth of ground-water sampled by any well or monitoring point at each site. This thickness ranged from 1.1 to 6.1 ft at the Hill AFB site and from 9.3 to 12.8 ft at the Layton site.

In addition to estimating the total mass of a compound within the dissolved plume at both sites at a given point in time, the representative center point of the combined plume mass can also be calculated. This representative mass center is termed the centroid of the mass. It is calculated by taking the first moment of inertia of the mass at each sampling point within the contaminant plume about specified X and Y axes. The X and Y coordinates of the centroid of the total mass identify that position which yields a moment of inertia for the total mass equivalent to that of the sum of the individual moments of the masses estimated for each of the sampling points. Mathematically this can be expressed as follows for the center of mass X and Y coordinates, respectively:

$$X = \frac{\sum_{i=1}^n x_i(\text{mass}_i)}{\sum_{i=1}^n (\text{mass}_i)} \quad (4-1)$$

$$Y = \frac{\sum_{i=1}^n y_i(\text{mass}_i)}{\sum_{i=1}^n (\text{mass}_i)} \quad (4-2)$$

These center of mass (CoM) calculations are critical for tracking and interpreting the movement of contaminants, reactants, and products within the contaminant plume over time. The calculations can be used to assess the status of the plume and interpret its migration pattern over time (Table 4-5). They can also be used to estimate constituent migration velocities during plume development so that effective retardation factors and plume attenuation can be estimated based on known aquifer pore water velocities. CoM calculations were carried out for all contaminants, terminal electron acceptors (TEAs), and products of interest at the field sites investigated in this study. Results of both total mass and CoM calculations are summarized in detail in Chapters 5 and 6.

If plume centerline analysis and CoM calculations suggest that the plume is growing over time, steady-state conditions have not been reached. Either ongoing monitoring should take place to ensure future attenuation of the plume, or active source removal and/or site remediation should occur if a sensitive receptor is, or will be, impacted in the near term. If the contaminant plume is shown to have reached steady-state conditions, further quantitation of the nature and extent of plume attenuation taking place under site conditions is warranted.

**Table 4-5. Changes in Contaminant Mass and Mass Center Coordinates Possible for a Contaminant Plume, and the Corresponding Interpretation of These Changes Relative to Plume Mobility and Persistence**

Contaminant Mass	Centroid of Mass	Interpretation
Increasing	Moving Downgradient	Continuous source; unstable plume; contaminant migration
Constant	Moving Downgradient	Finite source; plume migration; minimal natural attenuation
Constant	Stable	Continuous source; stable plume; contaminant attenuation
Decreasing	Moving Downgradient	Finite source; plume migration; contaminant attenuation
Decreasing	Moving Upgradient	Finite source; plume attenuation; rapid contaminant attenuation; optimal intrinsic bioremediation

### **Estimation of Contaminant Degradation Rates**

Estimation of contaminant degradation rates can be carried out using either plume dissolved contaminant mass data, if a declining mass of contaminant is observed over time in the plume, or from plume contaminant ground-water concentration data if the source is found to produce steady-state dissolved mass in the plume over time. If steady-state mass is indicated, degradation rates for the contaminants can be estimated directly from centerline concentration data or through the calibration of a contaminant fate-and-transport model to field data observed throughout the contaminant plume. Figure 4-6 presents the logic associated with the estimation of field determined degradation rates and suggests that if aquifer flow data are available, the use of a fate-and-transport model accounting for advection, dispersion, sorption, and degradation is preferred over the use of plume centerline concentration data alone. In addition, the use of less degradable "plume resident tracer" compounds in the calibration process is desirable for the calibration of the transport component of the fate-and-transport model if data for these tracer compounds are available. The use of the less degradable tracers allows flow calibration without complications from species degradation.

#### **Dissolved Plume Mass Changes Over Time**

As indicated in Table 4-5, when the total mass of contaminant in the dissolved plume is shown to be decreasing over time, a finite source is suggested and both the position and concentration profile for the plume would not be expected to be in a steady state. The source is behaving as a pulse source and to estimate the degradation rate of contaminants within the plume resulting from this pulse source, analysis of the changes in dissolved plume mass over time should be used.

A classical approach to the evaluation of contaminant degradation rates in biological systems is to analyze the time course of changes in contaminant concentration or mass and investigate the relationship between concentration or mass versus reaction time using zero or first order reaction rate laws. Zero order reactions are described by a contaminant reaction rate independent of contaminant mass, i.e., a constant degradation rate over time, or:

$$dM/dt = -k_0 \quad (4-3)$$

where  $k_0$  = the zero order degradation rate constant, mass/time. The integrated form of this equation is shown in Equation 4-4:

$$M = M_0 - k_0 t \quad (4-4)$$

where  $M$  = contaminant mass at time  $t$ , mass; and  $M_0$  = the initial contaminant mass at time  $t = 0$ , mass. If the reaction taking place is governed by a zero order

degradation rate law, a plot of contaminant mass versus time produces a linear relationship, the slope of which equals  $-k_0$ , and whose intercept value should equal  $M_0$ .

First order reactions are described by a contaminant reaction rate which is dependent on contaminant concentration or mass, i.e., a degradation rate changing over time, or:

$$dM/dt = -k_1 M \quad (4-5)$$

where  $k_1$  = the first degradation rate constant, 1/time. The integrated form of this equation is shown in Equation 4-6:

$$M = M_0 e^{-k_1 t} \quad (4-6)$$

A plot of contaminant mass versus time produces a non-linear relationship that can be linearized by plotting the natural log of contaminant mass versus time. The slope of this linearized relationship is equal to  $-k_1$ .

Figures 4-7 and 4-8 show total dissolved plume mass data for ethylbenzene and total petroleum hydrocarbons (TPH) collected from the Hill AFB, UT, field site showing both zero order and first order mass reduction over time, respectively. Time was calculated in these figures based on the cumulative time between sampling events, with August 1992 being the  $t = 0$  point in these figures.

As indicated in Figure 4-7, a plot of ethylbenzene mass versus time produced a linear relationship, the slope of which was significant based on an alpha value of 0.05 (95 percent confidence level), resulting in a zero order mass degradation rate of 0.063 g/d. The natural log transformed data for TPH mass linearizes its relationship with time as indicated in Figure 4-8, and produces a significant regression based on an alpha value of 0.05 (95 percent confidence level). The first order TPH degradation rate determined from this analysis from the Hill AFB site is 0.009/d.

#### **Plume Centerline Concentration Data**

If the dissolved plume mass does not change significantly over time, a continuous source is indicated (Table 4-5), and analysis of steady-state dissolved plume concentration data can be carried out. Using the data reduction approach described above for dissolved plume mass, contaminant concentration data can be analyzed using zero order reactions with Equation 4-7:

$$dC/dt = -k_0 \quad (4-7)$$

where  $k_0$  = the zero degradation rate constant, mass/volume/time. The integrated form of this equation is shown in Equation 4-8:

$$C = C_0 - k_0 t \quad (4-8)$$

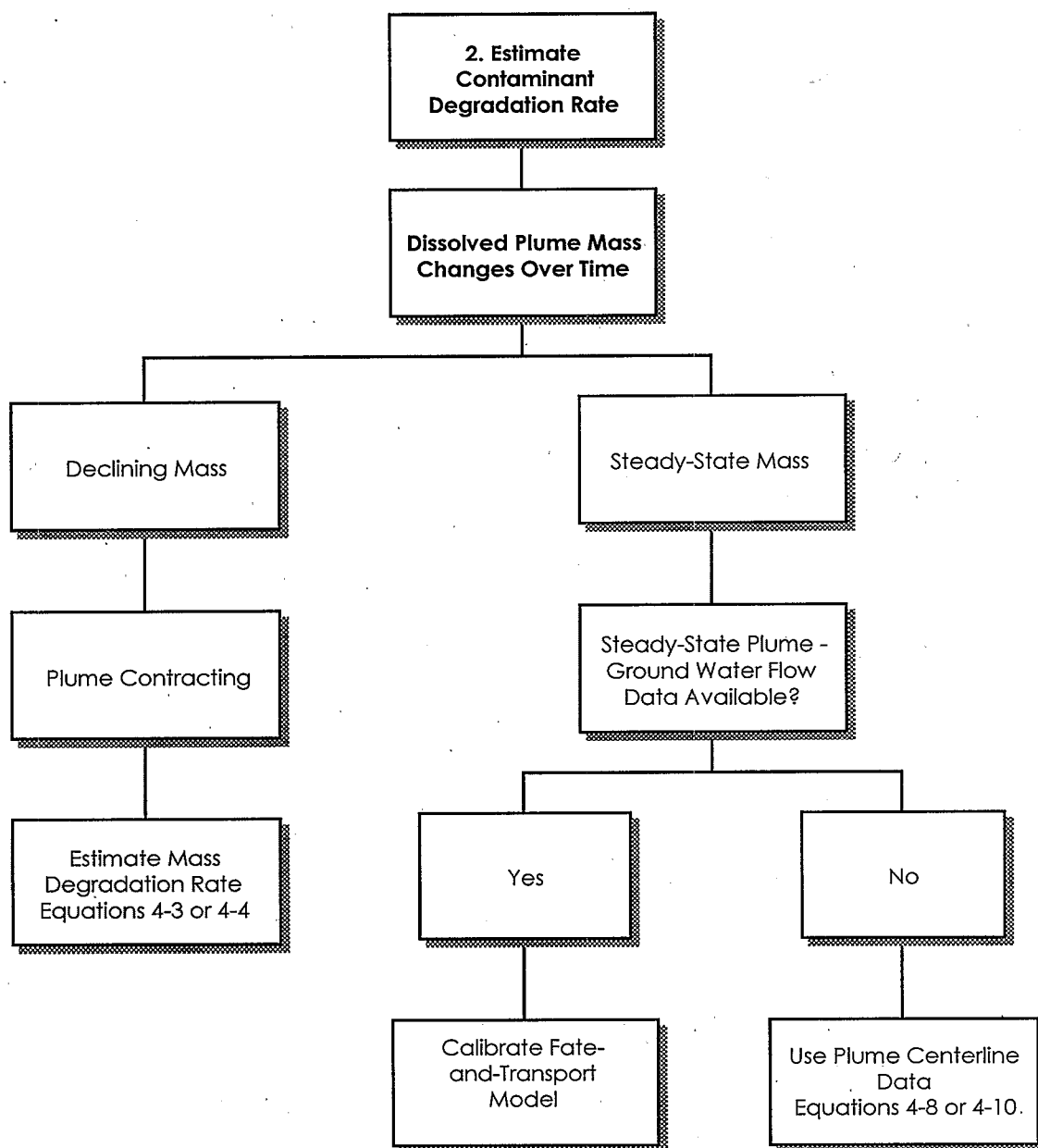


Figure 4-6. Decision logic in evaluating contaminant degradation rates.

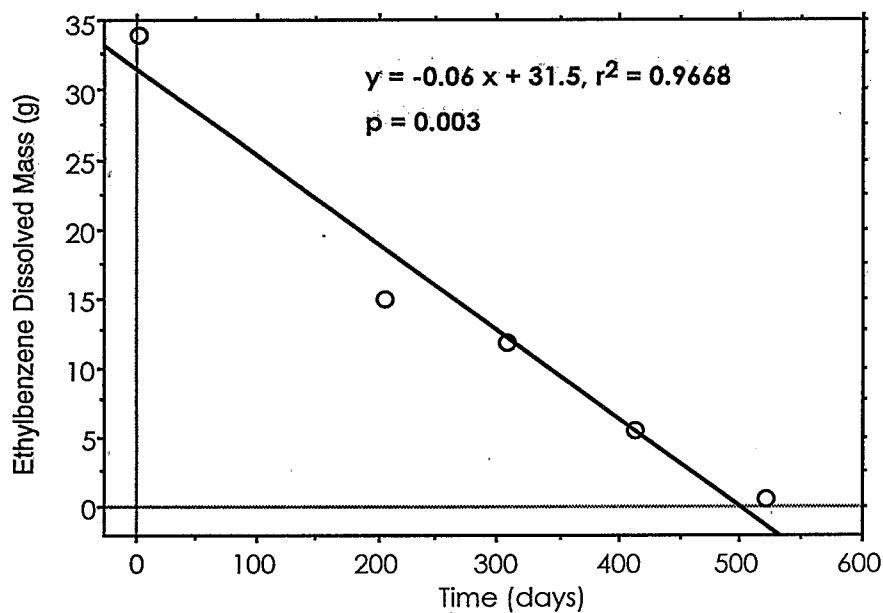


Figure 4-7. Time course of ethylbenzene dissolved plume mass data collected from the Hill AFB, UT, site from March 1992 to January 1994.

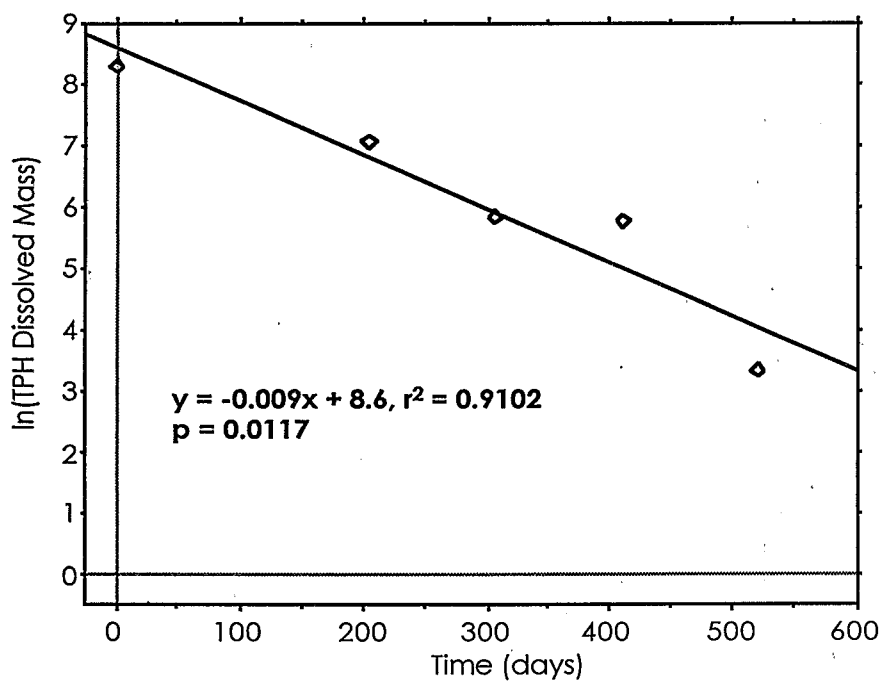


Figure 4-8. Time course of natural log transformed total petroleum hydrocarbon dissolved plume mass data collected from the Hill AFB, UT, site from March 1992 to January 1994.



where  $C$  = contaminant concentration at time  $t$ , mass/volume; and  $C_0$  = the initial contaminant concentration at time  $t = 0$ , mass/volume. A plot of contaminant concentration versus time produces a linear relationship, the slope of which equals  $-k_0$ , and whose intercept value should equal  $C_0$ .

First order reactions using contaminant concentration data are written as:

$$dC/dt = -k_1 C \quad (4-9)$$

where  $k_1$  = the first degradation rate constant, 1/time. The integrated form of this equation is shown in Equation 4-10:

$$C = C_0 e^{-k_1 t} \quad (4-10)$$

A plot of the natural log of contaminant concentration versus time is linear when first order degradation is taking place, with the slope of this linearized relationship equal to  $-k_1$ .

Figure 4-9 shows a typical data set collected from the Layton, UT, field site. These data represent centerline p-xylene plume concentrations measured at the site in January 1994. Figure 4-9a shows a plot of p-xylene concentration versus distance downgradient from the source area. These data are non-linear, and Figure 4-9b shows the natural log transformation of concentration versus time of travel downgradient. Time of travel was calculated based on the distance to a given monitoring point from the source area, divided by the average pore water velocity measured at the Layton site, 0.037 ft/d. This pore water velocity was based on hydraulic conductivity and hydraulic gradient data collected there during the study. As indicated in Figure 4-9b, the natural log transformed data are linearized and provide a significant regression based on an alpha value of 0.05 (95 percent confidence level). The first order p-xylene degradation rate, determined from this analysis of the January 1994 field data at the Layton site, is 0.0016/d.

#### Calibration of Analytical Fate-and-Transport Ground-Water Model

As indicated above, to obtain the best estimate of contaminant degradation rates when a continuous source scenario is observed at a site, calibration of fate-and-transport models to measured field data is desirable. These models integrate transport, retardation, and degradation using site-specific contaminant and aquifer properties. This was the case for the Layton field site investigated in this study, and Figure 4-10 shows a plot of the calibrated p-xylene data for Layton using an analytical, three-dimensional model described later in this chapter. As indicated in Figure 4-10, using a fate-

and-transport model accounting for flow and contaminant sorption characteristics, in addition to degradation, yields a "dilution-corrected" degradation rate for p-xylene approximately five times lower than that estimated from analysis of centerline concentration data which did not account for advection and dispersion of p-xylene within the aquifer. Details of this analytical fate-and-transport model and its use in the assessment of intrinsic remediation reactions at UST sites are described later in this chapter.

#### Estimation of Source Mass/Lifetime

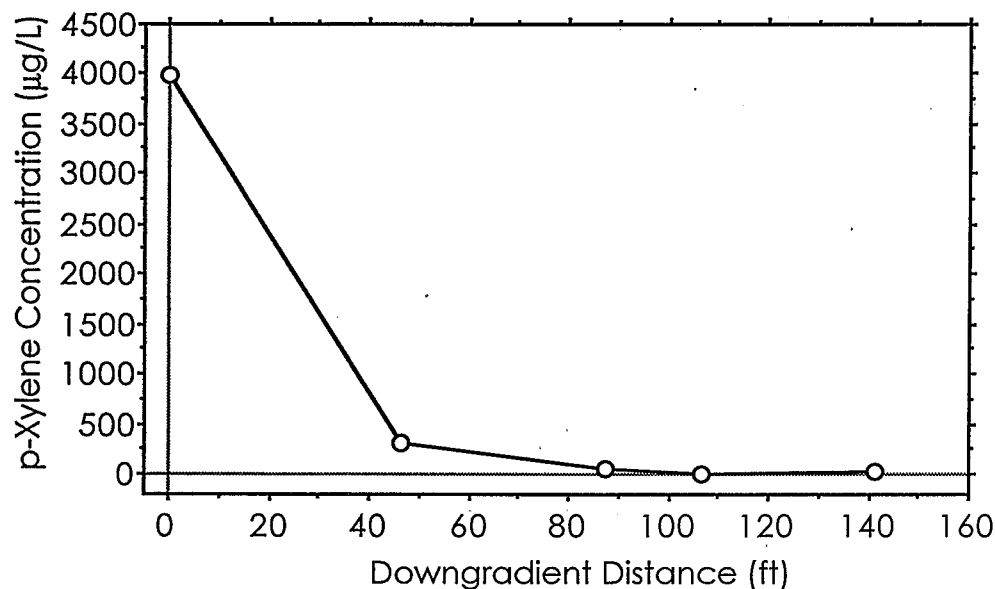
With an estimation of the rate of contaminant degradation taking place at a site, management decisions regarding the appropriateness of source removal actions and the effect of such actions on the projected lifetime of contamination at the site can be made. The logic associated with source mass and lifetime determinations is shown in Figure 4-11. If a pulse source exists at a site, little residual contaminant mass exists in the original source area. Calculations described above for the total dissolved mass existing within the plume allow a determination of the lifetime of the plume as follows for a zero order and first order degradation rate, respectively:

$$\text{Plume Lifetime}_{\text{zero}} = (\text{Last Dissolved Plume Mass})/k_0 \quad (4-11)$$

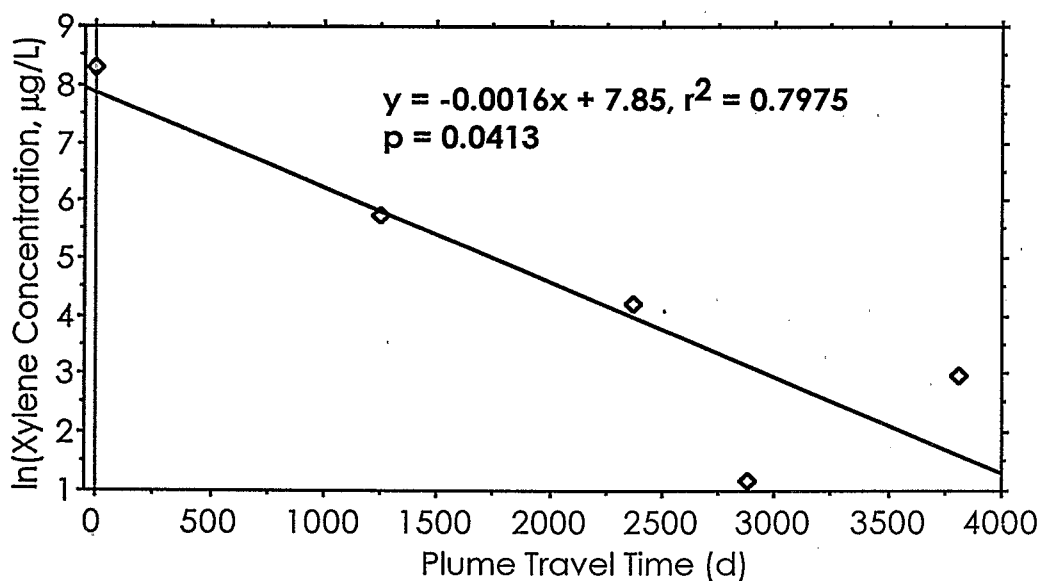
$$\text{Plume Lifetime}_{\text{first}} = -\ln(M/M_0)/k_1 \quad (4-12)$$

where  $k_0$  in Equation 4-11 has units of mass/time; and  $M$  in Equation 4-12 represents the final mass to be reached at the end of the calculated plume lifetime.

If a continuous source is found at a given site, contaminant mass within the source area continues to release mass to the ground-water, maintaining the contaminant plume that has developed over time. To arrive at an estimate of the potential lifetime of the plume, an estimate of contaminant both above and below the ground-water table must be made. These estimates should be based on soil core samples collected within the source area. This total mass estimate requires that the soil volume associated with each soil core be defined using a method such as the Thiessen polygon method that was described above. Once concentration and associated soil volume data are compiled, the estimation of total contaminant mass is based on the average borehole concentrations and volume averaged summation of masses from each core. Figure 4-12 indicates the configuration of soil cores and associated geometry used in the following equations for average borehole concentration,  $C_{\text{ave}}$ , and total contaminant mass,  $M_T$ , estimates in a source area:

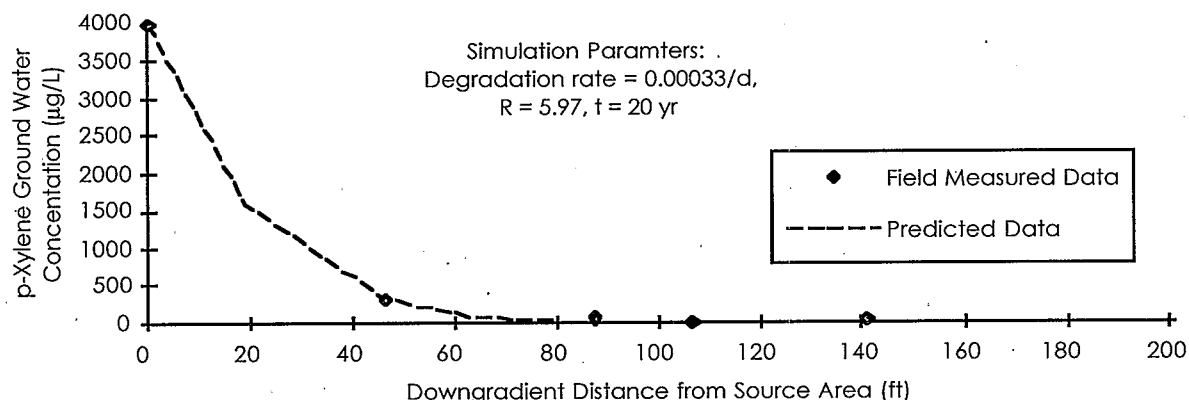


a) p-xylene concentration versus distance downgradient from the source area



b) Natural log transformed p-xylene concentration versus time of travel downgradient from the source area.

**Figure 4-9. p-xylene concentration data collected from the Layton, UT, site in January 1994. a) p-xylene concentration versus distance downgradient from the source area; b) Natural log transformed p-xylene concentration versus time of travel downgradient from the source area.**



**Figure 4-10. Calibration of fate-and-transport model using field-determined p-xylene concentration data collected from the Layton, UT, site in January 1994.**

$$C_{ave,j} = \frac{\sum_{i=1}^n C_{i,j} h_{i,j}}{\sum_{i=1}^n h_{i,j}} \quad (4-13)$$

where  $C_{i,j}$  = soil contaminant concentration in core  $j$  at depth  $i$  in the core, mass contaminant/mass soil;  $h_{i,j}$  = core  $j$  interval thickness at depth  $i$ , length; and  $n$  = total number of soil cores collected at the site.

$$M_T = \sum_{j=1}^n A_j \left( \sum_{i=1}^n C_{i,j} h_{i,j} \right) \quad (4-14)$$

where  $A_j$  = Thiessen area associated with core  $j$ , length<sup>2</sup>. It should be noted that the denominator of Equation 4-13 is the thickness of vadose zone contamination less an uncontaminated surface layer for mass above the ground-water table. For saturated zone mass determinations, this denominator is the thickness of contaminated soil below the ground-water table. Also, total mass calculations provided in Equation 4-14 should be carried out separately for mass above and below the ground-water table so that a picture of the vertical distribution of contaminant mass can be developed.

Once the total mass of contamination is estimated above and below the ground-water table, estimates for the total lifetime of the plume can be made. For a continuous source, the plume lifetime is the sum of the lifetime of the dissolved plume mass plus the mass remaining in the source area. If the mass removal rate is assumed to

be the contaminant degradation rate determined above, then the total plume lifetime,  $T_{continuous}$ , can be estimated as:

$$T_{continuous, zero} = (Mass_V + Mass_{SZ} + M_D)/k_0 \quad (4-15)$$

$$T_{continuous, first} = -\ln[M/(Mass_V + Mass_{SZ} + M_D)]/k_1 \quad (4-16)$$

for zero and first order degradation rate relationships, respectively, where  $Mass_V$  = contaminant mass in the vadose zone, mass;  $Mass_{SZ}$  = contaminant mass in the saturated zone, mass; and  $Mass_D$  = contaminant mass in the dissolved plume, mass.

#### **Predicting Long-Term Behavior of Plume**

The long-term behavior of a contaminant plume is impacted both by the characteristics of the source--affecting the duration of the release of contaminant into the aquifer--and by the characteristics of the aquifer itself affecting the transport and degradation of contaminant once it is released from the source area. Figure 4-13 presents the decision logic related to long-term source behavior, identifying differences in analysis of the plume based on whether it is considered a pulse or continuous source.

If the plume can be considered a pulse source, no residual source area exists, and the long-term behavior of the plume is related to the projected life-time of the plume based on calculations presented above.

If the site is shown to contain a significant source area, producing a "continuous source" plume, long-term plume behavior can be evaluated based on various

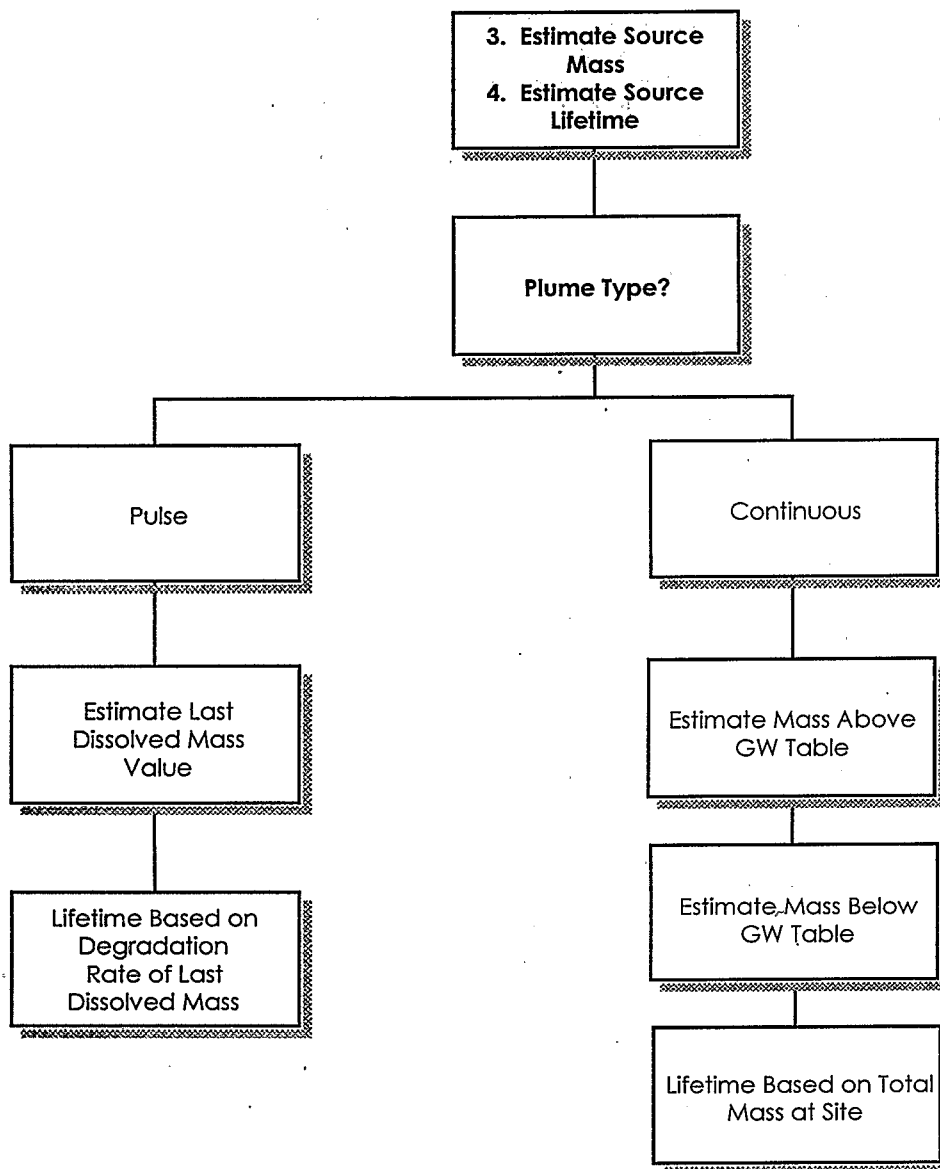
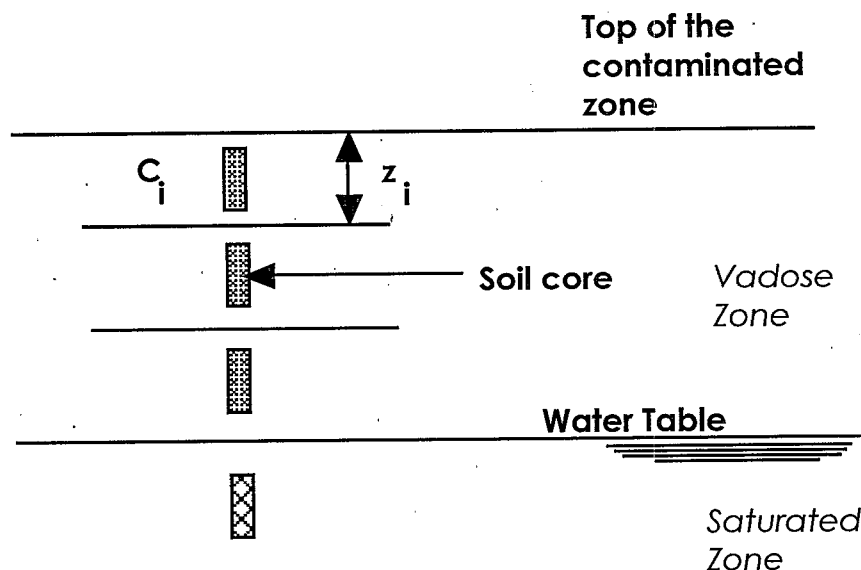


Figure 4-11. Decision logic in evaluating contaminant source mass and source lifetime.



**Figure 4-12. Configuration of soil cores and associated geometry used for calculation of average borehole contaminant concentrations as input to total mass estimates.**

source removal scenarios. If no source removal is to be carried out, a worst-case scenario develops in terms of the length of time the plume will persist. Under these conditions, the plume lifetime is predicted based on the sum of vadose zone, saturated zone, and dissolved plume masses. If contaminant source removal is being considered, the lifetime of the plume is controlled by the nature and extent of source removal taking place at the site. For example, if a significant mass of contaminant exists above the ground-water table, i.e.,  $Mass_v$  is large relative to  $Mass_T$ , an analysis of the effect of vadose zone source removal on the lifetime of the plume can be made using Equations 4-17 or 4-18.

In these equations,  $p$  = decimal percent removal of vadose zone contamination. Various removal scenarios can be carried out to evaluate the impact of these removal actions on the plume lifetime using this general approach. If 100 percent vadose and saturated zone

source removal is assumed, the continuous source plume lifetime equation reduces to that of the pulse source as shown in Equation 4-11.

Once source removal strategies are investigated, the complete long-term behavior of the contaminant plume can be predicted. This is done by the superposition of a continuous source, with a source concentration equal to the negative of the initial concentration, on top of the steady-state plume concentration profile. The time when this simulation begins is at a point in time,  $T$ , corresponding to the time of source removal, or the time at which natural source depletion is projected to occur. Both the steady-state plume and the imaginary - $C_0$  plume are then projected forward in time to time  $t + T$  and  $t$ , respectively, to yield a synthesized plume that reflects the effect of source removal on the overall plume footprint at the site.

$$T_{\text{continuous, zero}} = \frac{(1-p) (Mass_v + Mass_{sz} + Mass_D)}{k_0} \quad (4-17)$$

$$T_{\text{continuous, first}} = \frac{-\ln\left(\frac{M}{(1-p) (Mass_v + Mass_{sz} + Mass_D)}\right)}{k_1} \quad (4-18)$$

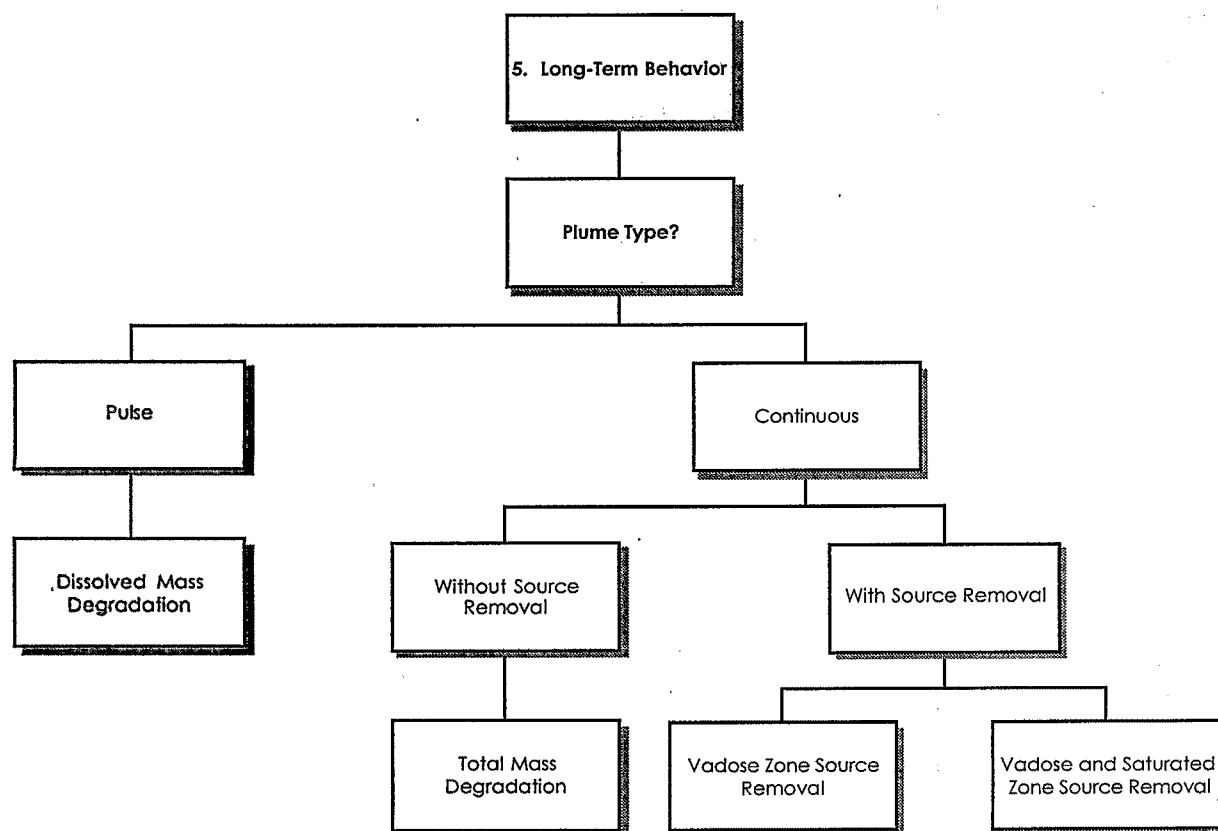


Figure 4-13. Decision logic in evaluating long-term behavior of contaminant plume.

For example, assume that a steady-state plume is observed 20 years after an original source release. If it is desired to predict the effect of source removal on this steady-state plume five years after source removal, the steady-state contaminant plume at Year 25 for a Co source concentration is modified by the addition of Year 5 modeling results for the -Co contaminant plume. This modification accounts for five years of plume transport and degradation without contaminant release from the source area. Results of this example source removal scenario are shown in Figure 4-14, and indicate, that with complete source removal, significant reductions in ground-water concentrations are predicted to occur. Within 20 years following 100 percent source removal, p-xylene ground-water concentrations are predicted to be less than 150 µg/L, nearly 100 times lower than the xylene MCL of 10,000 µg/L, within 80 ft of the source location at the Layton site.

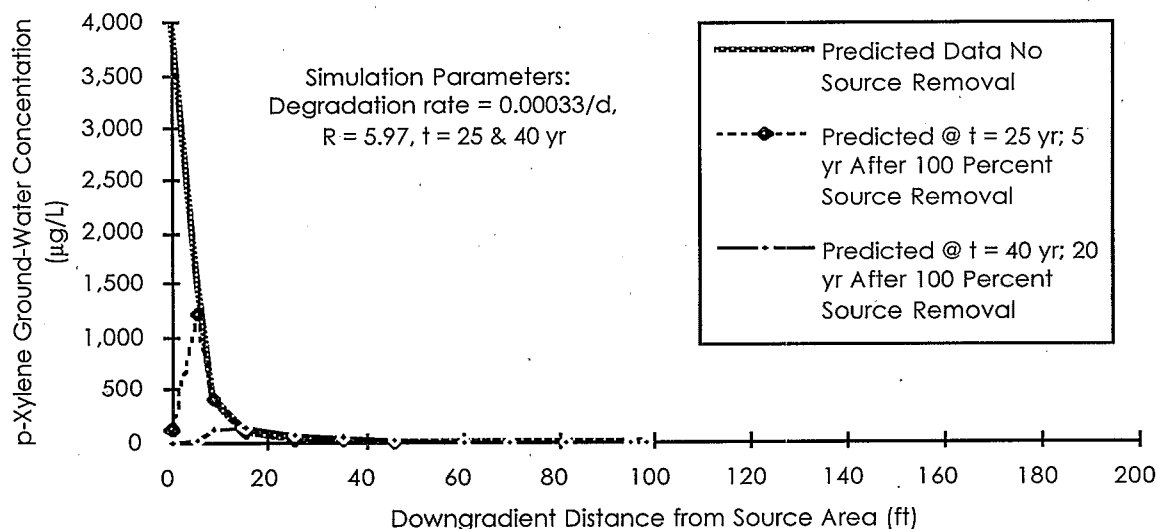
Similar scenarios could be carried out for various source removal efficiencies, affecting the point in time in the future when source depletion occurs and the -Co plume approach becomes applicable. It is important to note that the steady-state contaminant plume profile represents the highest downgradient concentration

profile that would be expected at a site. The concentrations at a given point in space will decrease over time following source removal activities if the plume is at steady-state, and if all other site conditions remain the same over time.

#### ***Decision Making Regarding Intrinsic Remediation***

The analyses described above provide a basis for making a decision regarding the applicability of an intrinsic remediation approach for a given site. Figure 4-15 provides a summary of the logic necessary to complete the decision making process based on the potential success of intrinsic attenuation reactions providing plume containment and control, and on the impact the plume has on downgradient receptors.

The focus of the previous discussion has been on quantifying the transport and degradation of contaminants of interest taking place under actual site conditions. Additional supporting evidence for verification that degradation reactions are biologically mediated can be provided through an analysis of the changes in background electron acceptor mass compared to that within the plume itself. If contaminant



**Figure 4-14. Predicted impact on plume centerline p-xylene concentrations 5 and 20 years after 100 percent source removal based on a field data calibrated fate-and-transport model for the Layton, UT, site.**

biodegradation is taking place, indigenous organisms will utilize electron acceptors ( $O_2$ ,  $NO_3^-$ ,  $Mn^{4+}$ ,  $Fe^{3+}$ ,  $SO_4^{2-}$ ,  $CO_2$ ) at a rate and to an extent that should correspond to contaminant loss observed at the site. The stoichiometry associated with microbial metabolism known to occur under various electron acceptor conditions allows a determination of the potential contaminant assimilative capacity of background ground-water moving into the source area and available in the solid phase within the plume itself. If this theoretical assimilative capacity is equal to or greater than the level of contamination observed at the site, biological intrinsic remediation processes can be expected to play a major role in contaminant attenuation. If this theoretical assimilative capacity is limited, some source removal and/or active site remediation action is likely warranted. A detailed discussion of procedures that can be used to estimate this theoretical assimilative capacity is provided in a later section of this chapter.

The final questions that must be answered regarding application of an intrinsic remediation management approach at a site are: whether or not a sensitive receptor is being impacted now or in the future when the plume is projected to reach steady-state conditions; and whether or not the projected lifetime of the plume is acceptable to the owner/operator, regulatory agencies, and other interested parties. In general, if an existing or projected receptor impact exists, active source removal and/or plume control/remediation may be required. The

issue of plume lifetime tends to be a more complicated one. If significant contaminant mass remains in the source area of a site, the resulting plume may persist for decades. If remediation goals are established with shorter timeframes, i.e., for property transfer reasons, etc., this assimilation time will likely not be acceptable, and active remediation may be required.

#### **Long-Term Monitoring Program for Site**

If an intrinsic remediation plume management approach is selected for a given site, the last step in the assessment process is the development of a long-term monitoring strategy for the site. Figure 4-16 shows that the requirements of the monitoring strategy are twofold, namely, for compliance monitoring purposes, as well as for intrinsic remediation process monitoring.

A compliance monitoring program is established to provide data to the regulatory agency to confirm that plume containment and risk management continue to take place at the site. Compliance monitoring normally involves the use of an upgradient, background monitoring well, two to three monitoring wells within the contaminant plume, and two to three downgradient compliance wells used to detect contaminant migration toward potential receptors. Ground-water elevation, contaminant concentration, and minimal ground-water quality data (pH, temperature, total dissolved solids) are generally required to be reported from these monitoring wells.

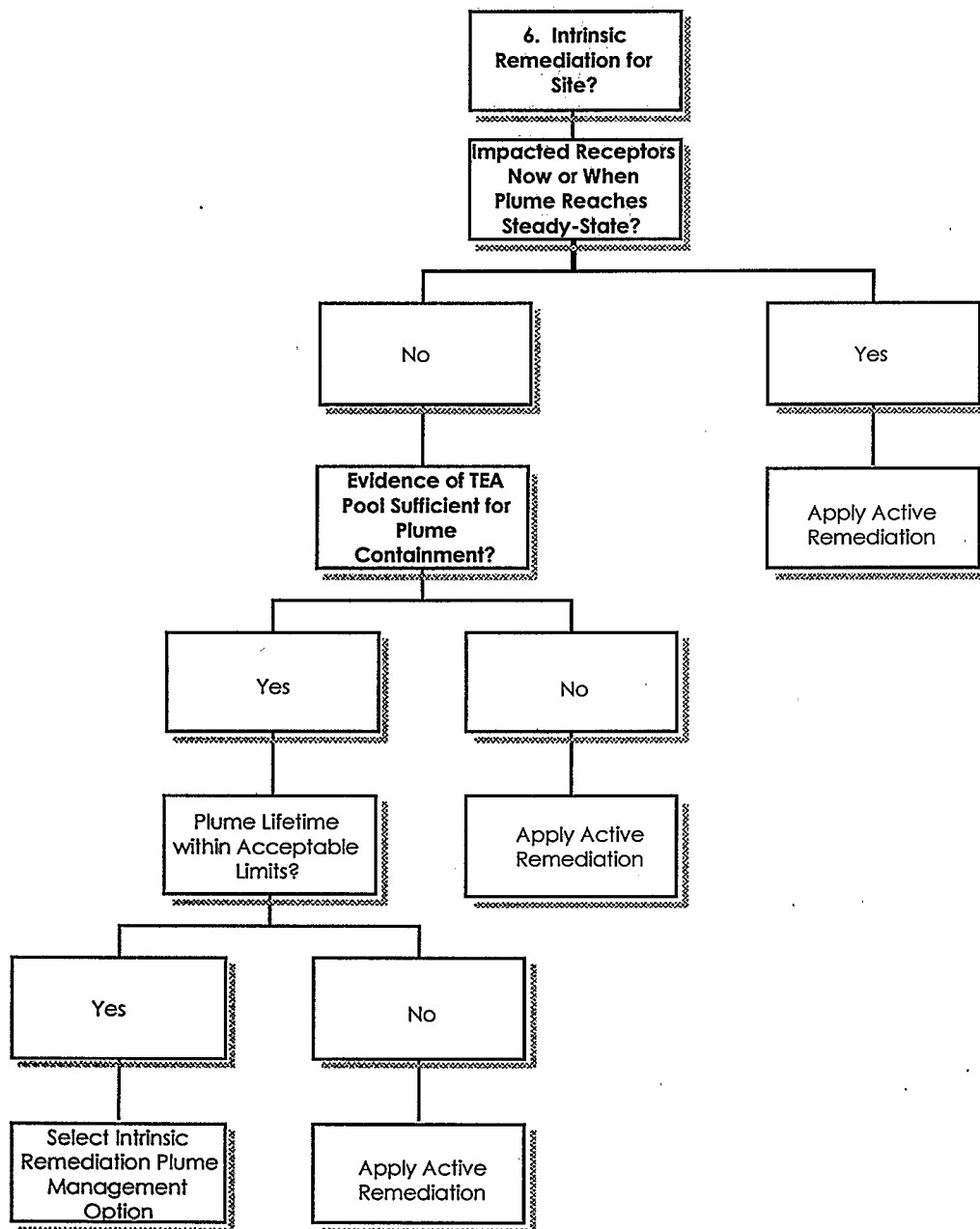


Figure 4-15. Decision logic in evaluating applicability of intrinsic remediation plume management approach for a given site.



The information generated for compliance monitoring purposes is necessary, but not sufficient for intrinsic remediation process monitoring. Additional monitoring locations and analyte data should be collected for process monitoring purposes. Figure 4-17 shows a typical monitoring well network that is appropriate for both initial intrinsic remediation evaluation and long-term compliance and intrinsic remediation process monitoring. The analytes that would typically be measured in addition to those used for compliance monitoring include: terminal electron acceptors ( $O_2$ ,  $NO_3^-$ ,  $SO_4^{2-}$ ); product ( $Mn^{2+}$ ,  $Fe^{2+}$ ,  $CH_4$ ) formed during contaminant biodegradation; and water quality characteristics (alkalinity and oxidation/reduction potential) which are indicative of biological processes taking place within a contaminated aquifer. With this network established and additional process monitoring data collected, the conceptual model of the site and model calibration results can be continuously updated to provide ongoing refinements to source lifetime predictions.

Finally, the frequency of ground-water monitoring is established as part of the long-term monitoring plan. Compliance monitoring schedules generally require quarterly to annual sampling. Under most circumstances, annual sampling is the shortest time interval necessary for intrinsic remediation process monitoring since low ground-water velocities observed at most sites do not warrant more frequent sampling intervals. At a site with a ground-water velocity of 0.04 ft/d (similar to the Layton site), unretarded ground-water moves less than 15 ft a year. With a retarded velocity 1/3 to 1/6 that of ground-water (appropriate for benzene and xylene, respectively), contaminant movement of less than three to five ft would be expected over a one year time period. With a monitoring grid spaced at 30-ft intervals, a one-year change in plume position cannot be detected. Again, the sampling interval should be assessed on a site-specific basis. Generally an annual to biannual sampling schedule should be sufficient to assure that adequate data are collected, while minimizing the sampling and analysis burden at intrinsic remediation sites.

#### **Potential Aquifer Assimilative Capacity**

Contaminant degradation by microorganisms takes place when the contaminant serves either as a primary energy source (electron donor) or are fortuitously metabolized when other primary substrates are available to the microorganisms (co-metabolism). In order for the electron donors to be utilized by the indigenous microbial community, compounds must also be available which allow energy transfer by the microorganisms to take place. These compounds are classified as electron acceptors and are generally believed to be utilized in a sequential fashion based on the relative energy yield to the microorganisms when energy production and

electron donor utilization is taking place. This sequence of electron acceptor utilization is as follows: oxygen, nitrate, manganese, iron, sulfate, carbon dioxide, and organic carbon. Oxygen provides the greatest energy yield and results in the broadest utilization of electron donors of all of the electron acceptors listed above.

Dominating electron acceptors and aquifer oxidation/reduction potential (ORP) conditions change as the plume moves downgradient from the source of ground-water contamination. Near the source, oxygen and nitrate are depleted, while high dissolved iron and manganese concentrations are observed. Under these highly reducing conditions, methanogenesis and sulfate utilization are generally the primary reaction mechanisms observed. Further downgradient from the source, sulfate reduction gives way primarily to iron and manganese metabolism. The system eventually switches to nitrate-dominated metabolism, and ultimately to areas away from the source that are once again enriched in dissolved oxygen. The occurrence of specific non-oxygen electron acceptor reaction zones is dependent upon the pool of each electron acceptor available in the aquifer and the nature of the electron donor available to the microorganisms from the contaminant release. In addition, the specific position of each reaction zone and the location of the points of transition from one dominant electron acceptor area to the other is dependent upon the release rate of the contaminants from the source, the nature of the contaminants in terms of their rate of utilization under specific electron acceptor conditions, and the rate of ground-water migration below the site.

The nature of microbial processes taking place at specific locations within an aquifer dictates the predominant ground-water quality conditions and specific dominant chemical species found there. It is important then to review the characteristics of metabolism under each electron acceptor condition. Monitoring of these microbial processes forms the basis for the detection and quantification of intrinsic remediation reaction rates taking place in aquifer systems and in estimating the potential assimilative capacity of a given aquifer.

#### **Dissolved Oxygen**

Dissolved oxygen (DO) is the most energetically favorable electron acceptor in respiratory metabolism. The consumption of dissolved oxygen in an aquifer indicates the activity of aerobic microorganisms and is a primary indicator for the existence of biologically mediated reactions at a contaminated site. In most pristine aquifers, some oxygen exists (Major, 1988; Manahan, 1990; Barcelona and Holm, 1991). In general, there are no readily available non-biotic sources or sinks for oxygen in aquifers. Oxygen, found in aquifers at a maximum concentration of 8 to 10 mg/L, can be used

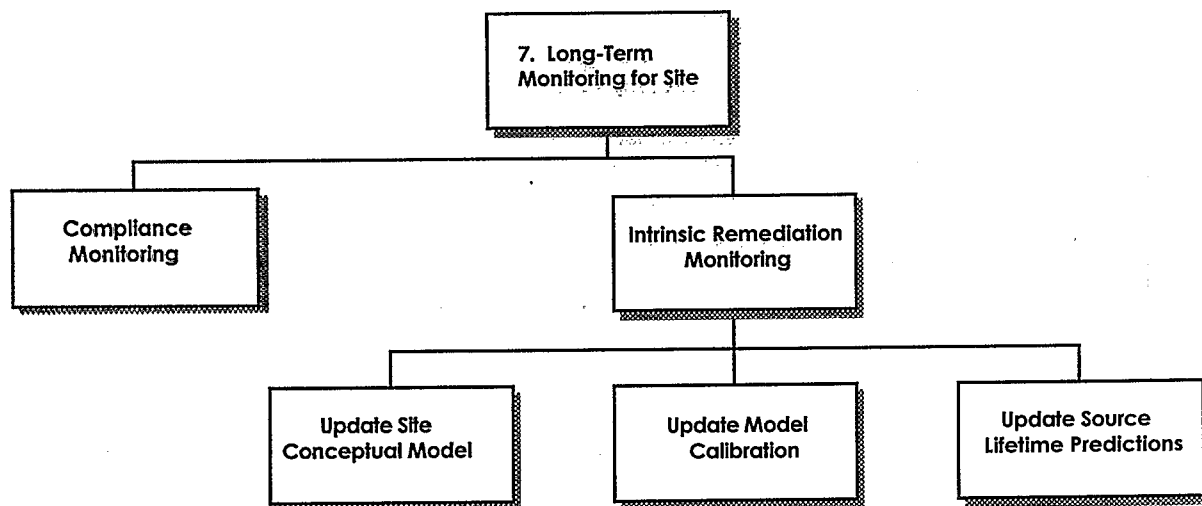


Figure 4-16. Requisite components of a long-term monitoring strategy applied at an intrinsic remediation site.

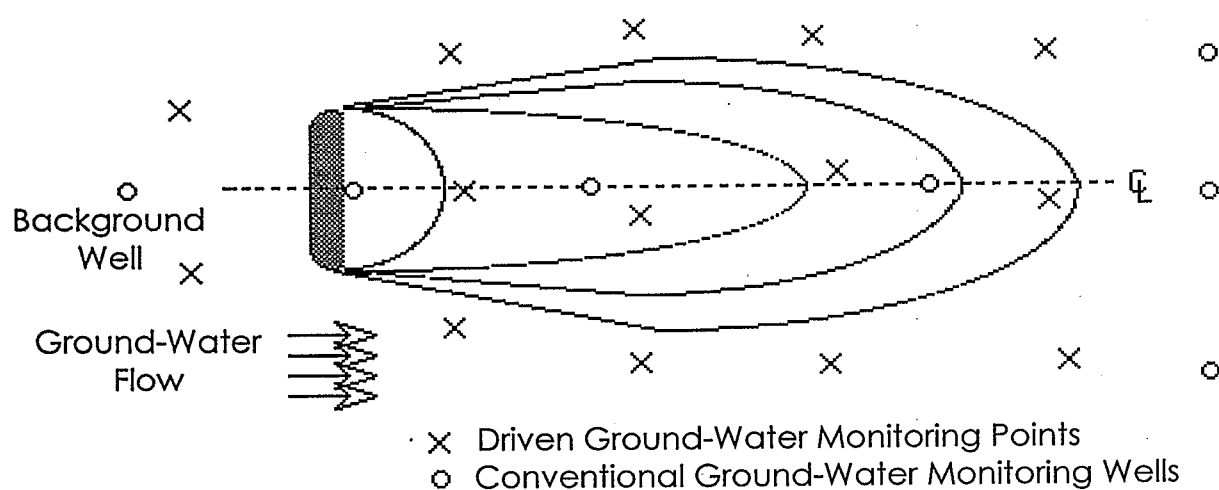


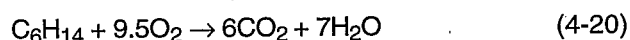
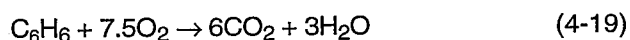
Figure 4-17. Ground-water monitoring network applied at an intrinsic remediation site for both compliance and intrinsic remediation process monitoring.

quickly when an aquifer becomes contaminated with biodegradable organic material such as hydrocarbons (Major, 1988; Manahan, 1990).

The size and structure of a hydrocarbon compound affect its aerobic degradation rate. Compared to other hydrocarbons, intermediate alkanes, C<sub>10</sub> to C<sub>24</sub>, are considered the most unstable in aerobic environments. Branched alkanes and aromatic compounds are found to be more stable in aerobic environments. It has been found that tertiary and quaternary carbon atoms interfere with degradation processes, or in some instances, even block degradation altogether (Atlas and Bartha, 1987) by inhibiting  $\beta$ -oxidation (Manahan, 1990).

The other terminal electron acceptors that can be used by hydrocarbon degrading organisms, NO<sub>3</sub><sup>-</sup>, Mn<sup>4+</sup>, Fe<sup>3+</sup>, SO<sub>4</sub><sup>2-</sup>, and CO<sub>2</sub>, require oxygen-free environments. The presence of oxygen will generally inhibit the utilization of the other terminal electron acceptors. In all but subsurface plumes with very low concentrations of hydrocarbons or well-oxygenated environments, the rate of oxygen utilization will exceed oxygen inputs, resulting in oxygen depletion and utilization of other terminal electron acceptors within major portions of the contaminant plume.

Quantitatively, the mass of oxygen depleted in the degradation of hydrocarbon contaminants can be estimated from the balanced equations for the conversion of benzene (representative compound for the aromatic hydrocarbons) and hexane (representative compound for the alkanes) to carbon dioxide and water using oxygen as the electron acceptor. These balanced equations can be written as follows:



These stoichiometric relationships indicate that 7.5 to 9.5 g/mol of oxygen are required to oxidize 1 g/mol of hydrocarbon contaminant. This suggests that 3.1 ([7.5 x 32]/78) to 3.5 g ([9.5 x 32]/86) of oxygen will be consumed per gram of hydrocarbon degraded. This provides a conservative estimate of oxygen consumption and expected hydrocarbon depletion since it does not account for the carbon utilized in cell mass production. The level of net cell mass would be expected to be low due to infinite solids residence times in the aquifer, and the low level of substrate available, making endogenous respiration a significant reaction under field aquifer conditions.

### Nitrate

Nitrate can be utilized for both assimilatory and dissimilatory metabolism. In either the presence or absence of oxygen, a group of enzymes produced by a

variety of organisms can reduce nitrate to ammonia and incorporate the ammonia into a variety of amino acids. This assimilatory metabolism is suppressed in the presence of large amounts of ammonia and by other than neutral pHs (Atlas and Bartha, 1987). In the absence of oxygen, nitrate can be used as a terminal electron acceptor. Nitrate reduction produces a variety of reduced nitrogen forms including: NO<sub>2</sub><sup>-</sup>, NO, N<sub>2</sub>O, and N<sub>2</sub>. As the nitrate is reduced, organic matter is oxidized. In this case, the reduction of nitrate can lead to the oxidation of hydrocarbons.

There are two types of dissimilatory nitrate reduction. In the first type, nitrate ammonification, nitrate is reduced to non-gaseous, water soluble products such as nitrite and ammonia. Unlike assimilatory nitrate metabolism, this process is not inhibited by increasing amounts of nitrite or ammonia. Nitrate ammonification is common in sewage treatment, stagnant water, and sediment. Facultative organisms such as *Alcaligenes*, *Escherichia*, *Aeromonas*, *Enterobacter*, *Flavobacterium*, and *Nocardia* species utilize nitrate reduction to nitrite and ammonia for dissimilatory metabolism (Brock and Madigan, 1991).

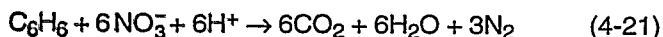
The second type of nitrate reduction, denitrification, is the reduction of nitrate to gaseous products. Nitrate reducing bacteria such as *Paracoccus denitrificans*, *Thiobacillus denitrificans*, and a variety of pseudomonads are capable of this nitrate reduction process (Brock and Madigan, 1991). Typically, a mixture of nitrous oxide and nitrogen is produced. The actual distribution of the oxidized product is dependent on both the active microbial population and the environment in which the reaction takes place:

Denitrification occurs under anaerobic conditions or in aerobic environments with anaerobic microhabitats. Dissimilatory nitrate reductase, the enzyme mediating the first step in denitrification, is competitively inhibited by oxygen, not inhibited by ammonia, and is particle bound. Denitrification produces more reducing equivalents than nitrate ammonification, making it the more environmentally significant system.

The bulk of the literature describing the degradation of hydrocarbons under denitrifying conditions has focused on toluene and the xylenes. Zeyer et al. (1986) described gaseous nitrogen products of the degradation of xylene under denitrification conditions, plus they calculated a first order rate of 0.45/day for the degradation rate for xylene. Kuhn (1985) and Hutchins (1991a, b) found degradation rates were not the same for the different xylene isomers. They found that o-xylene degraded at a slower rate than p- or m-xylene. Kuhn (1985) calculated rates for the faster degrading xylenes to be 0.5/day, matching the degradation rates Zeyer et al. (1986) observed for xylene under denitrifying conditions.

Benzene, toluene, and xylene (Major et al., 1988; Hutchins, 1991a, b) and some PAHs (Mihelcic and Luthy, 1988a, b) have also been shown to degrade under denitrifying conditions.

Quantitatively, the mass of nitrate depleted in the degradation of hydrocarbon contaminants can be estimated from the balanced equations for the conversion of benzene (representative compound for the aromatic hydrocarbons) to carbon dioxide and water using nitrate as the electron acceptor. This balanced equations can be written as follows:



It is evident then that 6 gmol of nitrate are required to oxidize 1 gmol of aromatic hydrocarbon contaminant. This suggests that 1.07 g  $[(6 \times 14)/78]$  of nitrate-nitrogen will be consumed per gram of hydrocarbon degraded. This provides a conservative estimate of nitrate consumption and expected hydrocarbon depletion since it does not account for the carbon utilized in cell mass production. As indicated above, however, the net production of cell mass would be expected to be small, making the calculations only slightly conservative in nature and acceptable for degradation potential estimates used in this report.

#### Iron/Manganese

Ferrous iron and  $\text{Mn}^{2+}$  found in ground-water samples may indicate the use of  $\text{Fe}^{3+}$  and  $\text{Mn}^{4+}$  as terminal electron acceptors for respiratory metabolism. Both iron and manganese are energetically favorable electron acceptors in anoxic systems and can play a major role in contaminant degradation when high oxygen demand in impacted aquifer systems exceeds the limited oxygen supply normally delivered in ground-water systems. Iron has been found to participate in the anaerobic degradation of creosote (Lovely and Phillips, 1987b) and crude oil (Lovely et al., 1989).

The anaerobic degradation of hydrocarbons using iron as a terminal electron acceptor may begin with fermentative bacteria producing  $\text{Fe(II)}$ ,  $\text{CO}_2$ , and a series of organic intermediate products. These fermentative products may then be mineralized by  $\text{Fe(III)}$ -reducing bacteria (Lovely and Phillips, 1988). The fermentative step is not always necessary. Compounds that have been mineralized in anoxic/ $\text{Fe(III)}$  systems without a fermentation step include toluene, benzoate, phenol, and p-cresol (it is important to note that catechol can reduce  $\text{Fe(III)}$  in an abiotic reaction at the near neutral pHs frequently encountered in ground-water) (Lovely et al., 1989).

There are connections between the nitrogen and iron systems. Nitrate reductase, the enzyme involved with nitrate reduction to nitrite, can also reduce  $\text{Fe(III)}$  (Brock and Madigan, 1991). The first organism isolated that

could utilize  $\text{Fe(III)}$  as a sole terminal electron acceptor, GS-15 (Lovely and Phillips, 1988), can also utilize nitrate as a terminal electron acceptor and is cultured with nitrate (Lovely, 1991). Organisms capable of reducing  $\text{Fe(III)}$  are often also denitrifying organisms (Sorensen, 1982). Iron-reducing bacteria can also be cultured aerobically, as in the case of *Alteromonas putrefaciens*.  $\text{Fe(III)}$ -reducing bacteria include both facultative and obligate anaerobes (Lovely et al., 1989).

There is some evidence that  $\text{Fe(III)}$  reduction can be the predominant anaerobic system in the absence of reducible nitrogen compounds (Lovely and Phillips, 1987b). However, there is some disagreement on the role of ferric iron as a terminal electron acceptor in systems where sulfate reduction is possible. Although the reduction to ferrous iron compared to sulfate reduction is thermodynamically favorable, Beller et al. (1992) reported that the microorganisms involved in their study utilized sulfate as a terminal electron acceptor. The amorphous ferric iron in the same system served a more abiotic role, perhaps in removing hydrogen sulfide from the system or serving as a required nutrient. Haag et al. (1992) also found the metabolism of toluene by sulfate reducers occurring in the presence of ferric iron hydroxides. Sorensen (1982) stated that there was no interaction between iron and sulfate metabolism, and that both occurred simultaneously. However, Lovely and Phillips (1987b) found that the presence of amorphous ferrous iron inhibited sulfate reduction as well as methanogenesis, differing from the results of Beller et al. (1992), Haag et al. (1992), and Sorensen (1982).

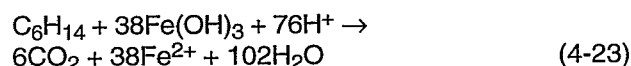
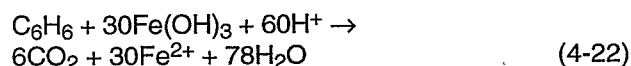
$\text{Fe(III)}$  bioavailability is determined by its form. Amorphous  $\text{Fe(III)}$  oxyhydroxides are the preferred form for the  $\text{Fe(III)}$  reducing bacteria. Crystalline forms are reduced much more slowly, if at all (Lovely and Phillips, 1987b). This need for amorphous iron can be a benefit for in-situ remediation efforts. Clay will stabilize amorphous iron (Lovely and Phillips, 1987b), creating a reducible iron-rich environment for biodegradative processes. From this amorphous iron, the bacteria will form magnetite, tying up two-thirds of the available oxidized iron in this unusable form. For each kilogram of magnetite produced, 10 kilograms of biomass can be produced (Frankel, 1987).

The rates of organic oxidation via iron reduction can approach the rates of reaction under aerobic processes. The free energy change of acetate oxidation coupled to  $\text{Fe(III)}$  or  $\text{Mn(IV)}$  reduction is near that of the oxygen coupled reaction (Lovely and Phillips, 1988).

Manganese metabolism is less studied than iron metabolism. Tetravalent manganese has been shown to be reduced to divalent manganese as a terminal electron acceptor (Lovely and Phillips, 1988; Lovely et al., 1989). The same reaction has also been demonstrated to occur

abiotically, resulting in the oxidation of organic substances.

Quantitatively, the mass of dissolved iron produced in the degradation of hydrocarbon contaminants can be estimated from the balanced equations for the conversion of benzene (representative compound for the aromatic hydrocarbons) and hexane (representative compound for the alkanes) to carbon dioxide and water using Fe(III) as the electron acceptor. These balanced equations can be written as follows:



These stoichiometric relationships indicate that from 30 to 38 gmol of dissolved iron are produced when 1 gmol of hydrocarbon contaminant is oxidized using amorphous iron as the terminal electron acceptor. This suggests that 21.5  $([30 \times 55.85]/78)$  to 24.7 grams  $([38 \times 55.85]/86)$  of dissolved iron will be produced per gram of hydrocarbon degraded. This provides a conservative estimate of dissolved iron production and expected hydrocarbon depletion as discussed above since it does not account for the small net mass of cell material generated during iron metabolism.

### Sulfate

In nature, sulfate reduction is both assimilatory and dissimilatory. For assimilatory metabolism, microorganisms use sulfate to create cysteine, methionine, and coenzymes. For dissimilatory sulfate reduction, hydrogen sulfide is produced from sulfate reduction. This sulfate reduction reaction is carried out by a number of obligate anaerobic organisms (Brock and Madigan, 1991); usually in aquatic environments. Hydrogen sulfide ( $\text{H}_2\text{S}$ ) is toxic to most organisms. In assimilatory metabolism, sulfide is utilized at a rate fast enough to prevent high concentrations of  $\text{H}_2\text{S}$  from occurring. For dissimilatory metabolism, released sulfide has a number of possible fates. Sulfide reacts readily with metals such as iron, forming iron sulfide, the black color often found in anaerobic sediments, or it is released as  $\text{H}_2\text{S}$  gas. In aquatic environments,  $\text{H}_2\text{S}$  finds its way to the atmosphere due to its low water solubility.

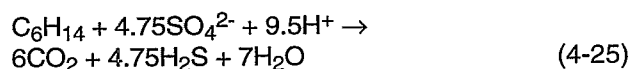
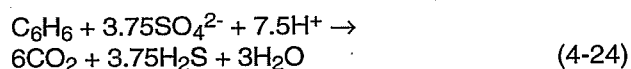
The dissimilatory reduction of sulfate can occur at a variety of pH conditions, although the products can be pH dependent. At pH values below 7,  $\text{H}_2\text{S}$  is the major product. At neutral pH,  $\text{HS}^-$  is the main product. When sulfate reduction is carried out at basic pHs, the sulfide ion is the main product (Brock and Madigan, 1991).

It is interesting to note that molybdenum, present in nitrate reductase (Brock and Madigan, 1991), suppresses sulfate metabolism, while the presence of

sulfate inhibits methanogens (Winfrey and Ward, 1983). To suppress methanogens, sulfate reducers out-compete the methanogens for acetate and hydrogen. As well as utilizing more complex substrates, the sulfate reducers can maintain concentrations of acetate and hydrogen too low for methanogens to utilize. Minor methane production can occur in sulfate reducing systems via the utilization of methylamines, a noncompetitive substrate, by the methanogens (Lovely and Phillips, 1987b).

Sulfate has been shown to be involved in the degradation of hydrocarbons, but higher rates of degradation have been observed for sulfate-mediated degradation of halogenated alkanes. Aeckersberg et al. (1991) experimented with a bacterium that could mineralize saturated hydrocarbons in anoxic environments via sulfate reduction. Once isolated in the lab, the bacteria was used to degrade hexadecane, n-dodecane, n-tetradecane, n-pentadecane, n-heptadecane, n-octadecane, n-eicosane, 1-hexadecane, 1-hexadecanol, and 2-hexadecanol (Aeckersberg et al., 1991). All of the systems reduced sulfate to sulfide. Growth or sulfide production by this organism has not been found using saturated hydrocarbon substrates with less than a 12-carbon chain.

Quantitatively, the mass of sulfate utilized in the degradation of hydrocarbon contaminants can be estimated from the balanced equations for the conversion of benzene (representative compound for the aromatic hydrocarbons) and hexane (representative compound for the alkanes) to carbon dioxide and water using sulfate as the electron acceptor. These balanced equations can be written as follows:



These stoichiometric relationships indicate that 3.75 to 4.75 gmol of sulfate are utilized when 1 gmol of hydrocarbon contaminant is oxidized using the dissolved sulfate as the terminal electron acceptor. This suggests that 4.6  $([3.75 \times 96]/78)$  to 5.3 g  $([4.75 \times 96]/86)$  of sulfate will be consumed per gram of hydrocarbon degraded.

### Methanogenic Systems

Methanogenic bacteria are a type of specialized archaeobacteria that typically produce methane by reducing carbon dioxide with electrons generated by the oxidation of hydrogen. They exist as strict obligate anaerobes. Methanogens require a redox potential between -350 and -450 mV to be active (Atlas and Bartha, 1987).

Methanogenic systems in general are considered to function orders of magnitude more slowly than aerobic systems (Borden and Bedient, 1986). In addition, only methanogenic systems, not methanogenic bacteria, have been shown to degrade fuel hydrocarbons. The participants in the degradation pathway are still relatively unstudied, particularly the fermentative bacteria that produce organic acids and other low molecular weight organic compounds as substrates for the methanogens.

Methanogens are substrate specific, using simple organic compounds such as methanol, formic acid, acetic acid, and some inorganic substances such as carbon dioxide, carbon monoxide, and diatomic hydrogen as substrates (Grady and Lim, 1980). Due to the small number of possible substrates they can utilize, methanogenic bacteria function in a consortia involving other microorganisms. These other microorganisms include fermentative bacteria and facultative anaerobic bacteria. The fermentative bacteria degrade the more complex organic compounds such as carbohydrates and proteins into substrates usable by the methanogens (Atlas and Bartha, 1987). The facultative anaerobic bacteria act as oxygen scavengers to maintain the anaerobic environment (Grady and Lim, 1980).

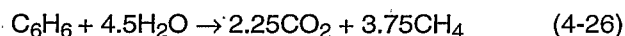
The methanogenic consortia for degrading hydrocarbons include fermentative organisms that provide substrate for the methanogenic organisms, possible through hydrogen-producing acetogens (Grbic-Galic, 1986). Fermentative organisms, with the methanogenic organisms suppressed, have been shown to be capable of degrading toluene and benzene. The reactions are both reductive and oxidative, with the reductive reaction most probably producing cyclohexane derivatives which have not yet been isolated. The oxidative reaction uses oxygen from water to produce phenol, p-cresol, and benzyl alcohol (Grbic-Galic, 1986). These reactions could explain the presence of ethylated and methylated phenols in anaerobic subsurfaces contaminated with gasoline (Rienhard et al., 1984). The absence of the reduced products at these sites could be explained by the higher vapor pressure of cyclohexane and some of its methylated derivatives as compared to that of toluene or benzene.

As with aerobic degradation, branched paraffinic compounds are less degradable than unbranched paraffinic compounds under methanogenic conditions (Battersby and Wilson, 1989). Degradation of aromatic compounds may be enhanced by the presence of carboxyl or hydroxyl groups (Schink, 1984).

Schink's (1984), Battersby and Wilson's (1989), and Grbic-Galic's (1986) experiments seem to compliment one another. Toluene, xylene, and benzene do not

lead to methane production in some methanogenic systems (Schink, 1984; Battersby and Wilson, 1989). Schink (1984) also stated that although these compounds were unsaturated, the  $\pi$ -electron system does not allow easy hydration of the double bonds. Grbic-Galic (1986) stated that the fermentative bacteria in the methanogenic consortium used in her experiments could oxidize toluene and benzene into hydroxylated products, perhaps more suitable for further degradation by methanogenic bacteria.

Quantitatively, the mass of methane produced in the degradation of hydrocarbon contaminants can be estimated from the balanced equations for the conversion of benzene (representative compound for the aromatic hydrocarbons) and hexane (representative compound for the alkanes) to carbon dioxide and methane using the following balanced equations:



These stoichiometric relationships indicate that 3.75 to 4.75 gmol of methane are produced when 1 gmol of hydrocarbon contaminant is metabolized under methanogenic conditions. This suggests that 0.77  $([3.75 \times 16]/78)$  to 0.88 g  $([4.75 \times 16]/86)$  of methane will be produced per gram of hydrocarbon degraded under highly reducing conditions.

Table 4-6 summarizes the stoichiometry and mass balance relationships that can be used to estimate the potential aquifer assimilative capacity for a given aquifer system. Negative values represent a utilization of electron acceptors (i.e., oxygen utilization at the rate of 7.5 gmol/gmol aromatic hydrocarbon), while positive values reflect the production of species related to electron acceptor use (i.e.,  $\text{Fe}^{2+}$  production at the rate of 30 gmol/gmol aromatic hydrocarbon). The values provided in the table are representative of aromatic and aliphatic hydrocarbons expected at fuel contaminated sites. The potential assimilative capacity, based on measured electron acceptor concentrations and the stoichiometric relationships given in Table 4-6, should exceed the hydrocarbon concentrations measured at a site to ensure that contaminant plume containment will take place there.

#### Fate-and-Transport Modeling

The degradation rates of contaminants of concern in the plumes at the two field sites investigated in this study were independently estimated using a ground-water fate-and-transport model describing the advection, dispersion, and degradation of dissolved compounds that take place within an aquifer system. The modeling effort carried out in this study had four fundamental

**Table 4-6. Potential Hydrocarbon Assimilative Capacity Relationships for Electron Acceptors of Importance at UST Sites**

Electron Acceptor	Hydrocarbon Type Degraded	Molar Relationship (gmol/gmol HC Degraded)	Mass Relationship (g/g HC Degraded)
Oxygen	Aromatic	-7.50	-3.10
	Aliphatic	-9.50	-3.50
Nitrate	Aromatic	-6.00	-1.07
Iron (Fe <sup>2+</sup> )	Aromatic	+30.00	+21.50
	Aliphatic	+38.00	+24.70
Sulfate	Aromatic	-3.75	-4.60
	Aliphatic	-4.75	-5.30
Methane	Aromatic	+3.75	+0.77
	Aliphatic	+4.75	+0.88

objectives: 1) to provide independent verification and support of apparent ground-water plume containment (intrinsic remediation) observed at the field sites; 2) to allow the evaluation of long-term plume behavior under an intrinsic remediation management approach applied at the sites; 3) to evaluate the impact of source removal on long-term plume behavior and plume life-time; and 4) to guide the development of a long-term monitoring plan.

#### Model Overview and Description

An analytical solution for the advection-dispersion equation, with degradation (Domenico, 1987), was applied, along with site-specific physical/chemical input parameters, in these modeling activities. Equation 4-28 is the form of the advection-dispersion equation (ADE) which describes contaminant transport in three dimensions. The first three terms of this equation describe contaminant dispersion in the x, y, and z directions; the fourth term describes contaminant advection with the moving ground-water, while the last term on the left side of Equation 4-28 is a generic kinetic term used to simulate processes which result in the degradation of the contaminant during migration.

The analytical solution for the ADE given in Equation 4-28 for a continuous source is provided in Equation 4-29 (Domenico, 1987). In Equation 4-29,  $C(x,y,z,t)$  = concentration at point x,y,z and time t, mass/volume;  $C_0$  = initial concentration, mass/volume;  $v_r$  = retarded ground-water velocity =  $v/R$ , L/time;  $v$  = ground-water velocity, L/time;  $R$  = contaminant retardation factor, unitless;  $\lambda$  = decay constant, 1/time;  $\alpha_L$  = dispersivity in x direction (longitudinal), L;  $\alpha_T$  = dispersivity in y direction (transverse), L;  $\alpha_Z$  = dispersivity in z direction (vertical), L;  $Y$  = source dimension in y direction, L; and  $Z$  = source dimension in z direction, L. This solution assumes a constant plane source perpendicular to the direction of ground-water flow, and that ground-water velocity is one-dimensional, i.e., no vertical flow occurs within the flow field.

$$\alpha_L v \frac{\partial^2 C}{\partial x^2} + \alpha_T v \frac{\partial^2 C}{\partial y^2} + \alpha_Z v \frac{\partial^2 C}{\partial z^2} + v_x \frac{\partial C}{\partial x} - \lambda C = \frac{\partial C}{\partial t} \quad (4-28)$$

$$C(x,y,t) = \left( \frac{C_0}{8} \right) \left( \exp \left\{ \left( \frac{x}{2\alpha_L} \right) \left[ 1 - \left( 1 + \frac{4\lambda\alpha_L}{v_r} \right)^{\frac{1}{2}} \right] \right\} \right) \left( \operatorname{erfc} \left[ \frac{x - v_r t \left( 1 + \frac{4\lambda\alpha_L}{v_r} \right)}{2(\alpha_L v_r t)^{\frac{1}{2}}} \right] \right) \left( \operatorname{erf} \left[ \frac{(y + \frac{Y}{2})}{2(\alpha_T x)^{\frac{1}{2}}} \right] - \operatorname{erf} \left[ \frac{(y - \frac{Y}{2})}{2(\alpha_T x)^{\frac{1}{2}}} \right] \right) \left( \operatorname{erf} \left[ \frac{(z + Z)}{2(\alpha_Z x)^{\frac{1}{2}}} \right] - \operatorname{erf} \left[ \frac{(z - Z)}{2(\alpha_Z x)^{\frac{1}{2}}} \right] \right) \quad (4-29)$$

### Model Input Requirements

Hydraulic and chemical properties affecting the transport of contaminants within the subsurface, and which are incorporated into the multidimensional transport model given in Equation 4-29, include aquifer pore water velocity and dispersivity and contaminant retardation. The following sections describe methods used in the determination of these parameters for input into the modeling effort at the study sites.

### Pore Water Velocity

Aquifer pore water velocities were calculated based on measured values of hydraulic gradient and hydraulic conductivity and estimated values of total aquifer porosity using Darcy's Law (Equation 4-30).

$$v = \frac{K \left( \frac{\partial H}{\partial L} \right)}{\theta} \quad (4-30)$$

where  $K$  = hydraulic conductivity, length/time;  $\partial H$  = change in ground-water table elevation, length;  $\partial L$  = corresponding horizontal distance between head measurements, length; and  $\theta$  = total porosity, unitless.

Hydraulic conductivity values were estimated at 1.5 ft/day for the Layton site, and 2.4 ft/d for the Hill AFB site based on results of slug tests conducted in April 1992. Total aquifer porosity was assumed to be 38 percent at Layton, and 25 percent at the Hill site. Finally, average hydraulic gradient values of 0.01 ft/ft and 0.029 ft/ft for the Layton and Hill AFB sites, respectively, were used to estimate average pore water velocities observed during the study of approximately 0.037 and 0.28 ft/day for the Layton and Hill AFB sites, respectively. Details of the slug tests conducted at these sites, along with all measured field hydraulic data, are provided in Appendix D.

### Dispersivity

Based on current practice in the field, a longitudinal dispersivity of 0.1 times the plume length was used at each site. Transverse dispersivity was assumed to be 20 times less than longitudinal dispersivity. Vertical dispersivity was assumed to be negligible (0.001 m) since the product released has a density less than that of water. In addition, the vertical distribution of contamination indicated by multi-level sampling probe data did not suggest significant vertical dispersion at either field site. The resultant longitudinal and transverse dispersivity values used in all modeling efforts for the Layton and Hill AFB sites were 14 and 0.7 ft, and 17 and 0.85 ft, respectively.

### Sorption Coefficient/Retardation Factor

The term retardation factor defines the reduction in contaminant velocity in an aquifer due to its sorption to

aquifer solids. It is the factor by which pore water velocity is reduced to estimate contaminant velocity in ground-water systems. The retardation factor is a function of the soil/water partition coefficient of the compound, bulk density, and porosity of the aquifer as defined by Equation 4-31:

$$R = 1 + \frac{\rho_b K_d}{\theta} \quad (4-31)$$

where  $R$  = retardation factor, unitless;  $\rho_b$  = soil bulk density, mass/volume; and  $K_d$  = soil/water partition coefficient, volume/mass.

Soil textural information was collected for each site using cone penetrometry techniques during the initial site assessment phase of the study. Based on these results, the soil texture at the ground-water table throughout the Layton site was found to be clayey silt to silty clay, while at the Hill AFB site the aquifer was predominantly sandy to clayey silt. The soil bulk density assumed for the Layton aquifer was 1.15 g/cm<sup>3</sup>, while for the Hill AFB site, a bulk density value of 1.30 g/cm<sup>3</sup> was used in all modeling simulations.

Compound soil organic carbon normalized distribution coefficients,  $K_{oc}$ , available from the literature were used to provide estimates of compound  $K_d$  values using the relationship between  $K_d$  and  $K_{oc}$  as follows:

$$K_d = K_{oc} (f_{oc}) \quad (4-32)$$

where  $f_{oc}$  = weight percent organic carbon in the aquifer material = 0.3 percent for the Layton site, and 0.25 percent for the Hill AFB site.

Using the input data listed above, results of  $K_d$  and  $R$  calculations for the typical compounds of interest at both fuel release sites (benzene, toluene, ethylbenzene, xylene, and naphthalene) are summarized in Table 4-7. These data were used as input for the fate-and-transport modeling carried out in this study.

### Model Calibration

Both statistical and visual methods were used to select a number of model input values which best matched contaminant ground-water concentrations observed over time at the two field sites. Model parameters that were varied to fit the measured data included: elapsed time since contaminant release and various contaminant degradation rates. Model parameters that were held constant during all calibration and model simulation runs included: contaminant sorption coefficients, aquifer pore water velocities and dispersivity values, source area dimensions, and the initial source strength. With the hydraulic parameters and source dimensions set for the sites, the other variables were changed to produce the



**Table 4-7. Input Data and Estimated Sorption Coefficients/Retardation Factors Used for Model Input at the Field Sites Investigated in This Study**

Compound	Layton Site			Hill AFB Site	
	$K_{oc}^*$ (mL/g)	$K_d$ (mL/g)	R	$K_d$ (mL/g)	R
Benzene	190	0.57	2.7	0.48	3.5
Toluene	380	1.14	4.4	0.95	5.9
Ethylbenzene	680	2.04	7.2	1.70	9.8
Xylenes	720	2.16	7.5	1.80	10.4
Naphthalene	1300	3.90	12.8	3.20	17.9

\*Compiled from U.S. EPA (1991), and API (1994)

best fit of observed field data for contaminant plume centerline concentrations observed at the sites in January 1994.

The best fit model result was selected based on the statistic, mean square error (MSE), which was determined for the output of the fate-and-transport model for a range of input parameters during a sensitivity analysis phase of the modeling effort. The MSE was used to determine goodness of fit of the model along the centerline transect of the plume. The MSE represents the sum of the square of the difference between the actual data points and model estimates, normalized by the number of data points available for model fit evaluation. The lower the value of the MSE, the better the model predictions fit the observed data. Equation 4-33 gives the mean square error.

$$MSE = \frac{\sum_{i=1}^n (C_{i(\text{observed})} - C_{i(\text{predicted})})^2}{n} \quad (4-33)$$

where  $C_{i(\text{observed})}$  = observed (measured) concentration at point i, mass/volume;  $C_{i(\text{predicted})}$  = predicted concentration at point i, mass/volume; and n = number of observations available for model fit evaluation. Once trends in MSE values were identified, continual refinement of the modeling effort was carried out by visual data fitting to further minimize the calculated MSE.

The following step-wise procedures were carried out during model calibration efforts:

1. Hydraulic properties for the aquifer at each field site were set constant at the values specified above.

2. The source vertical dimension, Z, and the simulated plume elevation, z, were set constant at the following values based on the thickness of the contaminated water column observed at each site: Z = 10 ft at the Layton site and 5 ft at the Hill AFB site; z = 1 ft for both sites.
3. The source lateral dimension, Y, and contaminant site characteristics, R and Co, were set constant to the values appropriate for each site.
4.  $\lambda$  and t were varied over ranges applicable for each contaminant and for each site to evaluate the sensitivity of model output to these parameter values and to determine those combinations of parameters producing the smallest MSE values.
5. For a given t value producing minimal MSE values,  $\lambda$  values were selected which provided best fit simulations of the January 1994 measured field dissolved contaminant ground-water data.
6. Based on a  $\lambda = 0$  versus calibrated  $\lambda$  degradation rates, a determination was made regarding evidence for biologically mediated contaminant degradation based on significant differences observed between these two simulation runs.
7. Finally, the effects of source removal on the lifetime of the plume and the maximum plume travel distance were assessed using the site-specific, field-data calibrated model.

Details of the application of this fate-and-transport model to each of the field sites investigated in this study are provided in Chapters 6 and 7.

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### **Use of the Model in Intrinsic Remediation Assessment**

As indicated above, the use of this ground-water fate-and-transport model is essential for the integration of contaminant- and site-specific parameters that control the overall fate of hazardous chemicals at a given site. This model can be used to assess existing monitoring data and to make determinations of both short- and long-term behavior of a contaminant plume under existing site conditions. It is also essential in providing quantitative estimates of the impact of source removal or source

control on the ultimate size and duration of a contaminant plume. The model can be used effectively to evaluate the desirability and cost-effectiveness of implementing source removal at a given site, but it is only as good as the data put into it. The model will not provide meaningful results if the required input data cannot be reliably determined, or if dynamic flow and/or source release conditions at the site do not justify the use of this constant, plane source, one-dimensional ground-water velocity model.

## Chapter 5

### Results and Discussion - Site Assessment and Monitoring Techniques

#### Cone Penetrometer Techniques

Cone penetrometer testing (CPT) was used at the field sites for the development of soil textural information for use as input to contaminant plume modeling. In addition, CPT measurements were coupled to the placement and sampling of small diameter ground-water monitoring probes during initial plume delineation activities. A cone penetrometer consists of a sampling probe (cone) which has a point that is instrumented to record the end bearing resistance forces that develop on the tip of the probe versus those developed due to side shear resistance when the point is pushed into a soil matrix.

The relationship between bearing and shear resistance is correlated with soil textural characteristics so that cost-effective soil stratigraphic information can be collected rapidly at a site without the extensive use of more conventional soil investigation efforts of soil sample collection, visual inspection, and interpretation above ground. Soil coring, soil cuttings, and surface exposure of subsurface materials are all eliminated by using CPT techniques. The use of CPT systems is severely limited at sites containing gravel and has a practical working depth limit of 75 to 150 ft depending upon subsurface conditions and the specific equipment being utilized. If CPT can be used at a given site, however, it can provide a great deal of subsurface geologic information rapidly and inexpensively.

Figure 5-1 is a schematic of a typical CPT system with a detail of the forces that develop during data collection. Recent advances in the use of CPT for site assessment activities have included the fabrication of sampling tips that allow the collection of discrete water samples from the cone while collecting resistance measurements (Zemo et al., 1994) and the collection of electrical conductivity data with CPT for the in-place detection of hydrocarbon contamination in saturated, coarse-grained soils (Strutynsky et al., 1991). Specific procedures and data interpretation methods are summarized by Klopp et al. (1988) among others.

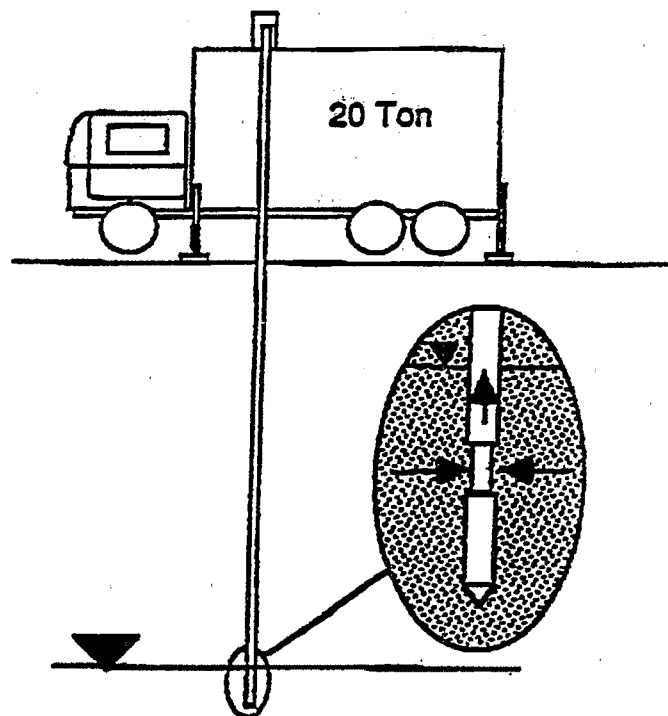
The CPT unit utilized in this study was operated in what is termed the "position" mode, where the cone is continuously pushed through the soil while resistance data were collected and reported with a resolution of approximately 0.25 m (10 in). The units can also be operated in the "time" mode where the cone is stopped at a selected depth and the dissipation in pore water pressure that develops initially due to displacement of water by the advancing cone is monitored over time to yield point measurements of aquifer permeability.

Finally, if the soil texture allows, as was the case in both field sites investigated in this study, once the tip is removed from the soil after cone measurements, a temporary or permanent sampling point can be placed in the open hole without the expense and effort required for placement of a conventional sampling well. Figures 5-2 and 5-3 show examples of the typical data generated from the CPT analysis carried out in this study.

Because of the "real-time" nature of data collection using CPT measurement techniques, and because of the nature of soils at the two field sites used in this study, CPT soil texture determinations and placement and sampling of small diameter ground-water monitoring probes were used to refine the conceptual site models that existed prior to this study. This application of CPT data collection coupled to piezometer well placement is appropriate for initial site investigation activities at sites where no prior data regarding ground-water plume characterization are available. These techniques can also be effectively applied at sites where existing data are limited in scope and detail as was exemplified from the results obtained from CPT and ground-water probe data collected at the Hill AFB site.

#### **Original Hill AFB Conceptual Site Model**

The CPT and initial ground-water probe contaminant concentration data collected from the Hill AFB site provide an excellent example of the desirability of collecting well distributed, high-density site



**Figure 5-1. Schematic of a typical CPT operation collecting soil resistance data for textural analysis below the ground-water table.**

characterization data early in the site assessment process so that subsequent sampling and corrective action efforts are carried out in an optimal manner. Details of the Hill AFB site are contained in Chapter 6, so only selected information will be presented here to illustrate the strength of this non-conventional site assessment approach.

The Hill AFB site was the location of a former 18,000-gallon underground storage tank (UST) that was excavated in 1989. At the time of excavation, holes were observed in the tank and petroleum odors were detected in the tank pit. Five conventional ground-water monitoring wells were installed at the site and soil gas, soil boring, and limited ground-water monitoring data collected from the site from 1989 to 1991 led to the conceptual site model shown in Figure 5-4. Ground-water elevation data collected from the five monitoring wells indicated a westerly flow through the site (Figure 5-5), with limited site data suggesting a plume migrating to the southwest (Figure 5-4). Initial site investigation activities were used to verify this site model using CPT

measurements. In addition, an assessment was made of the representativeness of ground-water probe sampling and field ambient temperature headspace determinations of contaminant concentrations relative to known conditions at the site. This assessment was carried out during initial site assessment efforts as if no data were available from the site.

### ***Revised Hill AFB Conceptual Site Model***

Soon after site investigation activities began, it became apparent that the initial conceptual model of contaminant distribution and plume migration at the Hill AFB site was significantly flawed. Ground probe samples that were collected near the source of contamination within the plume boundaries displayed in Figure 5-4 did not show any hydrocarbon levels above background concentrations. A decision was made to attempt to find the plume, and CPT analysis and ground-water piezometer sampling was moved into the north and northwest regions of the site.

# HILL AIR FORCE BASE

CONTRACTOR : TERRA TECH SW DATE : 07-22-92 SOUNDING NO. : MLP-36 Pg 1 / 1  
 LOCATION : BLDG. 1141 ELEVATION : 98.01 TERRA JOB NO. : 92-1014

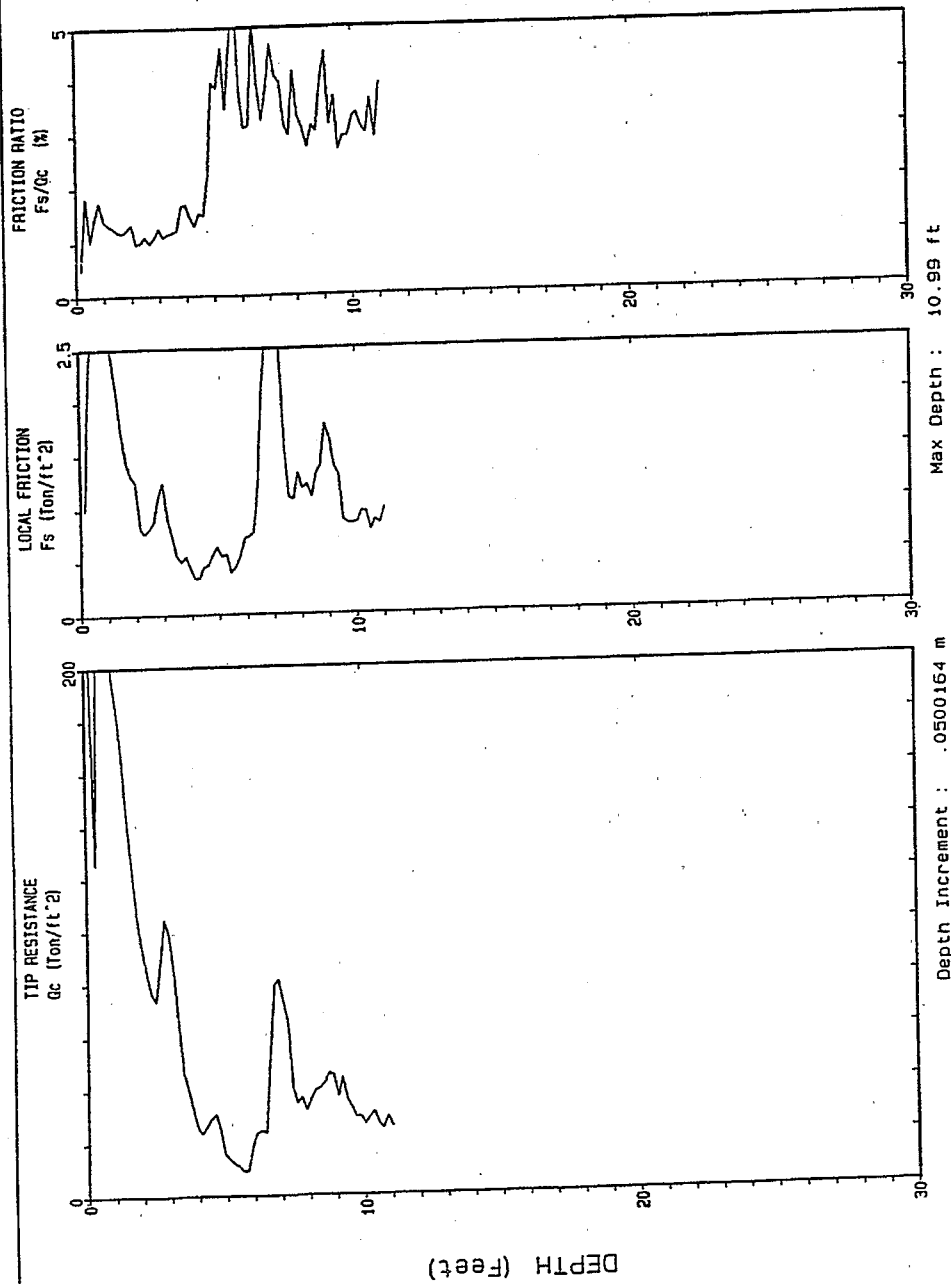


Figure 5.2. Graphical presentation of CPT data collected during initial site investigation activities from the Hill AFB site.

1 HILL AFB - BLDG. 1141

0

Contractor: TERRA TECH SW

Test Date : 07-22-92

Location: MLP-36

Elevation : 98.01 REF

No. 92-1014

Water table (meters) : 2.86

Lot. Unit Wt. (avg): 110 pcf

DEPTH (meters)	DEPTH (feet)	Qc (avg) (tsf)	Fs (avg) (tsf)	Rf (avg) (%)	SIGV' (tsf)	Soil Behavior Type	Eq - Dr (%)	PHI deg.	SPT N	Su tsf
0.25	0.82	212.60	2.71	1.27	0.02	sand	>90	>48	41	Undefined
0.50	1.64	161.44	2.09	1.29	0.07	sand to silty sand	>90	>48	39	Undefined
0.75	2.46	86.32	0.99	1.14	0.11	sand to silty sand	>90	>48	21	Undefined
1.00	3.28	87.62	0.97	1.11	0.16	sand to silty sand	80-90	>48	21	Undefined
1.25	4.10	33.66	0.47	1.40	0.20	silty sand to sandy silt	50-60	42-44	11	Undefined
1.50	4.92	25.28	0.49	1.92	0.25	sandy silt to clayey silt	UNDFND	UNDFD	10	1.56
1.75	5.74	11.16	0.49	4.43	0.29	clay	UNDFND	UNDFD	11	.67
2.00	6.56	28.30	1.10	3.87	0.34	clayey silt to silty clay	UNDFND	UNDFD	14	1.74
2.25	7.38	67.34	2.66	3.95	0.38	clayey silt to silty clay	UNDFND	UNDFD	32	4.18
2.50	8.20	35.34	1.18	3.34	0.43	clayey silt to silty clay	UNDFND	UNDFD	17	2.18
2.75	9.02	41.66	1.45	3.48	0.47	clayey silt to silty clay	UNDFND	UNDFD	20	2.57
3.00	9.84	33.82	1.05	3.12	0.52	clayey silt to silty clay	UNDFND	UNDFD	16	2.08
3.25	10.66	27.06	0.89	3.28	0.54	clayey silt to silty clay	UNDFND	UNDFD	13	1.65

Dr - All sands (Jamiolkowski et al., 1985)

PHI - Robertson and Campanella 1983

SU: Nk = 16

\*\*\*\*Note: For interpretation purposes the PLOTTED CPI PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02)

Figure 5-3. Tabular CPT data collected from the Hill AFB site showing soil textural interpretation from the CPT log represented in Figure 5-2.

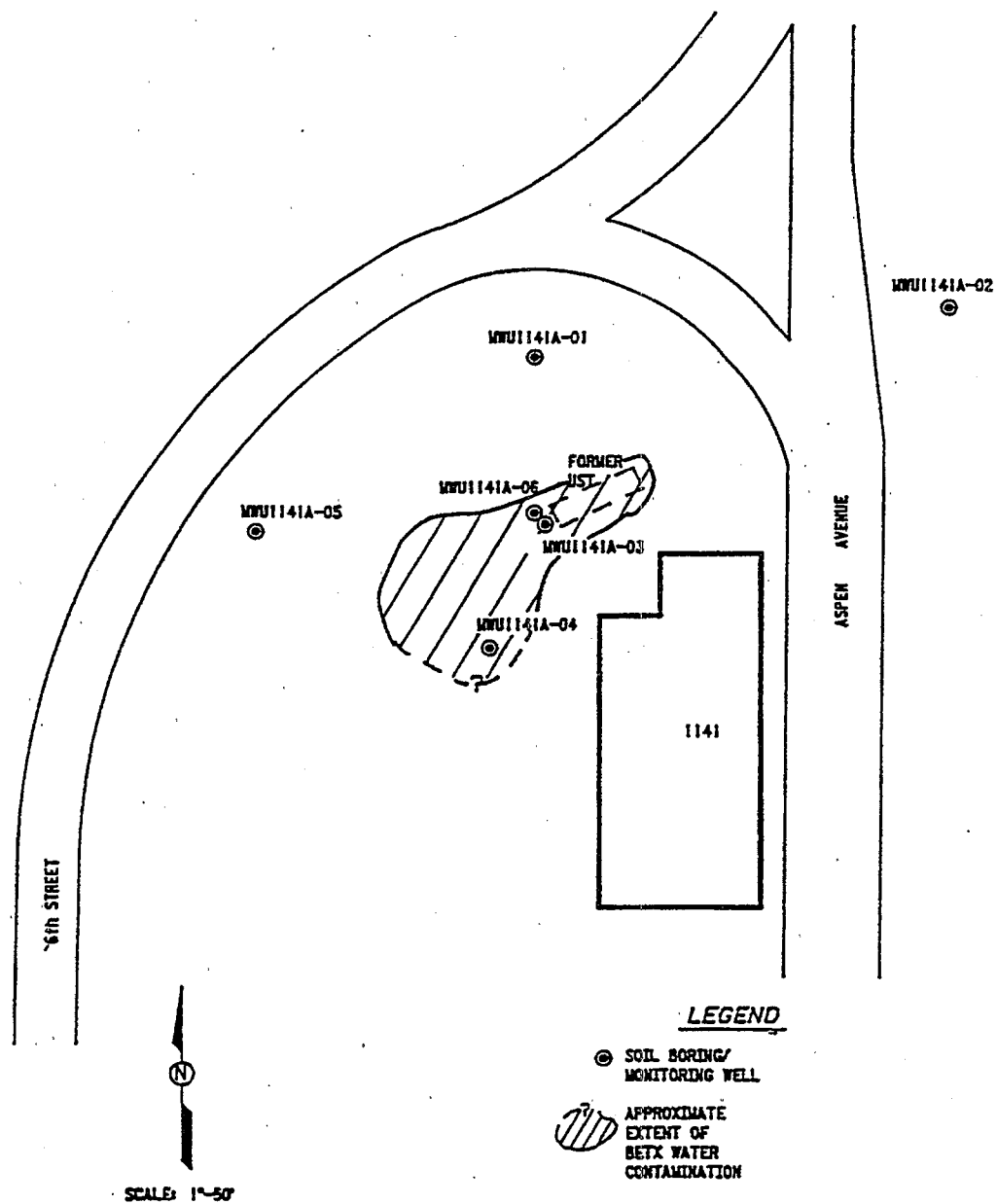


Figure 5-4. Conceptual site model for ground-water contaminant plume at the Hill AFB site based on conventional site data collected during the period from 1989 to 1991 (Engineering Science, 1991).

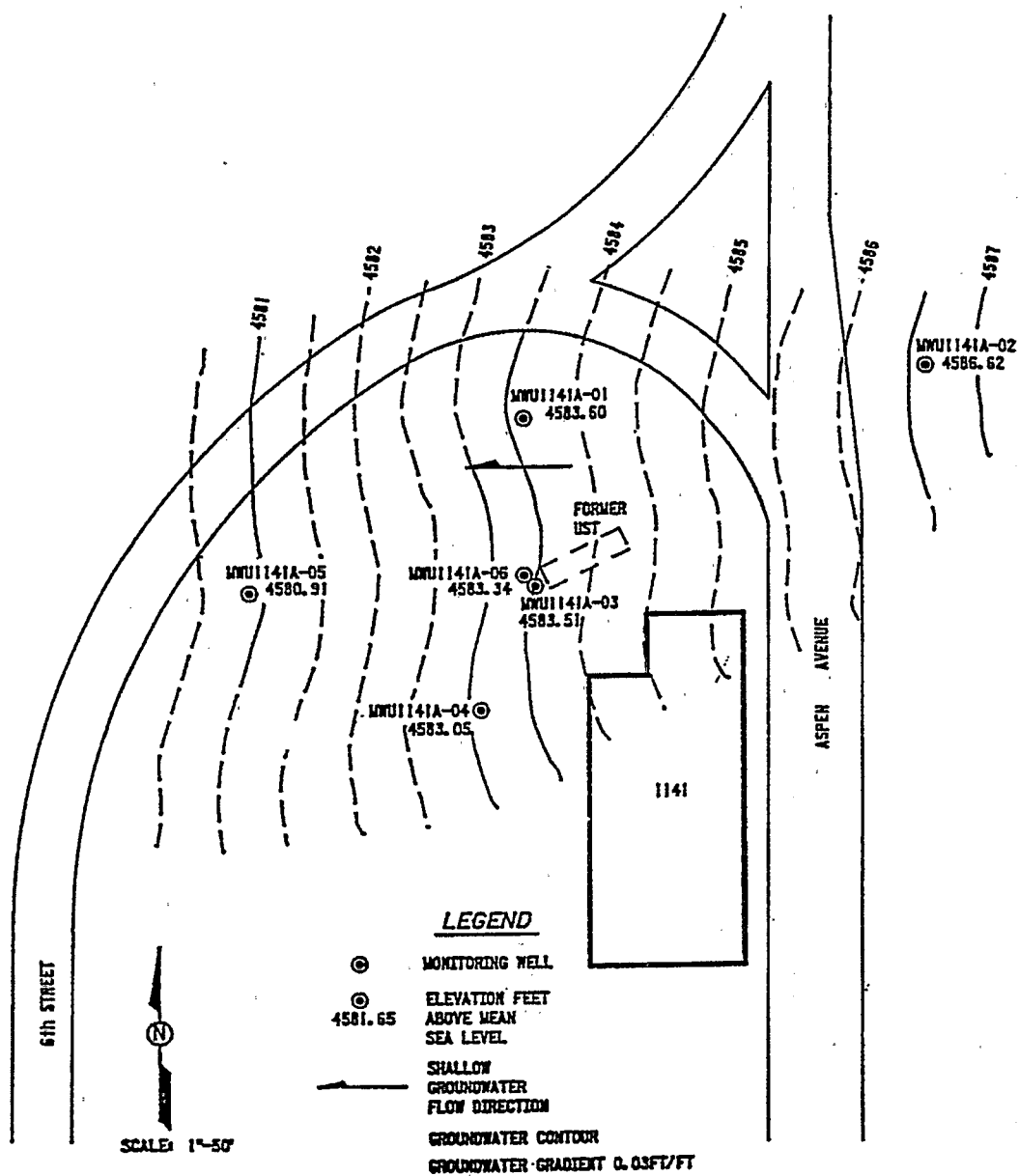


Figure 5-5. Ground-water elevation data collected from the Hill AFB site on April 23, 1991, showing westerly ground-water flow across the site (Engineering Science, 1991).



Figure 5-6 indicates the ground-water piezometer locations used throughout the Hill site. The piezometers were installed in numerical order; it is important to note the relative location and sequence of monitoring points indicated on this figure. Field hydrocarbon screening data collected from these piezometers were successful in identifying the true northwesterly direction of the hydrocarbon plume emanating from the source area at the Hill site. This is indicated by the ground-water concentration data determined from field screening ambient temperature headspace measurements shown in Figure 5-7.

CPT measurements collected in this study also provided insight into ground-water flow conditions existing below the Hill site through detailed ground-water level data (Figure 5-8) and soil textural characteristics (Figure 5-9) observed at the ground-water table. Figure 5-8 is a detailed potentiometric map generated from CPT point water elevation data and clearly shows a significant northwesterly component to ground-water flow that was not evident from the data available from the conventional, five-well monitoring network. Figure 5-9 is even more instructive in that it clearly indicates a distribution of high and low permeability deposits that correspond to what appears to be an old stream bed resulting in channeling of the regional westerly flow to the northwest direction beneath this UST site.

Similar plume delineation efforts carried out at the Layton site confirmed the accuracy of its initial site conceptual model. It is not known how widespread the findings for the Hill AFB site are in terms of the development of a less than complete picture of actual plume distribution and transport using limited, conventional site investigation data. It was found, however, that the use of CPT methods facilitated the rapid collection of soil textural information and the placement and sampling of ground-water probes. This yielded a much more comprehensive picture of both structural and chemical features of the subsurface than is possible using the soil core sampling and laboratory handling and analysis procedures routinely applied at UST sites. This added information is combined with the complete elimination of soil cuttings and large volumes of contaminated ground-water that are often costly and regulatorily challenging to manage, making the screening techniques used in this study ideal for application at many sites. The importance of additional insights into local ground-water flow conditions that can be provided by these CPT techniques, as in the Hill AFB case, is also unquestionable, especially when considering an intrinsic remediation management option at a site. Accurate and representative plume delineation is essential if successful and effective intrinsic remediation monitoring and modeling are to occur.

## Ambient Temperature Headspace Measurements

### Theory of Measurement Technique

The distribution of compounds between water and air and water and soil can be described at equilibrium by the Henry's law constant (H) and soil water partitioning coefficient ( $K_d$ ), respectively. These coefficients are generally assumed to be independent of concentration for linear partitioning relationships, with all other factors constant. In an air/water/soil system, partitioning between soil and air can be deduced from H and  $K_d$  using mass balance considerations. Values of the partition coefficients depend on several factors including: temperature, pressure, relative humidity, solutes in the water, and soil characteristics (organic carbon content, clay content, cation exchange capacity (CEC), etc.). In order to obtain consistent results when determining distribution coefficients, those factors which influence interphase partitioning must be controlled. Also, the relative amounts of the phases need to be constant. As so many soil characteristics affect contaminant distribution, distribution coefficient results would also be expected to be a function of soil type.

The relationships between sample concentration and headspace analysis can be developed following the logic of Robbins et al. (1989) and In-Situ, Inc. (1991), by describing the equilibrium distribution of a compound between the headspace and water phases using the Henry's law constant as follows:

$$H = C_a/C_w \quad (5-1)$$

where H = Henry's law constant,  $\text{volume}_{\text{water}}/\text{volume}_{\text{air}}$ ; C = concentration of solute, mass/volume; a = air; and w = water.

Mass balance requires that the mass of contaminant in the system remains the same after equilibrium partitioning, or:

$$M_{wo} = M_w + M_a \quad (5-2)$$

where M = mass; and o = original sample before adding headspace.

This mass balance can be expanded to the following form with solute mass expressed in terms of the product of volume, V, and concentration, and with Henry's law substituted for the equilibrium water concentration,  $C_w$ :

$$V_w C_{wo} = V_w C_a/H + V_a C_a \quad (5-3)$$

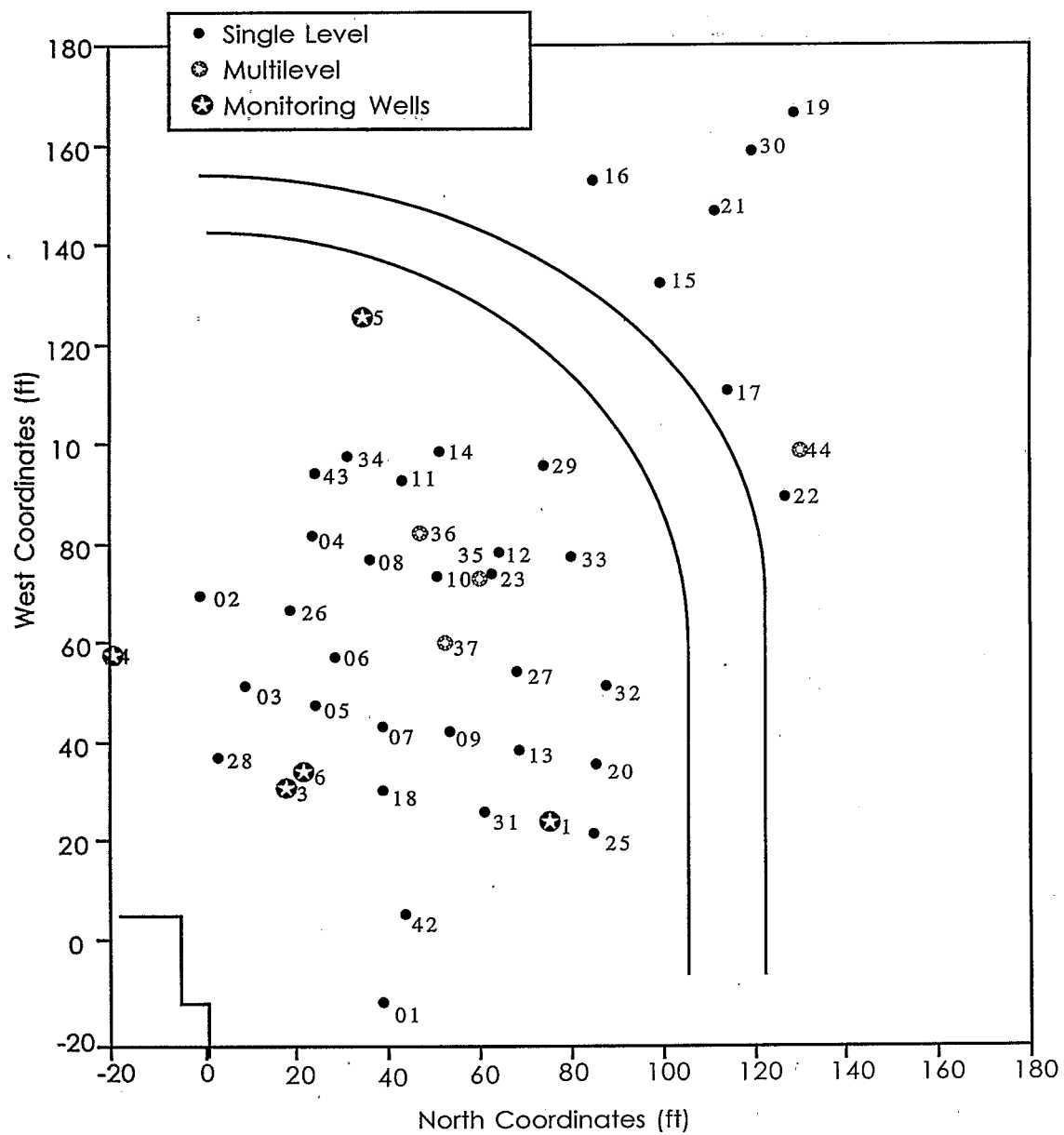
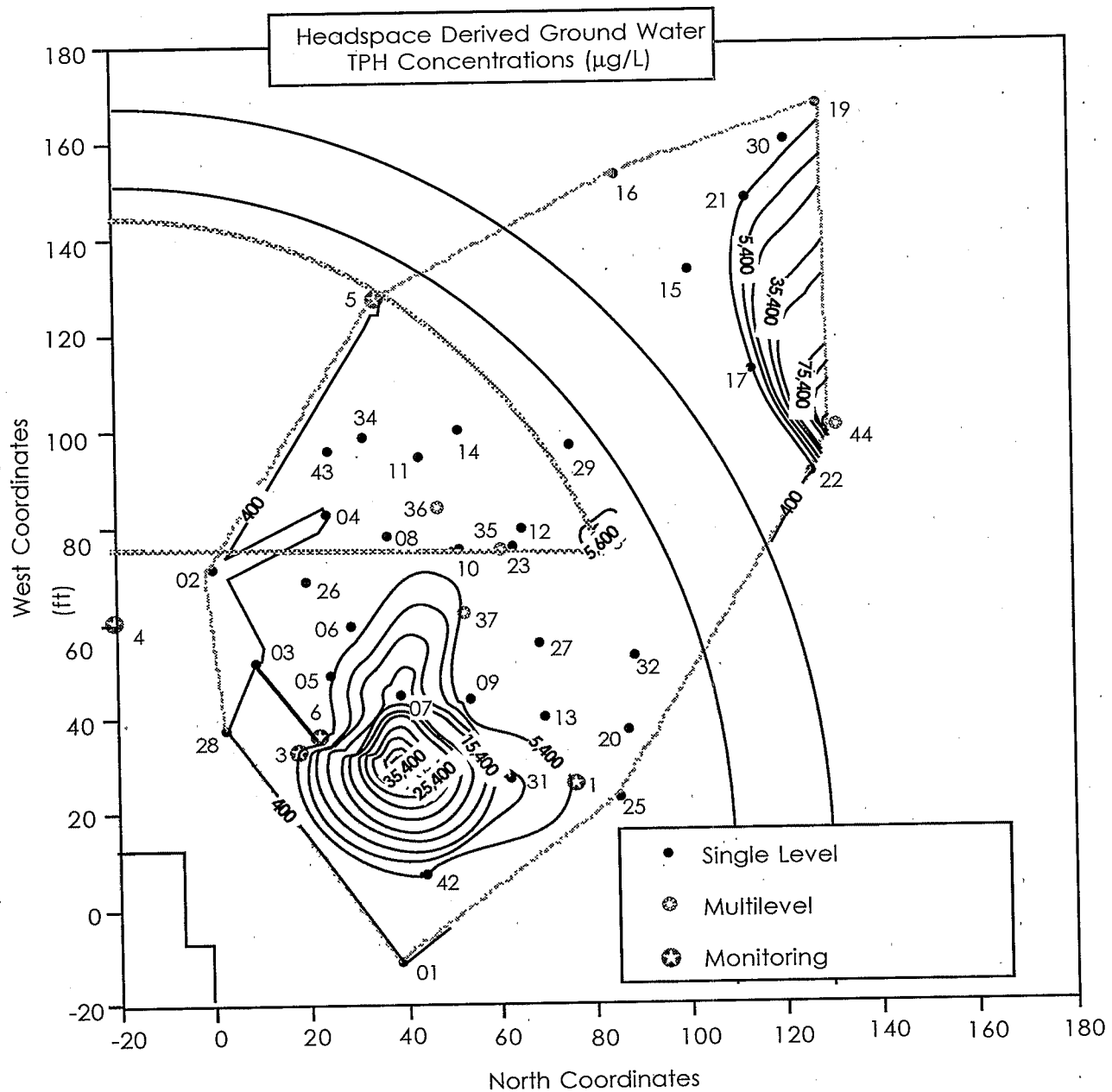


Figure 5-6. Ground-water piezometer and monitoring well locations placed throughout the Hill AFB site in July 1992.



**Figure 5-7. Initial ground-water plume hydrocarbon data developed from field screening headspace analyses conducted at the Hill AFB site, July 1992.**

# HILL AFB - BLDG 1141 POTENTIOMETRIC MAP

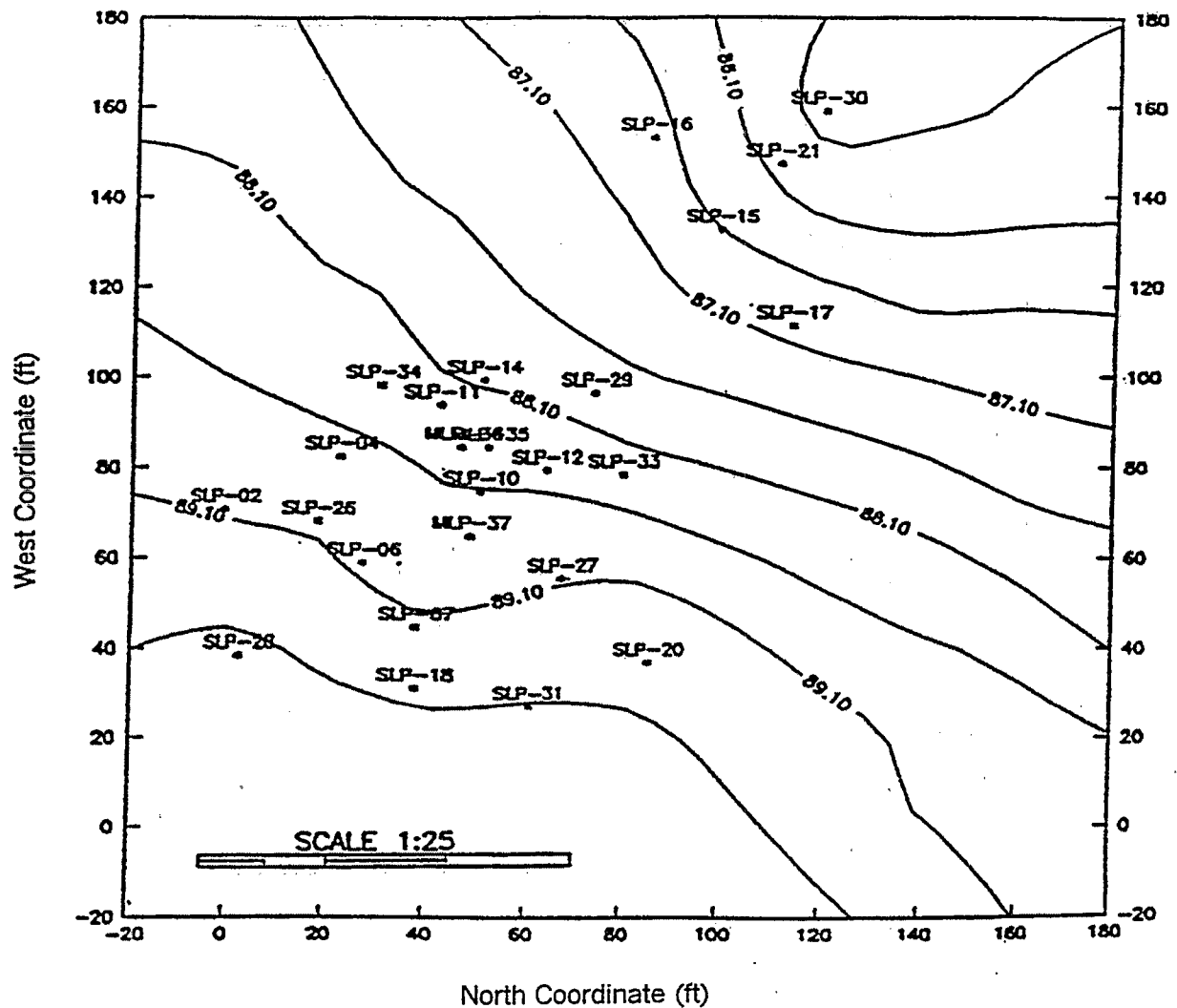
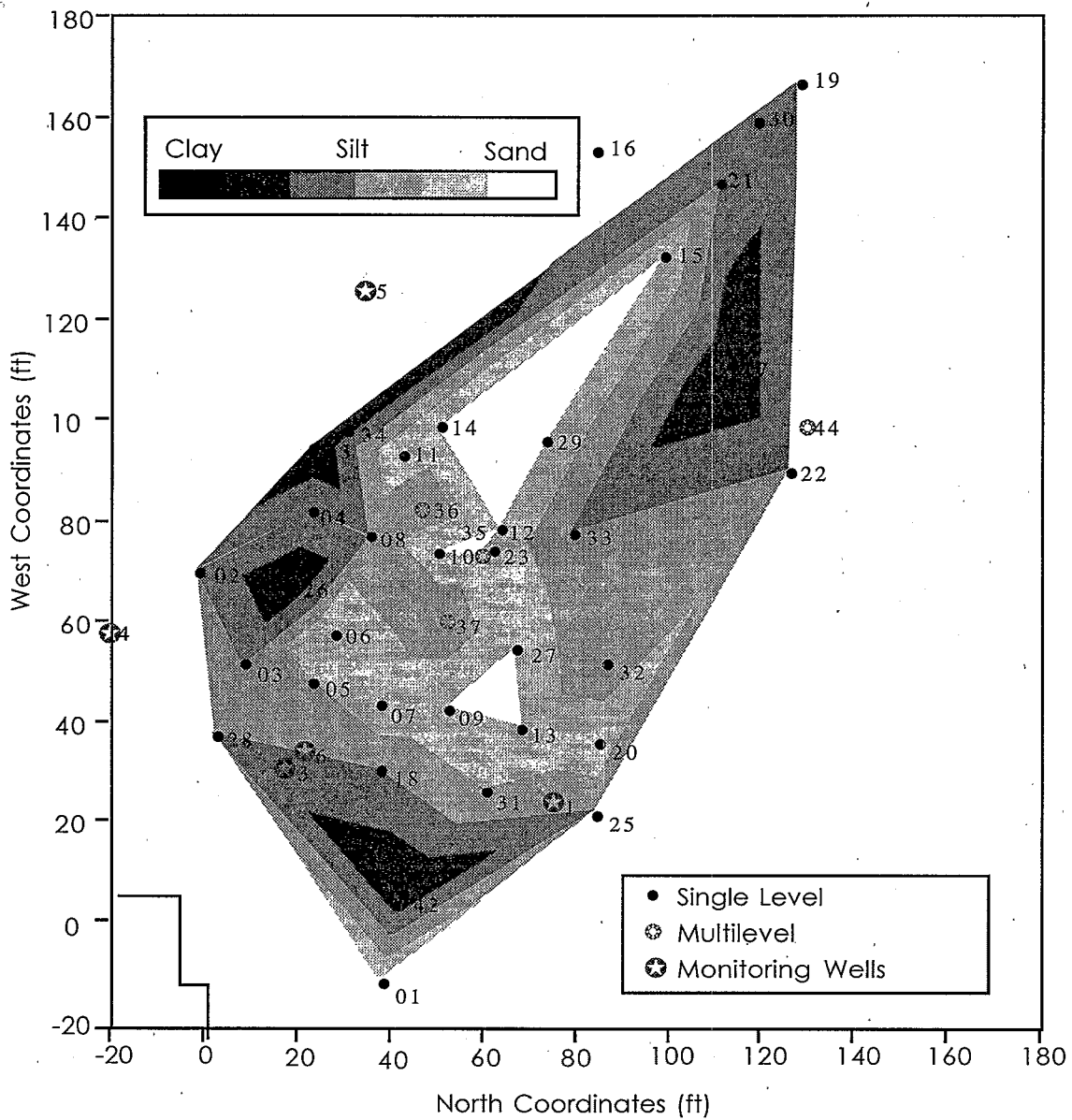


Figure 5-8. Ground-water elevation map generated from CPT installed monitoring probes at the Hill AFB site in July 1992.



**Figure 5-9. Textural map for soils at the ground-water table generated from CPT data collected at the Hill AFB site in July 1992.**

This relationship can be rearranged to an expression where headspace concentration is linear with initial sample concentration if the headspace to liquid volume ratio and Henry's law constant are kept constant:

$$C_a = C_{wp}/(1/H + V_a/V_w) \quad (5-4)$$

Henry's law constant depends on temperature and matrix properties (Griffith et al., 1988; Robbins et al., 1989). Volume ratios, matrix properties, and temperature ideally should be kept constant so that the relationship between sample and air phase concentration is the same among samples and standards. This may not be easy to do as ambient temperature can vary considerably at a site and contaminants can significantly influence matrix properties (Griffith et al., 1988). The effect of variations in Henry's law constant can be mitigated somewhat if the change in  $1/H$  is small relative to  $V_a/V_w$ . Larger air to water volume ratios will also make the method less sensitive to variations in Henry's law constant. However, increasing  $V_a/V_w$  will further dilute the contaminant and decrease the sensitivity of the method to detect site contamination. With the choice of a given set of operating conditions comes a trade-off between temperature sensitivity and the ability to measure low contaminant concentrations.

For a linear response, detector response to a specific compound in the headspace can be described by a response factor as follows:

$$D_i = R_i C_{ai} \quad (5-5)$$

where  $D$  = detector response, mV;  $R$  = response factor, mV/mass of compound; and  $i$  = a specific compound.

In a sample with multiple analytes, the concentration of an individual compound can be written in terms of the total analyte concentration.

$$C_{wtot} = C_{two} X_i \quad (5-6)$$

where  $X_i$  = mass fraction of total solutes represented by component  $i$  in sample; and  $t$  = total.

If individual analyte concentrations are expressed as a fraction of the total sample analyte concentration as shown in Equation 5-4, and the result is used to represent headspace concentration from Equation 5-5, total detector response to all solutes is as follows:

$$D = \sum_i^n \left( \frac{R_i C_{two} X_i}{\frac{1}{H_i} + \frac{V_a}{V_w}} \right) \quad (5-7)$$

where  $n$  = the total number of solutes in the sample. Every term in the summation contains  $C_{two}$ , so it can be moved outside the summation to yield:

$$D = C_{two} \sum_i^n \left( \frac{R_i X_i}{\frac{1}{H_i} + \frac{V_a}{V_w}} \right) \quad (5-8)$$

If this summation is constant, detector response is linear with the TPH ( $C_{two}$ ) in the water sample. For the summation to be constant with variations in  $C_{two}$ , the relative distribution of contaminants ( $X_{is}$ ) should remain constant. A sample richer in more volatile organics will have a larger fraction of the organics partitioned into the headspace and will produce a larger detector response for the same level of total contamination than one without high concentrations of volatile contaminants.

As indicated in Chapter 4, the equilibrium distribution of a compound between the water and soil is described by a soil/water partition coefficient as follows:

$$K_d = C_s/C_w \quad (5-9)$$

where  $K_d$  = soil water partition coefficient (volume<sub>water</sub>/mass<sub>soil</sub>); and  $s$  = soil.

When water and headspace are added to a soil sample, the following mass balance applies:

$$M_{so} = M_s + M_w + M_a \quad (5-10)$$

When solute masses are expressed in terms of concentrations and Equations 5-1 and 5-9 are substituted for the water and soil equilibrium concentrations, respectively, the following equation results:

$$WC_{so} = W K_d C_a/H + V_w C_a/H + V_a C_a \quad (5-11)$$

where  $W$  = weight of soil, mass.

This can be rearranged to yield an expression for the air phase concentration which is a linear function of soil sample concentration:

$$C_a = \frac{C_{so} W}{V_w \left( \frac{W K_d}{H V_w} + \frac{1}{H} + \frac{V_a}{V_w} \right)} \quad (5-12)$$

This expression makes it possible to develop the following relationship for soils in the same way that Equation 5-8 was developed for water:

$$D = \frac{C_{tso}}{V_w} W \sum_i^n \left( \frac{R_i X_{soi}}{\frac{W K_{di}}{H_i V_w} + \frac{1}{H_i} + \frac{V_a}{V_w}} \right) \quad (5-13)$$

Detector response is linear with TPH ( $C_{tso}$ ) if distribution coefficients, mass, and volume ratios and distribution of contaminants remain the same from one sample to the next.

### Previous Studies

Previous work with ATH analysis was conducted with rigid sample containers (Holbrook, 1987; Robbins et al., 1987; Griffith et al., 1988; Pavlostathis and Mathavan, 1992; Roe et al., 1989). This method for ATH analysis commonly involves setting up air and water compartments in a vial capped with a Teflon-lined septa. After the analyte(s) equilibrate between/among the compartments, a determination of the original sample contamination is made by injecting some of the headspace gas onto a GC for identification and quantification of the constituents it contains. Composition of the headspace is used to quantitate the analyte in the unpartitioned aqueous or soil sample. When rigid containers are sampled, the containers either leak, which dilutes the headspace, or a vacuum is created during sampling. The vacuum can slow the flow of gases to, and decreases the response of, the detector, and is highly undesirable.

In the Griffith et al. (1988) study, a methodology was explored for analyzing benzene, toluene, ethylbenzene, and xylene contamination in soil. Analyses were made by injecting headspace gas onto a portable GC with a packed column and FID. Standard and sample systems were prepared in 40-mL volatile organic analysis (VOA) vials. The standard systems were composed of 30-mL liquid and 10-mL headspace volumes. The soil systems were prepared by adding 2 to 4 g clean soil to the VOA vial, evacuating air from the vial, spiking the vial with aqueous standard, adding an amount of water such that the liquid to headspace ratio was the same as the standard, and allowing enough air in to bring the pressure to atmospheric. Loss of volatile contaminant from the system was minimized by adding the contaminant and water under a vacuum. This method of introducing the contaminant does not represent the situation of an actual field sample where the contaminant must desorb from the soil in order to be distributed among the compartments.

Soil contamination was estimated for a sample with all the contaminant in the soil before partitioning. The estimation was made by comparing headspace readings to those of aqueous standards and assuming that the contaminant was distributed entirely between the liquid and headspace (complete extraction of the soil). A mass

balance allowed an estimation of the original, unpartitioned soil concentration.

Systems were contaminated with toluene at seven soil concentrations from 0.005 to 16 mg toluene/kg of soil (Griffith et al., 1988). Measured soil concentration levels produced extraction efficiencies with a mean percent recovery across contamination levels of 93.6 percent with a standard deviation of  $\pm 27.7$  percent. The relationship between contamination level and percent recovery appeared to be random, however.

Another set of systems evaluated by Griffith et al. (1988) was contaminated with a mixture of equal amounts of benzene, toluene, ethylbenzene, and xylene. Nine concentration levels from 0.78 to 6.71 mg/kg of each analyte were represented. Average recoveries of benzene, toluene, ethylbenzene, and o-xylene were 96, 93, 99, and 114 percent, respectively.

The above tests were conducted with a very fine sand fraction of a sandy soil with low organic carbon content. One final test by Griffith et al. (1988) was used to compare recoveries of the BTEX components from seven sieved fractions of this soil. Soil grain size was found to have no effect on recovery efficiency off the sandy test soil for any of the compounds investigated. Temperature effects were explored by analyzing the headspace of toluene contaminated samples at different temperatures. The response to toluene more than doubled from 10 to 40 °C for samples with both 0.35 and 3.5 mg/L toluene aqueous concentrations. This sensitivity to temperature was likely due to the large ratio of liquid to headspace volume used in these systems (approximately 3:1).

Roe et al. (1989) explored a similar technique for analyzing BTEX in aqueous samples. Forty-mL VOA vials were filled with samples or standards. The vials were prepared for analysis by removing 10-mL of liquid and allowing time for the analytes to equilibrate between compartments. The headspace was injected onto a GC with a capillary column and PID and FID in series. BTEX components of samples were identified and quantitated by comparison to standards.

In the Pavlostathis and Mathavan (1992) study, soil/liquid/air systems were prepared in 8-mL amber vials capped with Teflon faced septa. Trichloroethylene (TCE) and toluene were injected into the systems and allowed to equilibrate. Samples of the air and water phases and a methanol extract of the soil phase were injected into the purge chamber of a purge-and-trap apparatus. The traps were desorbed onto a GC with an electron capture detector (ECD) and a flame ionization detector (FID) in series. Laboratory contaminated systems were made with TCE and toluene, both separately and together. Soil concentrations in these systems of TCE and toluene were 1,015 and 600  $\mu\text{g/g}$ ,

respectively. A sample of the same soil which was contaminated in the field was also analyzed in this way. The field sample systems had methanol/water liquid phases from 0 to 81 percent methanol. Dimensionless Henry's law constants and soil/liquid partition coefficients ( $K_d$ ) were calculated for laboratory and field contaminated systems.

A comparison of the laboratory contaminated systems showed that the presence of TCE decreased the  $K_d$  of toluene by more than an order of magnitude. Comparison of laboratory and field contaminated samples showed that the  $K_d$  of toluene was also concentration-dependent. This indicates that there are possible matrix effects from other contaminants, and partition coefficients might not be constant from sample to sample even at a given field site. A constant partition coefficient is one of the requirements for linearity in Equations 5-8 and 5-13, and partition coefficient variability can be a significant limitation to the general use of ATH methods for soil and ground-water assessment activities.

Holbrook (1987) described an investigation of an ATH method for analyzing soils for volatile hydrocarbons. A pint jar was filled halfway with soil and the top was sealed with aluminum foil. After the system was agitated for 2 hours and equilibrated for an additional 2 hours, the foil was pierced with the probe of a portable PID and a reading was taken between 5 and 10 seconds afterward. The PID was calibrated with a benzene standard and results were reported as ppm benzene in the headspace. Soils which had been spiked with gasoline between 1 and 1,500 ppm were analyzed in this manner. There was no response to unspiked soil and some response to the 1 ppm soil. The response was non-linear through the concentration range investigated. Response began to decrease between 75 and 150 ppm and continued to drop with increasing concentration. Readings were unstable at and above 300 ppm. This was explained as a quenching of the PID at high vapor phase concentrations, a known characteristic of PIDs.

ATH results using a PID detection system were compared with SW 846 Method 8240 (U.S. EPA, 1986d) for samples from a leaking underground storage site and a refinery landfarm. Method 8240 analyses were used to quantify BTEX components from both sites and naphthalene from the landfarm. When ATH results were less than 30 ppm benzene, Method 8240 was non-detect for BTEX and naphthalene. When the ATH results indicated more than 70 ppm benzene, BTEX and naphthalene were detected in all samples using Method 8240 procedures. The ATH method with PID responds to any ionizable constituent in the headspace, not just those reported in Method 8240 analysis, and consequently would be expected to be

more sensitive for samples containing constituents detectable with a PID.

The procedure described in Robbins et al. (1989) is the closest to those utilized in this study. ATH systems were set up in a quart-sized polyethylene bag. The bag was penetrated and sealed to a tube and a three-way valve. One port of the valve was connected to a portable FID. The three-way valve routed air from the bag to the FID in one position and from ambient air in the other position. Compartment ratios were kept consistent throughout the study, with a 100-mL aqueous compartment and 25-g soil compartment. The air compartment volume was consistent as bags were filled with air to an average volume of 1391 mL ( $n=8$ ,  $CV = 1.4\%$ ). After the headspace was pumped into the bags with a hand pump, the bags were agitated by hand in a water bath until the headspace was routed to the detector for analysis. The detector was calibrated with a methane standard and ATH results were reported in ppm methane.

Separate tests with equilibration times between 0.5 and 8 minutes and aqueous solutions of benzene, xylene, a mixture of benzene and xylene, and a gasoline contaminated ground-water sample, showed that the system generally equilibrated within 4 minutes. The benzene and gasoline contaminated soil samples equilibrated within 30 seconds (Robbins et al., 1989).

ATH measurements were made of a single benzene standard at temperatures between 11 and 41°C. The system was insensitive to these temperature fluctuations within the precision of the test and can be attributed to the relatively large headspace in this system. The headspace-to-liquid-volume ratio of this system is approximately 13:1, whereas the system in the Griffith et al. (1988) study, which was much more temperature-sensitive, had a headspace-to-liquid-volume ratio of 1:3. This finding strongly indicates that for reproducible, temperature-insensitive ATH measurements, headspace-to-liquid-volume ratios should be as high as possible without compromising contaminant sensitivity. Values between 10:1 and 20:1 should be sufficient to yield robust measurements, with acceptable low method detection limits.

The importance of constant relative distribution of analytes to the linearity of results with total contamination was demonstrated by comparing ATH results of aqueous benzene/xylene solutions with the same total contamination and different ratios of constituents. Response increased by a factor of 3 as benzene increased from 0 to 100 percent of total contamination. The relationship between contamination level and ATH response was linear for the following cases (Robbins et al., 1989).



1. Aqueous benzene (n = 5, correlation coefficient = 0.997).
2. Aqueous xylene (n = 5, correlation coefficient = 0.999).
3. Dilutions of a gasoline contaminated ground-water sample (n = 5, correlation coefficient = 0.997).
4. Benzene contaminated soil (n = 5, correlation coefficient = 0.957).
5. Soil spiked with gasoline (n = 6, correlation coefficient = 0.989).

The ATH method was used at two UST sites (a motor pool and a service station) to measure contamination of ground-water samples from monitoring wells. Duplicate samples were analyzed in the laboratory for BTEX. The laboratory analysis was done with a headspace technique on a GC with a capillary column and PID and FID detectors in series. Results of the two methods were in different units but contours drawn from the total BTEX and ATH data had similar shapes. The log (total BTEX) versus log ATH headspace relationship was linear (n = 12, correlation coefficient = 0.945). ATH and laboratory analyses were also compared for samples collected from a bailer at various intervals during purging of a monitoring well at these sites. Total BTEX and ATH measurements decreased in a similar fashion during the purging process. Finally, laboratory and ATH analyses were compared at 10 depths of a soil core at the motor pool site. The shape of the contamination profile was similar between methods.

The results reported by Robbins et al. (1989) support the use of ATH methods for rapid site screening during the initial site assessment phase when detailed plume delineation is taking place. Their results provide strong evidence that ATH methods can be used to quantify general relationships of ground-water and soil contamination that support more analytically rigorous laboratory findings if ATH methods are carried out using procedures that generally support the assumptions of linearity. In general, the preferred methods for conducting field ATH analyses include the use of:

1. Large headspace to aqueous volume ratios 10:1 to 20:1 to minimize the effect of temperature change on the distribution of contaminant between the aqueous and air phases.
2. Use of a detector that provides a linear response to organics over a wide range of contaminant concentrations. The FID has this characteristic (Perry, 1981) and is generally preferred over a PID which is more sensitive to moisture and has a narrower linear range than a FID (EPA, 1990b; Holbrook, 1987).

3. The use of ATH methods must be based on a general knowledge of the nature of the contamination being screened for. As indicated in the work by Robbins et al. (1989), for a given contaminant distribution the ATH method provides consistent and representative indications of the level of contamination in a given sample. However, when contaminant composition varies significantly between sites or within a given site, this contaminant level/ATH relationship begins to lose its validity.

## Field Versus Laboratory Generated Data

Two data sets (July and December 1992) were collected in this study from each field site to evaluate the representativeness of ATH field screening techniques, and were compared to results from standard laboratory-generated purge-and-trap hydrocarbon measurements. Because no component speciation was carried out on the headspace measured in the field, the comparison between field and laboratory generated results was based only on total hydrocarbon determinations using serial dilutions of a gasoline saturated water standard in the field and hexane equivalent concentrations for laboratory results. Raw data for this comparison study are included in Appendix E, while Tables 5-1 and 5-2 provide a quantitative summary of findings.

As indicated in Tables 5-1 and 5-2, the relationship between field and laboratory determined ground-water TPH results was quite variable, with the ratio of field/laboratory-determined concentrations ranging from a low of 0.0 to a high of 446. This ratio was generally consistent for a given sampling location between the two sampling times; however, some ratios varied by one to two orders of magnitude (i.e., CPT-08 from the Hill AFB site and CPT-09 from the Layton site). The average ratio of field to laboratory determined ground-water hydrocarbon concentrations was greater than 1 for both sampling events at both sites and ranged from 4.9 to 32.1. This result suggests that the field ATH procedures used in this study provided a conservative estimate of contaminant concentration from most sampling locations by a factor of 5 to 30.

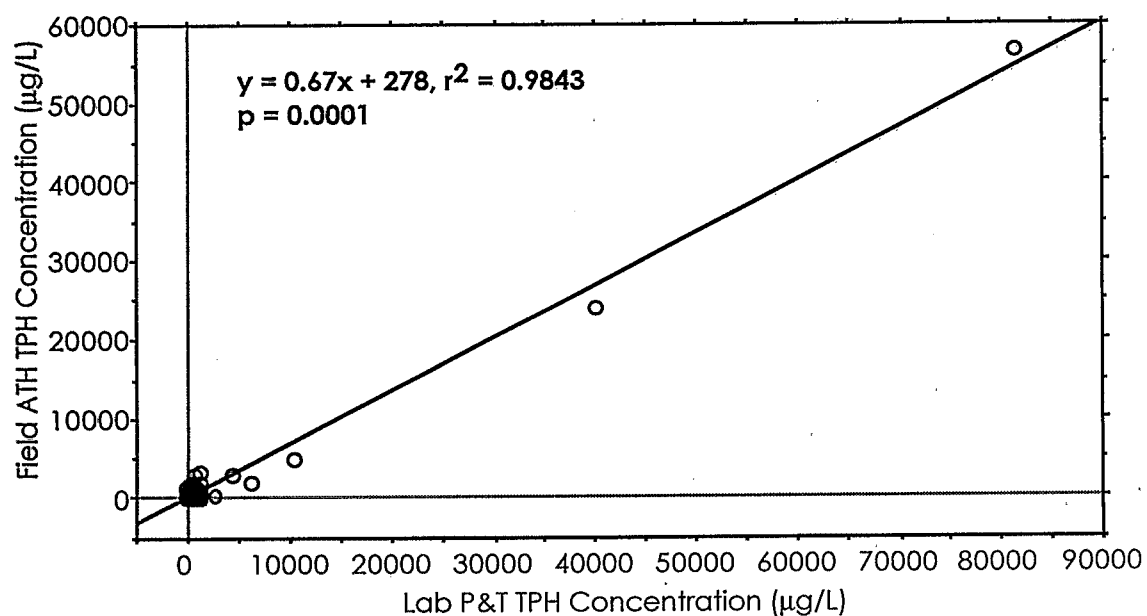
These field and laboratory comparison data are plotted in Figures 5-10 to 5-15 to explore the sensitivity of the field method for the quantitative prediction of differences in concentration observed throughout the sites based on laboratory determined purge-and-trap data. Figure 5-10 shows a linear regression of field versus laboratory TPH data for the Hill AFB site collected during both July and December 1992. One data point, that of MLP-44 for the July data set, was excluded for this analysis because it was identified as a clear outlier.

Table 5-1. Field Versus Laboratory Total Hydrocarbon Results from the Hill AFB, UT, Field Site Collected July and December 1992

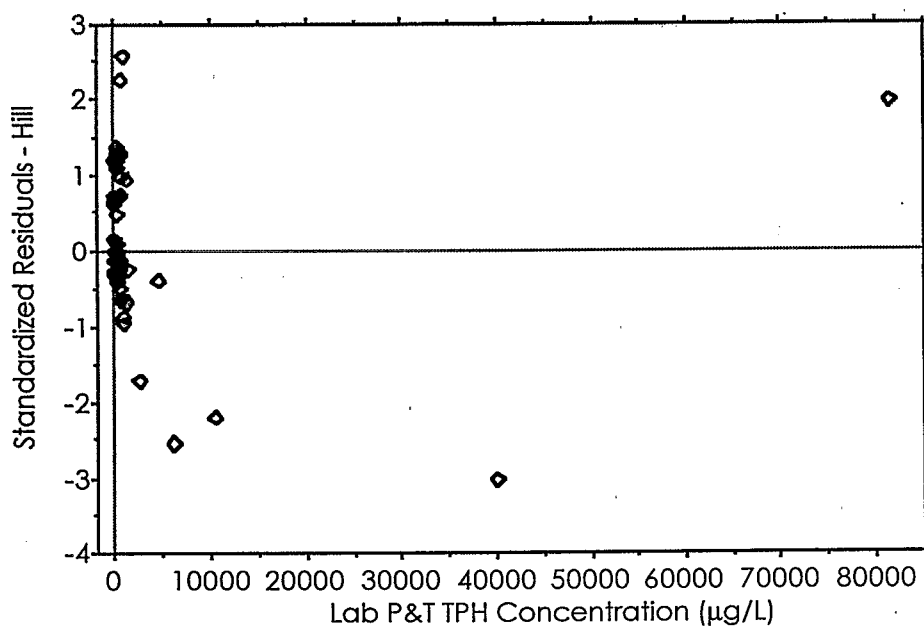
Hill AFB - 7/92				Hill AFB - 12/92			
	Field	Lab			Field	Lab	
Sample	ATH Results (µg/L)	P&T Results (µg/L)	Field/Lab Response	Sample	ATH Results (µg/L)	P&T Results (µg/L)	Field/Lab Response
CPT-01	0	60	0.00				
CPT-02	0	0	1.00				
CPT-03	0	41	0.00	CPT-03	0	58	0.00
CPT-04	0	172	0.00	CPT-04	1,490	213	7.01
CPT-05	2,809	544	5.16	CPT-05	277	57	4.85
CPT-06	294	992	0.30	CPT-06	176	257	0.69
CPT-07	24,178	40,135	0.60				
CPT-08	480	653	0.73	CPT-08	1,659	103	16.10
CPT-09	1,966	6,196	0.32				
CPT-10	827	124	6.69				
CPT-11	1,399	107	13.03	CPT-11	1,659	227	7.30
CPT-12	1,495	736	2.03	CPT-12	1,998	1,198	1.67
CPT-13	863	1,234	0.70	CPT-13	0	157	0.00
CPT-14	396	141	2.82	CPT-14	1,829	409	4.47
CPT-15	0	294	0.00				
CPT-16	1,452	8	179.05				
CPT-17	930	8	115.24				
CPT-18	56,608	81,509	0.69	CPT-18	138	169	0.82
CPT-19	28	0					
CPT-20	295	2,517	0.12	CPT-20	0	63	0.00
CPT-21	151	0		CPT-21	0	149	0.00
CPT-22	0	3	0.00				
CPT-25	0	0	1.00	CPT-25	0	193	0.00
CPT-26	0	0	1.00	CPT-26	0	107	0.00
CPT-27	545	266	2.05	CPT-27	0	523	0.00
CPT-28	0	25	0.00	CPT-28	0	62	0.00
CPT-29	893	18	50.15				
CPT-30	0	0	1.00	CPT-30	0	17	0.00
CPT-31	288	29	9.98	CPT-31	0	946	0.00
CPT-32	1,093	196	5.56	CPT-32	585	662	0.88
CPT-33	5,067	10,362	0.49				
CPT-34	429	0		CPT-34	1,490	68	21.92
CPT-42	3,380	962	3.51	CPT-42	0	97	0.00
CPT-43	0	180	0.00	CPT-43	1,659	667	2.49
MLP38(9.6)	1,437						
MLP38(10.1)	383						
MLP39(9.7)	1,049						
MLP39(10.2)	273						
MLP40(10.25)	20,683						
MLP44(12.9)	93,558	12,003	7.79				
MW3	2,812	4,351	0.65	MW2	0	813	0.00
MW4	0	24	0.00	MW3	973	18	53.24
MW5	0	6	0.00	MW5	1,659	271	6.11
MW6	0	4	0.00	MW6	0	67	0.00
Method Blanks	902			Method Blanks	16		
		Average	11.43			Average	4.91
		St.Dev.	35.30			St.Dev.	11.21
		C.V (%)	308.71			C.V (%)	228.57

**Table 5-2. Field Versus Laboratory Total Hydrocarbon Results from the Layton, UT, Field Site Collected July and December 1992**

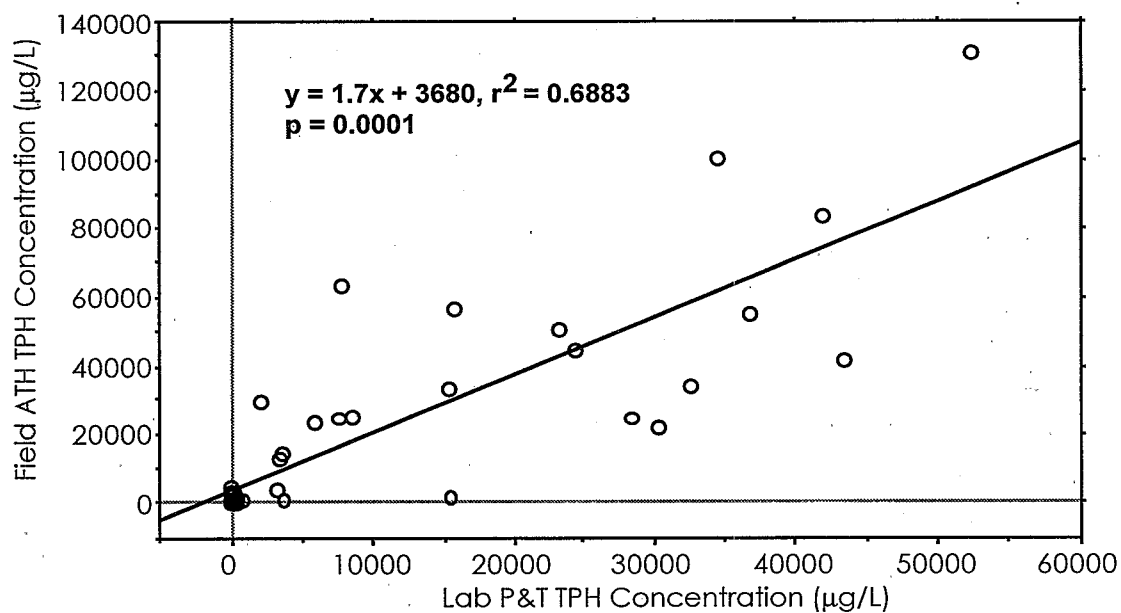
Layton - 7/92				Layton - 12/92			
Sample	Field ATH Results (µg/L)	Lab P&T Results (µg/L)	Field/Lab Response	Sample	Field ATH Results (µg/L)	Lab P&T Results (µg/L)	Field/Lab Response
CPT-01	441	0		CPT-01	981	2	445.91
CPT-02	872	0					
CPT-03	4,507	0		CPT-03	1,549	392	3.95
CPT-04	63,523	7,840	8.10	CPT-04	56,064	15,923	3.52
CPT-05	0	4	0.00	CPT-05	0	33	0.00
CPT-06	0	3	0.00				
CPT-07	23,053	5,993	3.85				
CPT-08	24,611	7,661	3.21	CPT-08	0	78,090	0.00
CPT-09	896	796	1.13	CPT-09	3,210	148	21.69
CPT-10	411	313	1.31				
CPT-11	9,842						
CPT-12	24,591	28,269	0.87	CPT-12	33,340	15,341	2.17
CPT-13	41,624	43,478	0.96	CPT-13	99,786	34,394	2.90
CPT-14	50,612	23,351	2.17	CPT-14		41,841	
CPT-15	44,516	24,504	1.82	CPT-15	25,071	8,532	2.94
CPT-16	22,032	30,322	0.73	CPT-16	54,957	36,698	1.50
CPT-17	14,377	3,537	4.06	CPT-17	25,985		
CPT-18	427	17	24.88	CPT-18	1,471	136	10.82
CPT-19	1,108			CPT-19	34,203	32,583	1.05
CPT-20	84,124	41,899	2.01	CPT-20	130,778	52,403	2.50
CPT-21	0	135	0.00	CPT-21	0	13	0.00
MLP4(9.0)	1,194	15,472	0.08				
MLP4(9.5)	853	3,785	0.23				
MLP6(9.0)	3,585	52	68.94				
MW1	802	397	2.02	MW1	4,040	3,313	1.22
MW3	12,848	3,354	3.83	MW3	29,775	2,111	14.10
MW4	150	4	35.71	MW4	55,403		
Method Blanks	902			Method Blanks	1,067		
		Average	7.54			Average	32.14
		St.Dev.	16.2			St.Dev.	110.50
		C.V.(%)	215			C.V.(%)	343.79



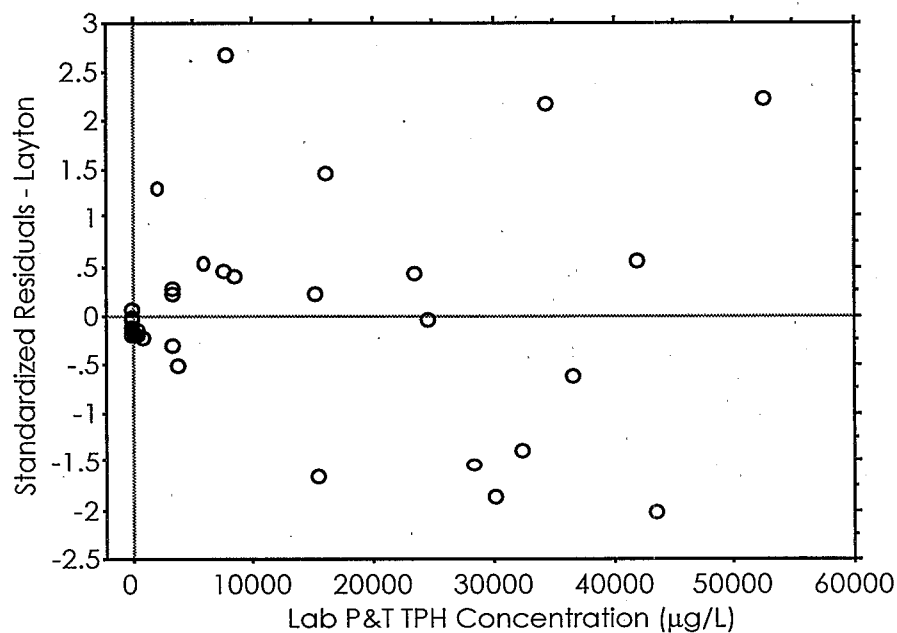
**Figure 5-10. Relationship between laboratory- and field-determined ground-water TPH concentrations for Hill AFB for data collected July and December 1992.**



**Figure 5-11. Normalized residuals for Hill AFB data shown in Figure 5-10.**



**Figure 5-12. Relationship between laboratory- and field-determined ground-water TPH concentrations for Layton for data collected July and December 1992.**



**Figure 5-13. Normalized residuals for the Layton data shown in Figure 5-12.**

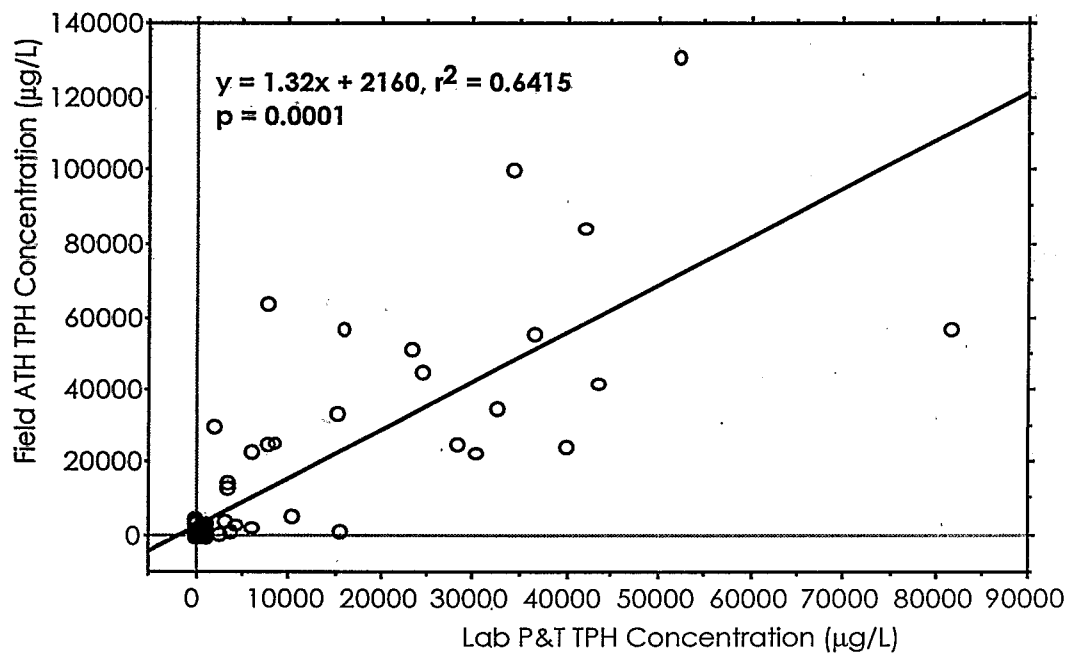


Figure 5-14. Relationship between laboratory- and field-determined ground-water TPH concentrations for the combined Hill AFB and Layton data collected July and December 1992.

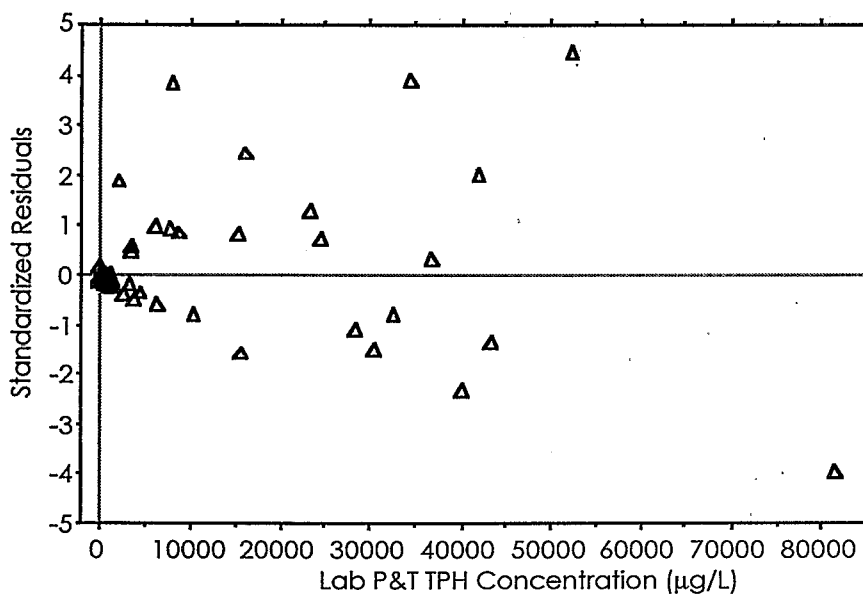


Figure 5-15. Normalized residuals for the combined Hill and Layton data shown in Figure 5-14.

As indicated in the figure, a statistically-significant relationship was found between laboratory and field data, with a background field concentration of 279  $\mu\text{g/L}$  found when laboratory results indicated a 0 TPH concentration. The slope of this relationship is less than one, however, indicating that for the Hill AFB site, when true ground-water concentrations (as defined by laboratory purge-and-trap results) exceed 842  $\mu\text{g/L}$ , field ATH values under predict actual ground-water TPH concentrations. Figure 5-11 is a plot of the normalized residuals for the regression relationship shown in Figure 5-10. If the regression relationship is a valid description of the regressed data, the normalized residuals plot should be randomly distributed when plotted against laboratory purge-and-trap concentration results. This random distribution requirement appears to be met by the data in Figure 5-11, suggesting that the assumption of linearity between field and laboratory determined ground-water concentrations is a valid one for the Hill AFB site data.

Figure 5-12 shows the laboratory versus field ground-water TPH relationship observed for the Layton data. Data from the Layton site were more scattered than those from the Hill site but also produced a statistically-significant relationship based on a 95 percent confidence interval. Again, a data point (CPT-08 from the December sampling event) was visually identified as an outlier and was not included in this analysis. At the Layton site, background field ATH readings indicated much higher background ground-water concentrations than was observed at the Hill AFB site. Here, a ground-water concentration of 3,680  $\mu\text{g/L}$  was indicated from ATH readings before laboratory purge-and-trap methods detected TPH contamination. The slope of the Layton relationship was greater than one, however, indicating that unlike the Hill AFB data, field ATH measurements consistently over predicted laboratory purge-and-trap ground-water concentrations by nearly a factor of 2. Figure 5-13 shows the normalized residuals for the Layton data set, suggesting the validity of the regression relationship found for the laboratory versus field determined ground-water TPH concentrations at the Layton site.

Figure 5-14 shows the combined concentration data from the Hill AFB and Layton sites with the two outliers removed from the analysis as mentioned above. For this combined data set, a significant relationship between laboratory and field determined ground-water TPH concentrations exists. This relationship indicates that throughout the range of concentrations determined at the two sites, the ATH method was found to consistently overpredict actual laboratory-determined ground-water concentrations. The normalized residuals indicate an increasing residual value with increasing ground-water concentrations, suggesting an increase in uncertainty of

ATH predictions with increasing concentrations for the combined field data.

The data summarized above for the Hill AFB and Layton sites support the findings of Robbins et al. (1989) which suggest that for a given distribution of contamination, for example, at a given site, it can be expected that field ATH measurements provide a consistent and representative indication of the level of contamination in a given sample. As indicated above based on individual site results versus those from the combined data set, specific laboratory versus field concentrations relationships were site-dependent. ATH measurements appeared more sensitive to the contaminant distribution found at the Layton site compared to that observed at the Hill AFB site based on the slope of the laboratory versus field concentration relationships observed at each site. The slope of this relationship was less than one at the Hill AFB site, while it was nearly two at the Layton site. In addition, the combined data set normalized residuals suggested that the combined regression loses its accuracy at high ground-water concentrations. This later finding was not observed for either of the individual site data sets.

The results of the individual site laboratory versus field concentration relationships can be rationalized based on the observation of free product at the Layton site and the lack of such an observation at the Hill site. It follows that the fraction of aromatic, volatile constituents dissolved in the ground-water at a site with evidence of free product, or high levels of residual saturation would be higher than if this free product did not exist. With a higher fraction of volatile constituents in the aqueous phase, a higher concentration of hydrocarbon in the equilibrated headspace would result, with a higher ATH response, and higher method sensitivity, expected for a given aqueous phase TPH concentration.

The findings of this field data evaluation are significant in that they suggest there is a general relationship between laboratory and field ATH determined hydrocarbon concentrations; but this relationship is very much site-specific. The use of these field ATH measurements appears then to be in the initial site assessment phase, as was done in this study, where rapid, semi-quantitative results generated from the method are used for detailed plume delineation efforts. Field ATH measurements can be used to effectively guide initial ground-water quality investigations and to optimize ground-water monitoring probe and monitoring well placement for long-term site monitoring. Once this initial screening is completed, however, it appears that laboratory analyses are necessary to provide accurate ground-water quality data for further site fate-and-transport and intrinsic remediation evaluation.





## Chapter 6

### Results and Discussion—Site 1 Building 1141 Site, Hill Air Force Base, Utah

#### Site Description and Site History

This site is located in the west area of Hill Air Force Base (HAFB), south of the city of Ogden, Utah. The site is immediately north of Building 1141, located at the convergence of Aspen Road and 6th Street (Figure 6-1). Surrounding buildings are used for maintenance, motor vehicle offices, and for storage of U.S. Air Force railroad engines. Underground utilities are located on and adjacent to the site property. Building 1141 was used by the Air Force for small vehicle maintenance. An 18,000-gallon UST was located in the subsurface immediately northwest of Building 1141 (Figure 6-1).

#### Geologic Setting

HAFB is located along the Wasatch Front of northern Utah. The area west of the Wasatch Front was the site of prolonged marine basin and shallow water sediment accumulation during earliest Precambrian time through the Paleozoic era. Structural deformation and limited depositional events persisted until Pleistocene times when lakes inundated the Wasatch Front area (Engineering Science, 1991). The site lies on sands and gravels of the ancient Weber Delta and associated beach deposits. These deposits coalesce with similar sediments of adjacent and smaller deltas to the north and grade to the west and south into finer grained lacustrine and flood-plain deposits. Shallow soils directly beneath the site consist of interbedded sands, silts, and clays (Engineering Science, 1991).

Generally, the regional shallow and deep ground-water flow direction through the fluvial and lacustrine deposits underlying the base is from the mountains on the east toward the Great Salt Lake on the west. Water level information gathered at the site indicates that the regional flow direction of the shallow ground-water table is also from east to west.

The regional hydraulic conductivity of the unconsolidated sediments underlying Hill AFB has been reported to be in the range of 0.1 to 1 cm/s. However, hydraulic conductivity values of the shallow soils at the Building 1141 site, as determined by slug tests per-

formed on selected wells by Engineering Science, were found to be significantly lower between  $1.0 \times 10^{-5}$  and  $7.7 \times 10^{-5}$  cm/s (Engineering Science, 1991).

#### Previous Site Activities

In December 1989, an 18,000-gallon bare steel gasoline UST was excavated and removed from the subsurface at the Building 1141 site. No free-phase hydrocarbons were observed at the time of removal although observations of odors and holes in the UST indicated that a release may have occurred. To better document environmental conditions during tank removal, two soil samples and a ground-water sample were collected and analyzed for benzene, toluene, ethylbenzene, xylenes (BTEX), and total petroleum hydrocarbons (TPH). The analytical data from this sampling event indicated that residual and dissolved BTEX and TPH contaminants were present in the soil and shallow ground-water, respectively (Engineering Science, 1991).

An Abatement and Site Check Report was prepared by HAFB Environmental Management Directorate personnel and submitted on June 28, 1990 to the State of Utah Department of Health, Division of Environmental Health, Bureau of Solid and Hazardous Waste.

A January 2, 1991, Investigation Report (Engineering Science, 1991) summarized results from field investigative activities which were conducted in October and November 1990. These activities included a soil gas survey, soil borings, installation of ground-water monitoring wells, collection of soil and ground-water samples for laboratory analyses, slug tests, and a site survey.

These activities documented the presence of limited residual phase and dissolved hydrocarbons in soil and ground-water beneath the site. The highest levels of BTEX and TPH contaminants in soils were detected in the nested pair of borings and wells (MWU1141A-03 and MWU1141A-06, Figure 6-1), located 5 ft west of the former UST location. Only one other soil sample, from soil boring MWU1141A-04, located approximately 50 ft

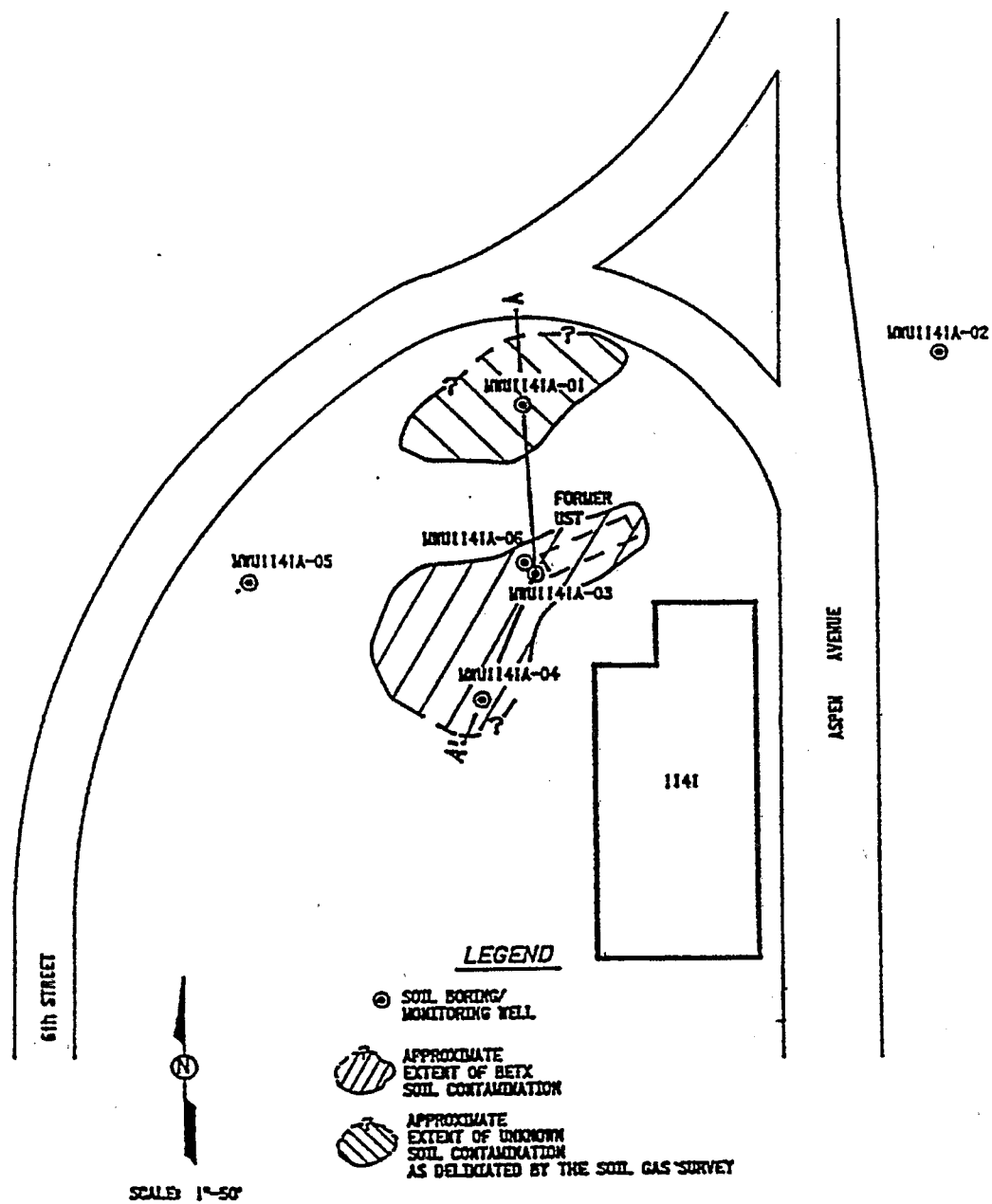


Figure 6-1. Site map for Hill AFB, UT, Site 1141 (Engineering Science, 1991).

southwest of the former UST, had detectable xylene concentrations. Ground-water contamination in the form of dissolved BTEX and TPH was determined to be restricted to the upper portion of the shallow aquifer and only immediately downgradient and adjacent to the former UST.

A second round of ground-water sampling was performed in March 1991. In addition, new flush mount surface well completions were installed to better protect the wells. A May 31, 1991, report (Engineering Science, 1991) summarized ground-water analytical data and documented surface elevations for newly completed wells. Levels of dissolved contaminants found during the March 1991 sampling event were very similar to those documented in November 1990. Of significance was the higher TPH value for MWU1141A-03 in the March 1991 data. In addition, the laboratory stated that the TPH gas chromatograph profile for the March 1991 sample more closely resembled gasoline, while the November 1990 sample resembled diesel. For analysis purposes, the laboratory used a diesel standard for the November 1990 sample, while a gasoline standard was used for the March 1991 sample. The results of the analyses imply that some volatile constituents of the hydrocarbon contamination persisted in the shallow aquifer and vadose zone at the site. The apparent increase in volatiles may have been due to the transfer of more mobile gasoline constituents from the vadose zone due to increased infiltration of water to the aquifer due to spring thaws.

Gasoline and/or diesel related residual and dissolved contaminants appear to have migrated from the former UST, due to either tank leakage or surface spills, into near surface soils and into the shallow ground-water system. The lack of free-phase product indicates that the bulk of the released product was bound in capillary pore spaces of the shallow soils. The restricted extent of contamination was likely due to seasonal fluctuations in the water table and indicates that migration occurred both laterally and downward within the former sandy fill material and into native soils immediately surrounding the UST (Engineering Science, 1991).

Migration of contaminated ground-water was minimal, presumably due to the low hydraulic conductivities of the native sediments and to the relatively low levels of BTEX and TPH contaminants present in the upper portion of the shallow aquifer. No dissolved hydrocarbon was detected in the upgradient well (MWU1141A-02) and what was thought at the time to be a downgradient well (MWU1141A-04) during the November 1990 and March 1991 sampling events. Moreover, lack of contamination in the bottom depth of the nested pair of monitoring wells (MWU1141A-06, 10 ft below the ground-water table and MWU1141A-03 screened across the ground-water table) demonstrated

that vertical migration of dissolved hydrocarbons had not occurred by March 1991.

### ***UWRL Site Activities***

As indicated in Chapter 5, site investigation protocols utilizing CPT soil textural data collection and small diameter ground-water piezometer sample placement for detailed plume delineation were evaluated in July and August 1992 at the Hill AFB site. CPT data were collected at 44 locations throughout the Hill AFB site to augment the existing monitoring network consisting of five conventional ground-water monitoring wells. CPT soil profile data collected at the Hill AFB site successfully identified a subsurface stream channel (Figure 5-9) existing at the ground-water table which produced a significant northerly flow component to the ground-water flow observed at the Hill AFB site (Figure 5-8). This modified flow pattern significantly changed the conceptual model of the Hill site, resulting in a plume that was found to move north and west from the former UST location, rather than west and south (Figure 6-1) as was originally proposed from limited site data available prior to this study. With the additional ground-water data collected in this study, it was found that MWU1141A-04 was an upgradient monitoring point, not a downgradient one which was initially thought. No true downgradient monitoring location actually existed at the site with the original monitoring network in place in March 1991 as shown in Figure 6-1.

Seven sampling events were used at the Hill AFB site to describe the distribution and movement of contaminants and electron acceptors taking place at the site between April 1992 and January 1994. These sampling events included: April 1992, prior to installation of the piezometer sampling network; July 1992, immediately following installation of the piezometer sampling network; November to December 1992; February 1993; June 1993; September 1993; and January 1994. Ground-water hydrocarbon composition data for these sampling events are summarized in Appendix F, while all nutrient, iron and manganese data collected at the Hill AFB site are summarized in Appendix L. These data were used to determine steady-state plume conditions and to estimate total mass and mass center values for these various analytes at the Hill AFB site over time as prescribed by the intrinsic remediation assessment protocol described in Chapter 4.

### **Determination Of Steady-State Plume Conditions**

#### ***Contaminant Centerline Concentrations***

Once the true centerline position was determined during site assessment activities that took place in July 1992, a centerline transect was used to make a determination regarding steady-state plume conditions

at the Hill AFB site. This centerline transect was composed of data collected from the following single-level ground-water piezometers (see Figure 5-6 for their specific locations throughout the site): CPT-18 in the source area, and downgradient locations within the dissolved plume at CPT-07, CPT-09, CPT-23, CPT-12, CPT-29, CPT-15, CPT-21, CPT-30, and CPT-19.

The traditional compounds of concern from a health and fate-and-transport perspective include BTEX and naphthalene. These compounds were used along with TPH to generate centerline concentration profiles for each sampling event to evaluate plume steady-state conditions at the site. Appendix F contains summarized BTEX, naphthalene, and TPH data for each sampling event, while Figures 6-2 through 6-5 show the plume centerline concentration data for combined BTEX and TPH concentrations at the Hill AFB site over time, respectively.

It appears from these figures that a significant decline in centerline concentrations for both BTEX components and TPH occurred in the dissolved plume between July and December 1992. The expanded concentration scale plots of Figure 6-3 and 6-5 indicate that following this initial decline in centerline concentration, the concentration profile for BTEX and TPH constituents remained at pseudo-steady-state. While both a BTEX and a TPH concentration spike were observed in monitoring point CPT-21, no consistent patterns of increasing concentrations downgradient of the source over time were evident, again suggesting that this criteria for steady-state was satisfied at the Hill AFB site.

### ***Dissolved Contaminant Plume Mass and Center of Mass Calculations***

As indicated in Chapter 4, Thiessen areas were generated for each sampling event using a fixed outer plume boundary and individual areas determined based on the actual sampling locations used in a given sampling event. This outer plume boundary is shown in Figure 6-6 along with Thiessen areas based on the July 1993 sampling event. A summary of specific Thiessen area calculations for each sampling event is provided in Appendix C.

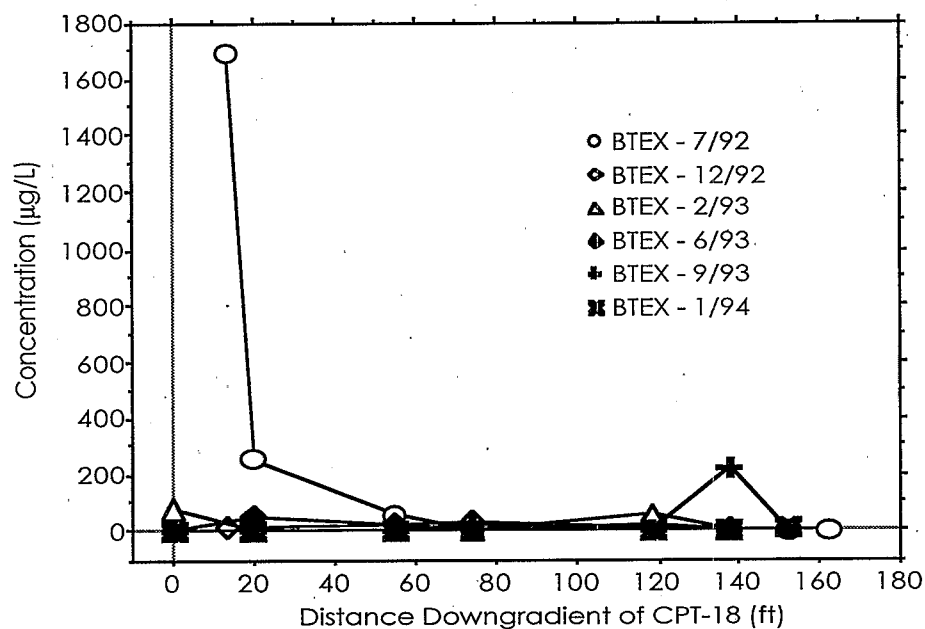
Based on the Thiessen areas associated with each sampling point used for plume monitoring at each sampling time, estimates of the total dissolved plume mass and center of mass of BTEX, naphthalene, and TPH were made following the procedures described in Chapter 4. The results of the total mass and center of mass calculations are provided in detail in Appendix G, while summary data are provided in Table 6-1.

Several items are important to note from Table 6-1. The need for a finely gridded sampling network is evident

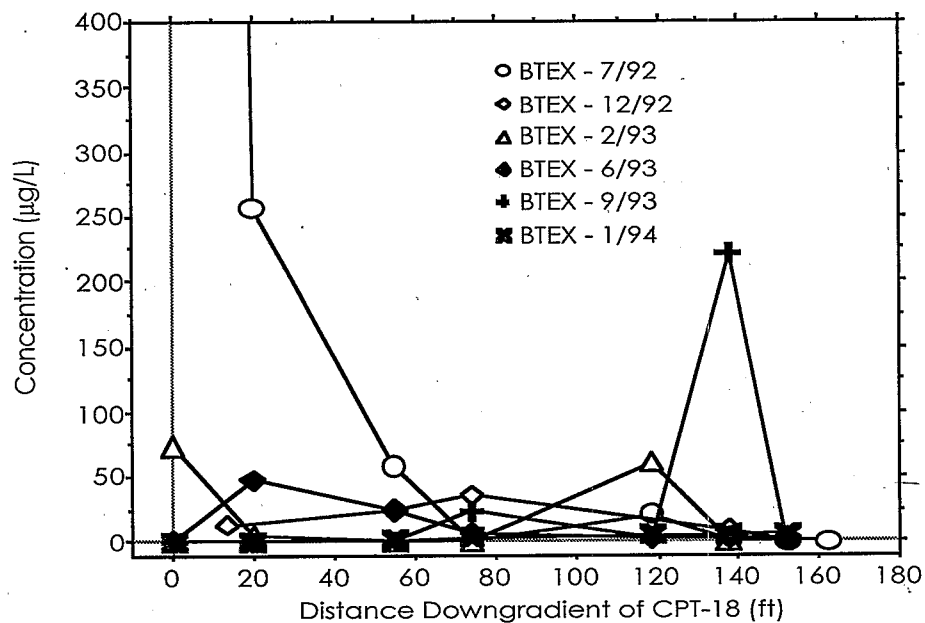
from a comparison of April 1992 data with that from subsequent sampling events. Results from April 1992 were based only on the five well monitoring network established at the site prior to this study. As indicated in Table 6-1, this limited sampling grid underestimated the actual dissolved contaminant mass that was present at the site by a factor of approximately 10 for all analytes of interest due to improper initial sample location placement and the large area of the plume assigned to each of only five points. With an increased number of sampling points in the grid and much finer spacing of these points, an improved total mass estimate is possible. This finer grid also allows more sensitive tracking of the change in dissolved plume contaminant mass and the position of its mass center over time.

The data in Table 6-1 can be used to assess whether the plume has reached steady-state conditions from both the time course of total mass of each analyte and the center of mass of each analyte over time. Graphical representations of the total mass of contaminant over time are presented in Figures 6-7 and 6-8, while Figures 6-9 to 6-14 show the position of the center of mass for each analyte over time at the Hill AFB site. Because of the small number of data points that could be sampled in December of 1992 due to adverse site conditions, this sampling event produced significantly lower dissolved mass estimates than the balance of the 1992 and 1993 sampling results (Table 6-1). As a consequence, this sampling event was not thought to be representative of true conditions throughout the site and was omitted from the total mass and center of mass analyses shown in Figures 6-7 through 6-14.

Specific compound mass data shown in Figure 6-7 suggest that steady-state conditions existed for some of the compounds (benzene, toluene, naphthalene) during a portion of the study period, while a continuously declining mass was seen for ethylbenzene and p-xylene during the entire study period. All of the specific compounds of interest did show a significant decline at the end of the study, suggesting that steady-state conditions did not persist. Dissolved plume TPH mass confirmed the non-steady-state conditions existing at the Hill AFB site, as contaminant mass was found to exponentially decay over time (Figure 6-8). Center of mass plots in Figures 6-9 to 6-14 show migration of the mass center downgradient from its location in August of 1992, although the total downgradient distance traveled was small, ranging from a maximum of 106 ft for TPH, to a low of only 17.2 ft for naphthalene (Table 6-2). Based on the interpretation of the changes observed in the center of mass over time as presented in Table 4-5, this decreasing contaminant mass and center of mass moving downgradient suggests that the source was finite, and despite plume migration, contaminant attenuation was indicated.



**Figure 6-2. Combined BTEX plume centerline concentration data collected from Hill AFB, UT, Site 1141 from July 1992 to January 1994.**



**Figure 6-3. Expanded concentration scale for combined BTEX plume centerline concentration data presented in Figure 6-2.**

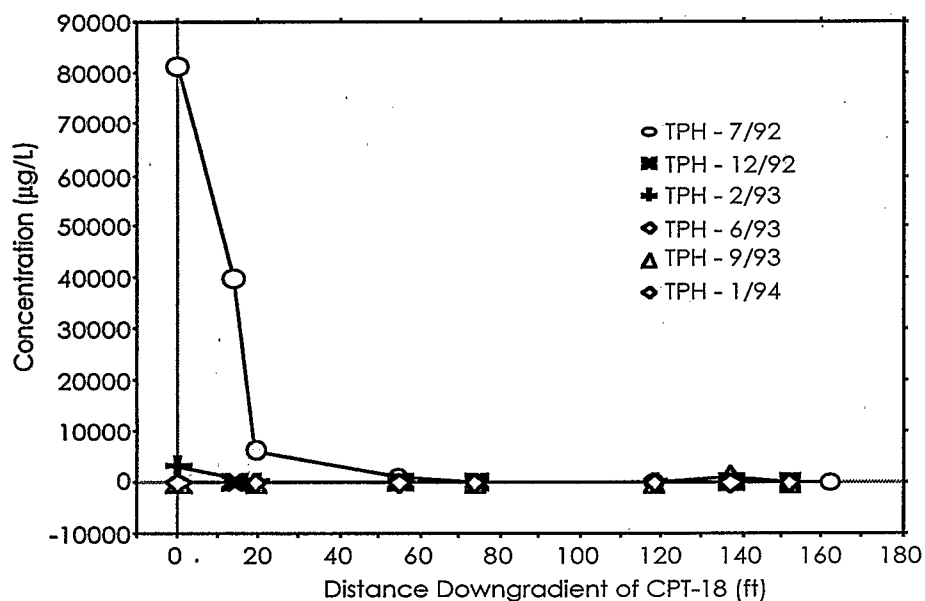


Figure 6-4. TPH plume centerline concentration data collected from Hill AFB, UT, Site 1141 from July 1992 to January 1994.

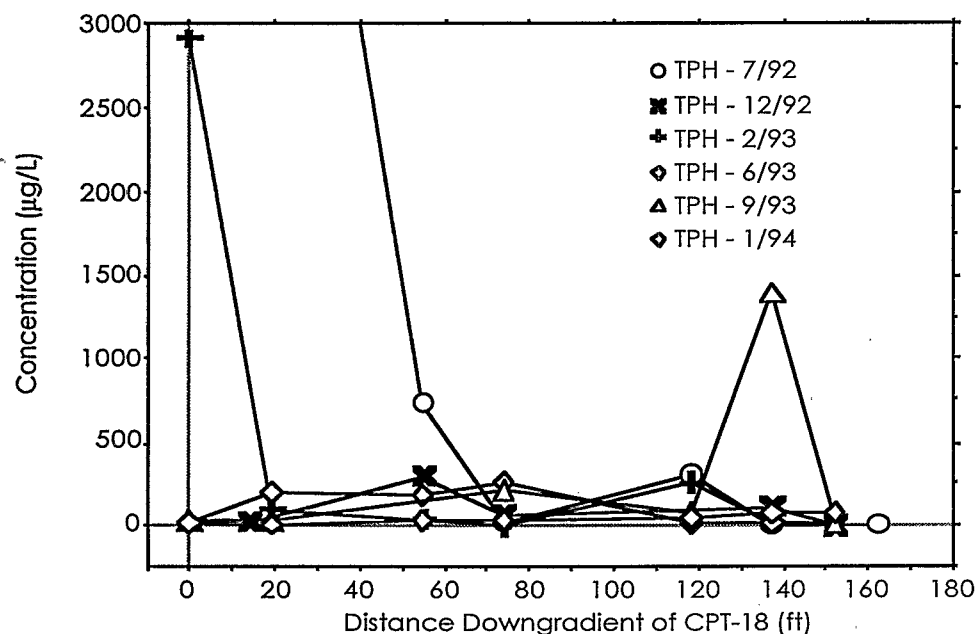


Figure 6-5. Expanded concentration scale for TPH plume centerline concentration data presented in Figure 6-4.

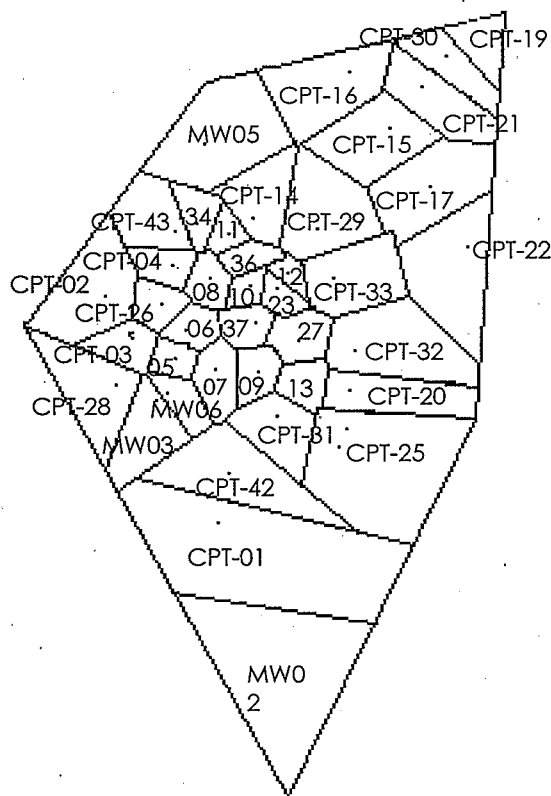


Figure 6-6. Outer plume boundary used for Hill AFB site plume total mass and mass center calculations. Thiessen areas for the July 1993 sampling event are shown.

### Estimation of Contaminant Degradation Rate

The estimation of contaminant degradation rates with a declining mass within the plume is carried out using dissolved plume mass changes over time as described in Chapter 4. This procedure is highlighted below as applied to the Hill AFB site.

### Dissolved Plume Mass Changes Over Time

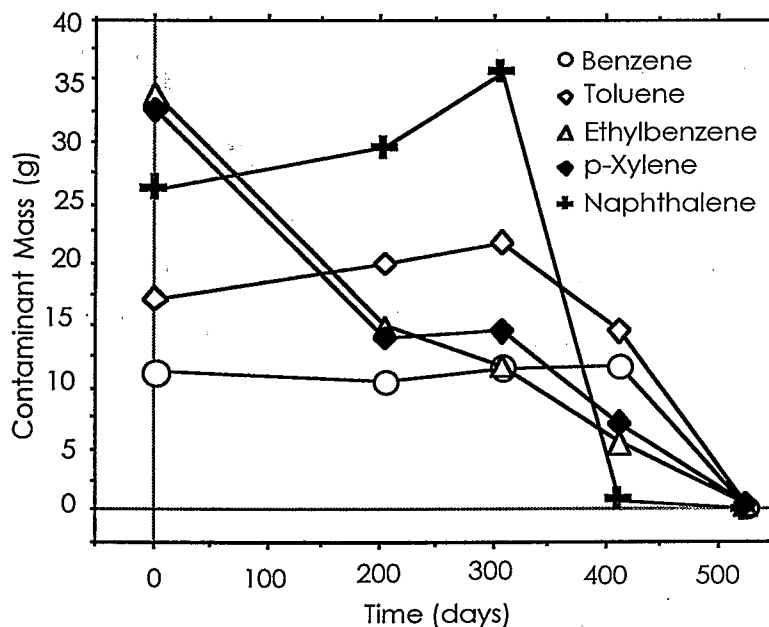
The total mass of each dissolved constituent in the Hill AFB ground-water plume over time from Table 6-1 was used to estimate contaminant degradation rates through linear regression of zero and first order rate law descriptions of these data. The entire ethylbenzene, p-xylene, and TPH data sets were used in the regression analysis as these contaminants displayed continuously decreasing masses over time. For benzene, toluene, and naphthalene, only the data showing mass declines over time (toluene and naphthalene data after 307 days, and only the last two data points for benzene) were used in their degradation rate estimates.

Table 6-2 summarizes contaminant transport and degradation rate calculations for BTEX, naphthalene, and TPH observed at the Hill AFB site, while Figures 6-15 through 6-20 graphically show the data used to calculate these estimated contaminant degradation rates.

As indicated in Table 6-2, the projected lifetime of the ground-water plumes generated from the BTEX components is quite short, being less than two weeks from the last sampling event, due to the low mass of contaminant remaining in the plume as of January 1994. The naphthalene and TPH plumes could persist for a much longer time period but were estimated to last only slightly longer than two years at the current rate of degradation, if all site conditions remain the same as those observed during the study. The TPH plume mass center is projected to move a total of 156 ft downgradient from its position in January 1994 during its 768 day lifetime. This puts the mass center approximately 50 ft downgradient of the existing monitoring network, still within the boundaries of Hill AFB, and without impact to a downgradient receptor.

**Table 6-1. Summary Total Mass and Center of Mass Coordinate Data for BTEX, Naphthalene, and TPH Estimated from Data Collected at the Hill AFB Site from March 1992 to January 1994**

Parameter	Sampling Date						
	4/92	8/92	12/92	2/93	6/93	9/93	1/94
Benzene Mass (g)	2.8	11.4	10.3	10.6	11.7	11.9	0.4
Toluene Mass (g)	2.7	17.3	11.6	20.0	21.7	14.5	0.7
Ethylbenzene Mass (g)	3.9	33.9	8.9	15.1	11.8	5.6	0.5
p-Xylene Mass (g)	14.1	32.6	8.9	14.0	14.5	7.1	0.8
Naphthalene Mass (g)	2.3	26.2	2.3	29.5	35.5	1.0	0.1
TPH Mass (g)	127.9	3,955	138	1,167	348	316.7	28.8
Benzene-x (ft)	16.7	36.6	52.4	66.8	61.3	98.4	21.8
Benzene-y (ft)	32.9	36.4	11.3	85.7	53.1	103.6	57.4
Toluene-x (ft)	1.8	58.9	40.7	42.7	57.4	94.5	67.1
Toluene-y (ft)	43.6	41.0	80.4	47.9	39.7	98.9	93.7
Ethylbenzene-x (ft)	1.0	74.0	58.4	40.6	57.4	92.9	79.8
Ethylbenzene-y (ft)	44.1	66.4	38.1	42.7	42.1	88.6	108.9
p-Xylene-x (ft)	-1.3	58.4	55.1	47.3	58.7	100.9	82.6
p-Xylene-y (ft)	45.7	59.2	15.1	49.0	38.4	108.7	109.2
Naphthalene-x (ft)	16.7	63.1	62.9	39.5	72.8	55.2	62.2
Naphthalene-y (ft)	32.9	60.2	68.8	35.2	90.0	36.4	77.4
TPH-x (ft)	14.8	63.4	59.9	37.6	64.0	86.6	73.1
TPH-y (ft)	37.8	-17.1	37.4	38.7	54.8	88.5	88.2



**Figure 6-7. Time course of total dissolved plume mass estimates for BTEX and naphthalene contaminants at the Hill AFB site over the course of the study.**



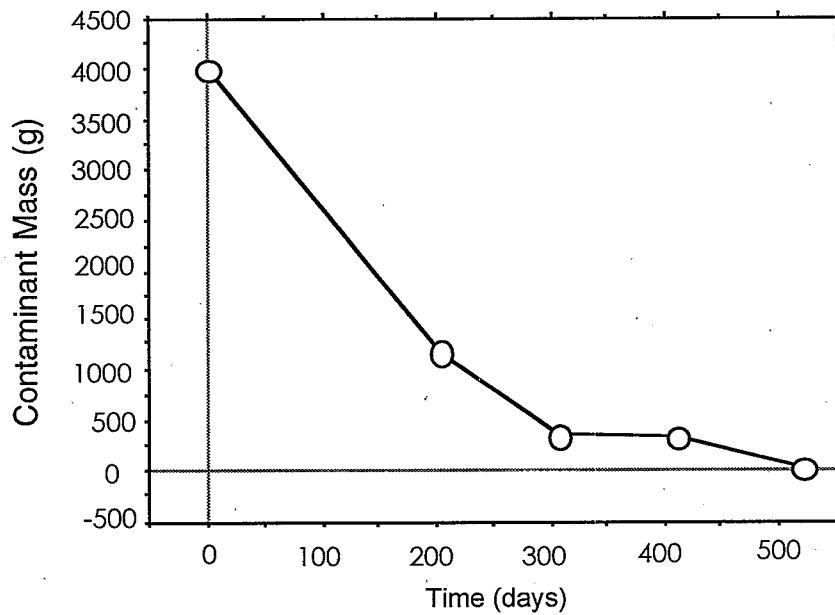


Figure 6-8. Time course of total dissolved plume mass estimates for TPH at the Hill AFB site over the course of the study.

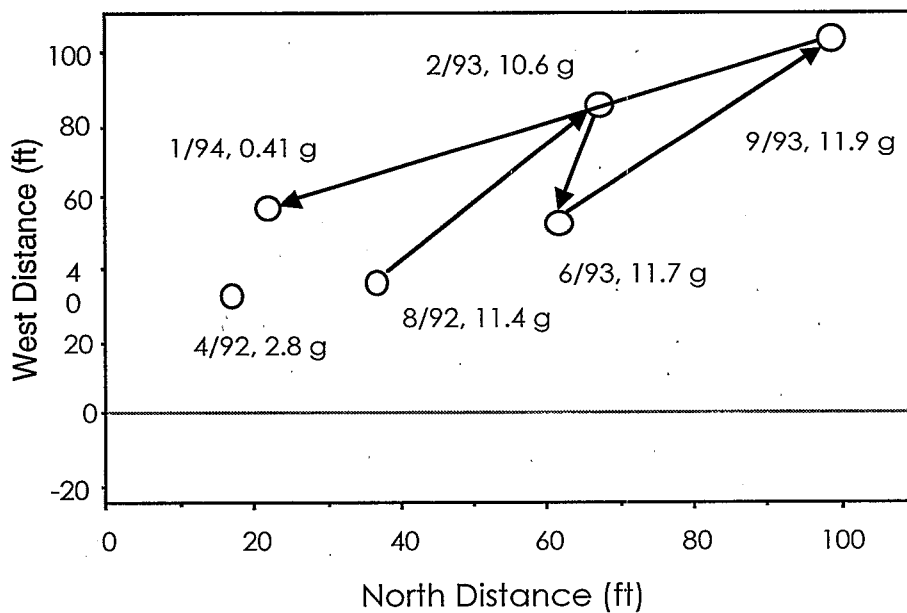


Figure 6-9. Center of mass positions for benzene at the Hill AFB site during the study.

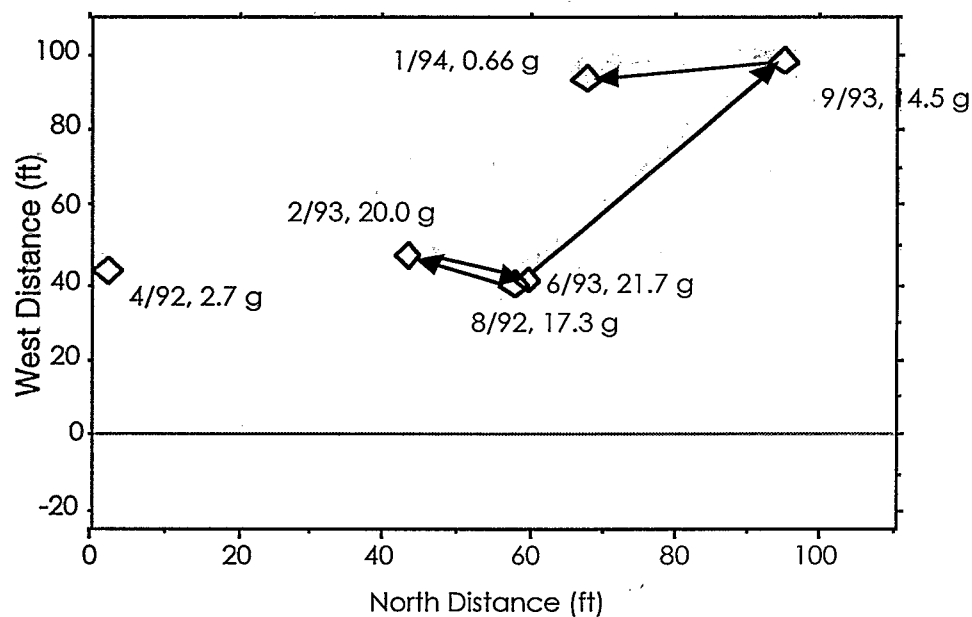


Figure 6-10. Center of mass positions for toluene at the Hill AFB site during the study.

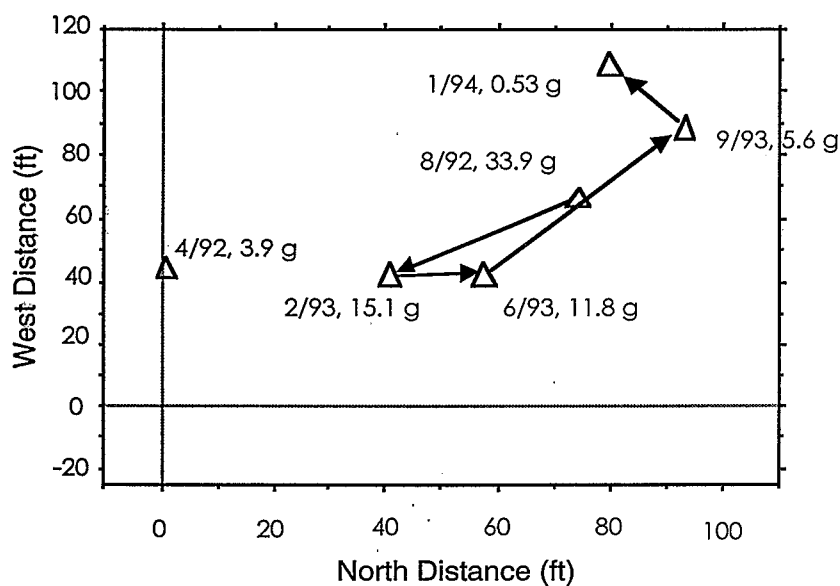


Figure 6-11. Center of mass positions for ethylbenzene at the Hill AFB site during the study.

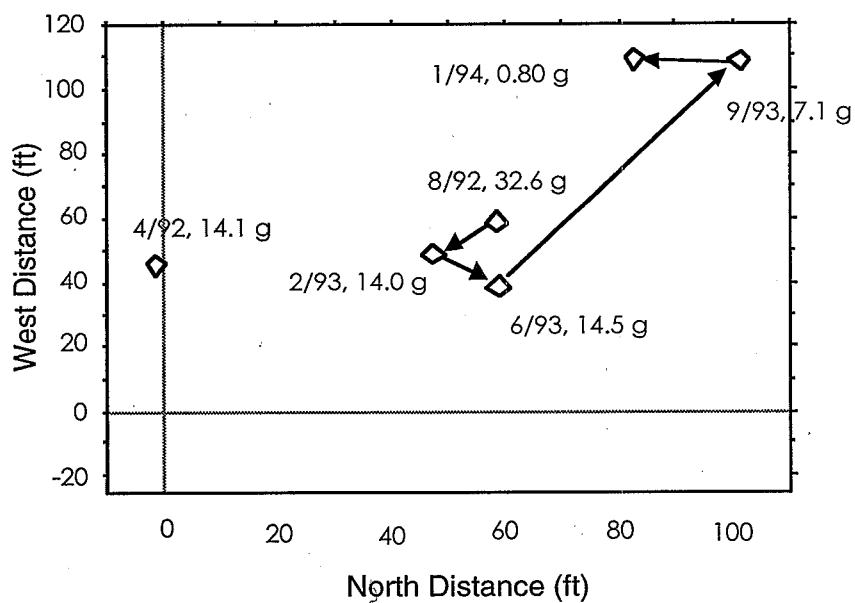


Figure 6-12. Center of mass positions for p-xylene at the Hill AFB site during the study.

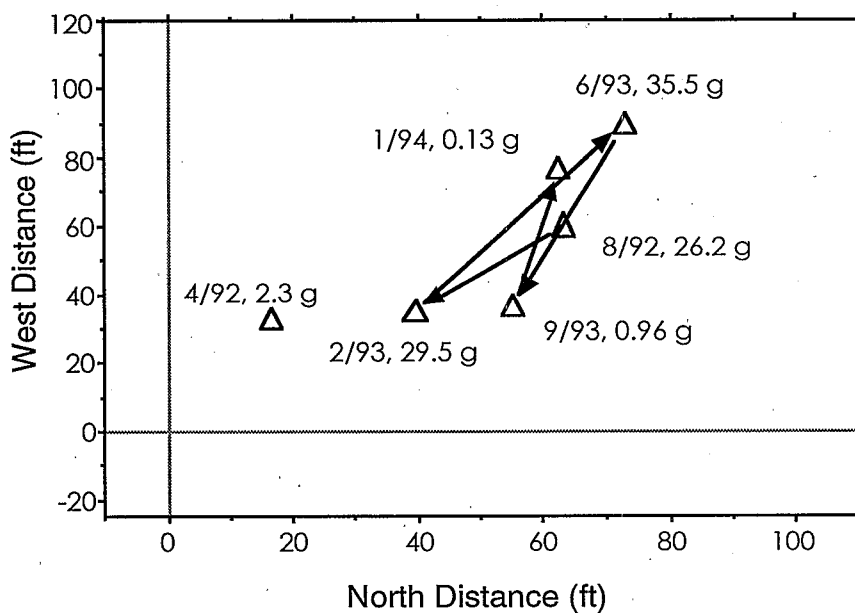


Figure 6-13. Center of mass positions for naphthalene at the Hill AFB site during the study.

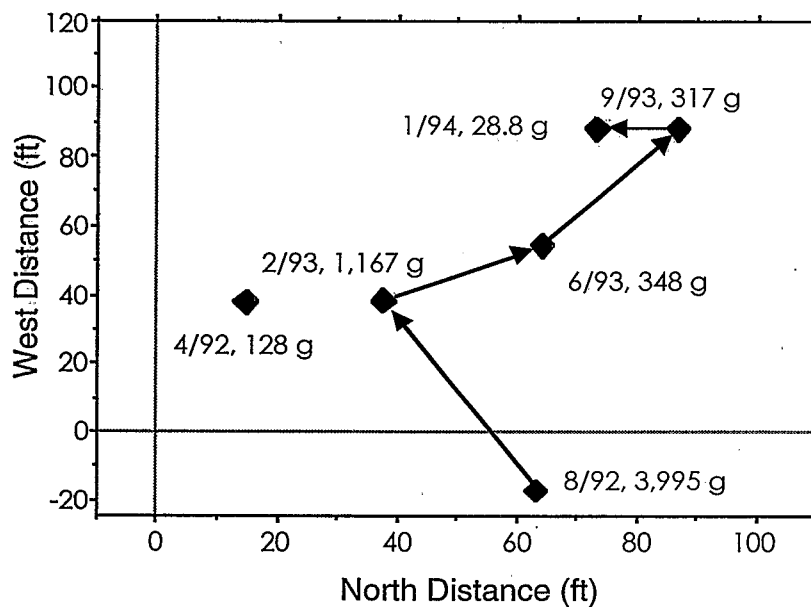


Figure 6-14. Center of mass positions for TPH at the Hill AFB site during the study.

Table 6-2. Contaminant Center of Mass Velocities and Degradation Rates Based on Ground-Water Data Collected at the Hill AFB Site from March 1992 to January 1994

	Benzene	Toluene	Ethyl- benzene	p-Xylene	Naphthalene	TPH
Distance Traveled (ft) =	25.70	53.30	42.90	55.60	17.20	106.00
Contaminant Velocity (ft/d) =	0.05	0.10	0.08	0.11	0.03	0.20
Contaminant Velocity (ft/yr) =	18.00	37.40	30.10	39.00	12.10	74.20
Zero Order Degradation Rate (g/d) =	≈0.10	≈0.10	0.06	0.06		
Zero Order Degradation Rate (g/yr) =	≈36.90	≈28.50	23.40	22.30		
First Order Degradation Rate (1/d) =					≈0.03	0.01
First Order Degradation Rate (1/yr) =					≈9.50	3.29
Remaining Mass as of 1/94 (g) =	0.41	0.66	0.53	0.80	0.13	28.80
Time to Degrade Remaining Mass - Zero Order (dl) =	≈4.10	≈6.70	8.41	13.79		
Time to Degrade 99.9% Mass - First Order (d) =					≈266.00	767.53
Travel Distance in Degradation Time (ft) =	≈0.20	≈0.67	0.67	1.52	≈8.00	153.51

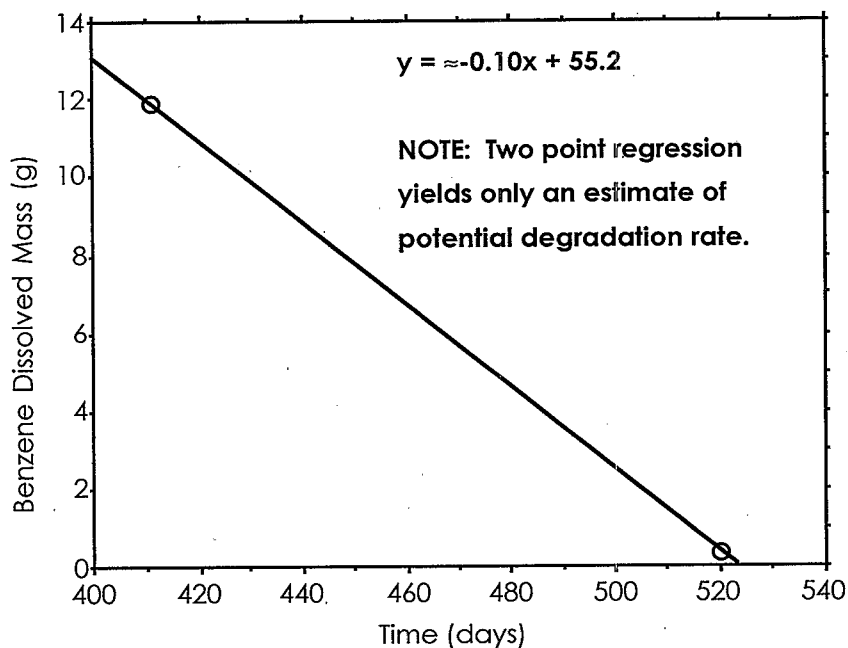


Figure 6-15. Zero order regression for changes in dissolved benzene mass in the ground-water plume at the Hill AFB site over time.

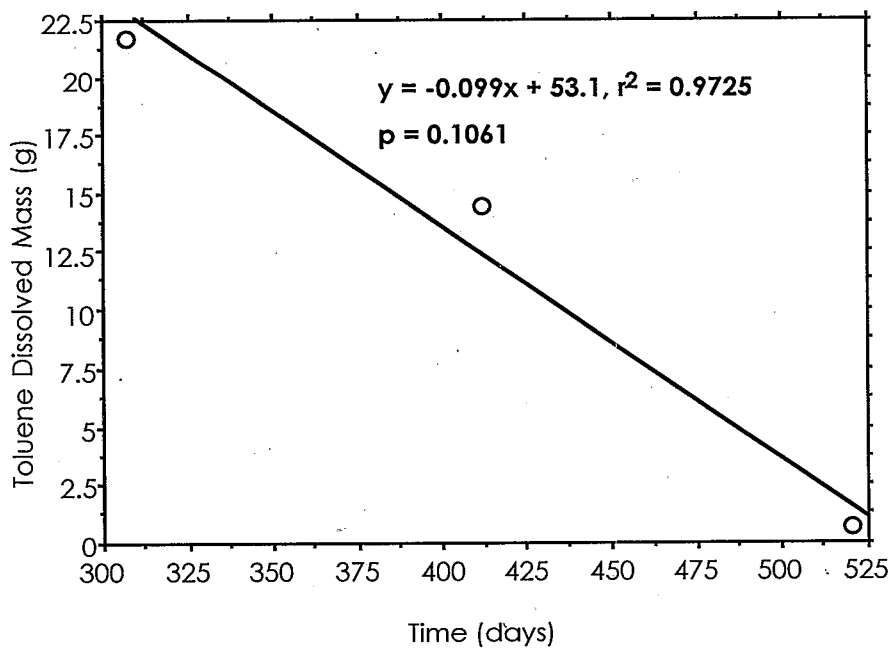


Figure 6-16. Zero order regression for changes in dissolved toluene mass in the ground-water plume at the Hill AFB site over time.

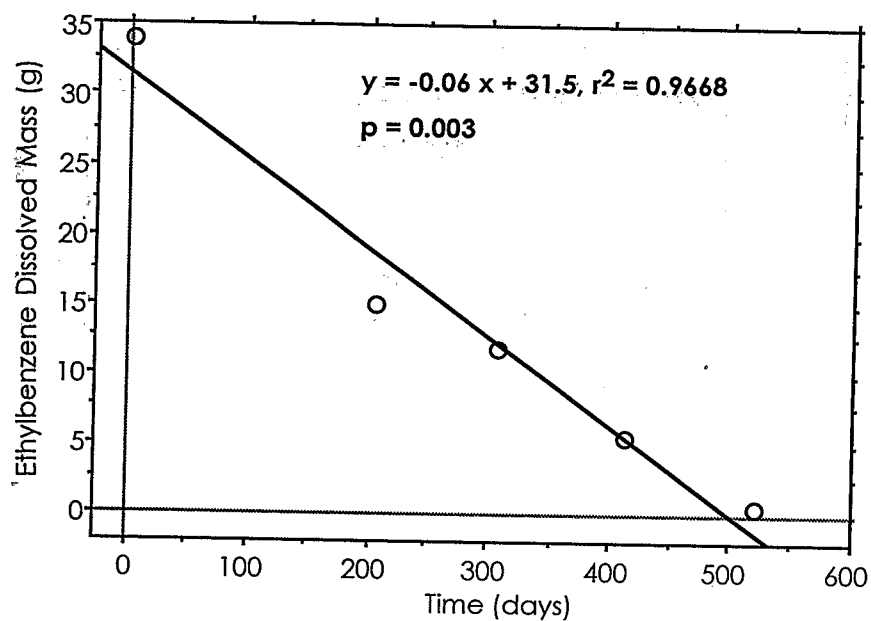


Figure 6-17. Zero order regression for changes in dissolved ethylbenzene mass in the ground-water plume at the Hill AFB site over time.

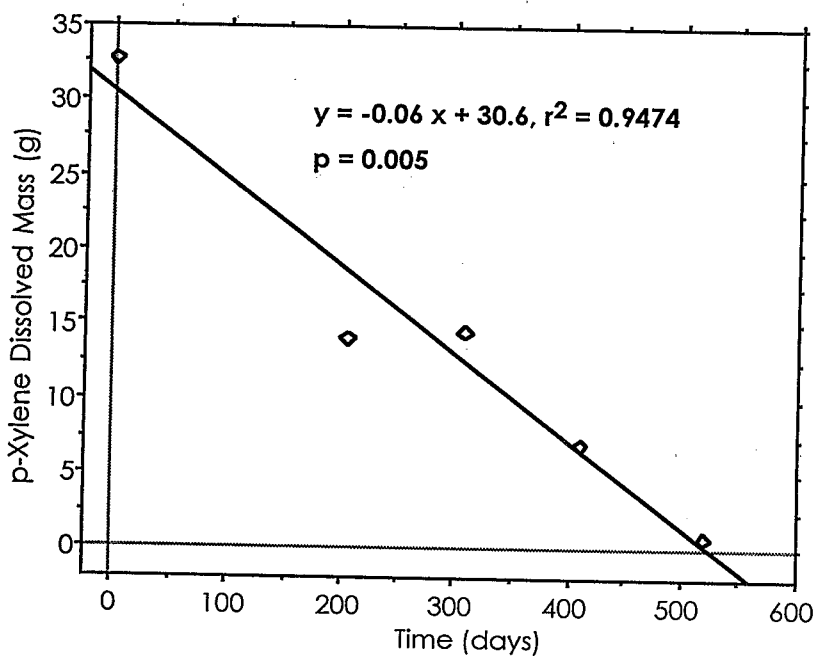


Figure 6-18. Zero order regression for changes in dissolved p-xylene mass in the ground-water plume at the Hill AFB site over time.

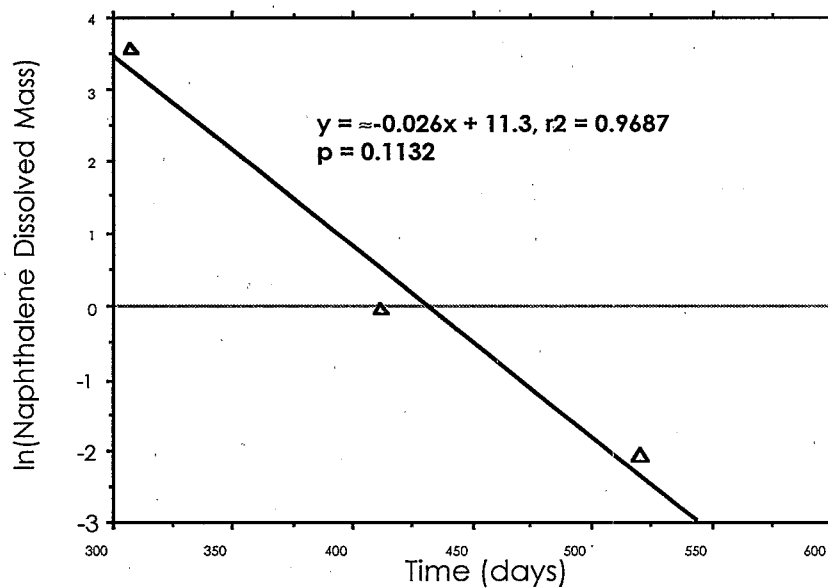


Figure 6-19. First order regression for changes in dissolved naphthalene mass in the ground-water plume at the Hill AFB site over time.

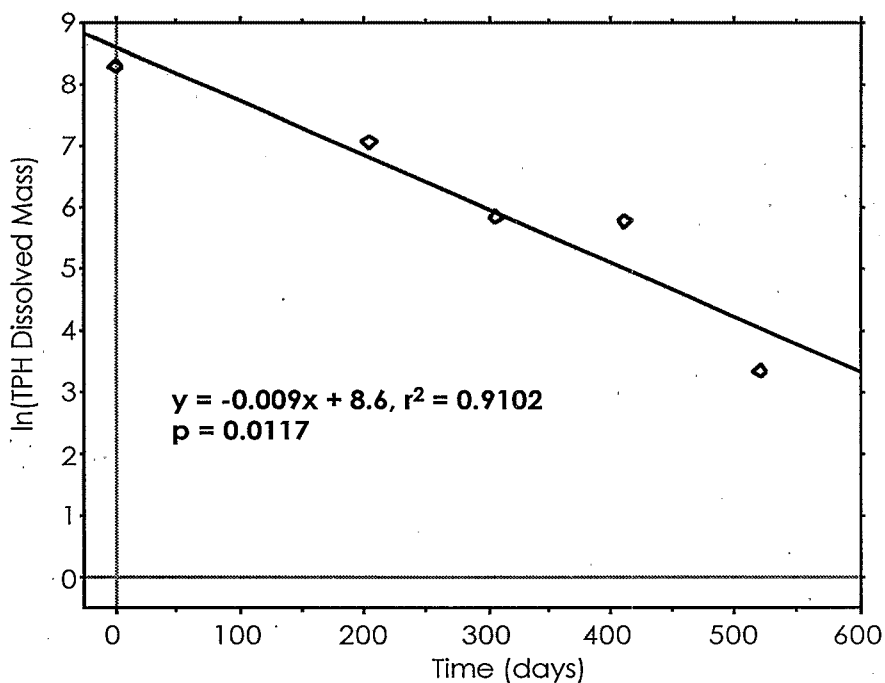


Figure 6-20. First order regression for changes in dissolved TPH mass in the ground-water plume at the Hill AFB site over time.

### **Plume Centerline Concentration Data**

The centerline ground-water concentrations and dissolved plume mass changes over time indicated that over the life of the project the plumes were not at steady-state but were declining. Because of this, the centerline ground-water concentration approach for estimating contaminant degradation rates was not applicable to the Hill AFB site, and consequently, was not carried out.

### **Estimation of Source Mass/Lifetime**

As indicated in Chapter 4, when a decreasing plume mass and pulse source is identified at a site, the estimation of source mass and source lifetime can be based on the dissolved plume mass observed at a given point in time. Since the plume at the Hill AFB site was observed to have evolved from a continuous source into a pulse source with declining mass during the course of this study, lifetime calculations based on observed contaminant degradation rates are applicable here. These calculations are summarized in Table 6-2 and are based on the estimated degradation rates for BTEX, naphthalene, and TPH generated from dissolved plume mass changes over time. Only estimates of degradation rate and remaining contaminant lifetime could be made for benzene, toluene, and naphthalene due to a limited data set available for these compounds and regression relationships that were not significant at the 95 percent confidence level. Due to the small dissolved mass of these compounds, however, their projected lifetimes at the site were low, with naphthalene, the most slowly degrading specific compound, having a lifetime less than one year. The projected TPH plume lifetime, based on its observed first order degradation rate, was slightly over two years.

### **Predicting Long-Term Behavior of Plume**

The long-term behavior of the dissolved plume at the Hill AFB site is controlled by the apparent pulse nature of the release. Consideration of a source removal scenario for this site is not relevant as data indicate that the plume has moved away from the original source area following depletion of the initial contaminant mass there. The source area has effectively been removed through intrinsic processes of contaminant dissolution, dispersion, and degradation. The long-term behavior of the plume is then dependent upon the degradation rates of the contaminants within the "detached" dissolved plume and the rate at which the contaminants are migrating within the aquifer.

Contaminant degradation and transport analyses are summarized in Table 6-2 above. These data suggest again that naphthalene is the specific compound with the greatest potential mobility since its degradation rate is low relative to the other compounds of interest at the site. The time required for 99.9 percent naphthalene degradation is projected to be approximately 266 days,

during which time the center of mass of the naphthalene plume would have moved downgradient approximately 8 ft. Based on these estimates, none of the specific compounds investigated in this study will move off the Hill AFB site and beyond the monitoring network currently in place. The non-specific analyte, TPH, plume is expected to persist for more than two years (time for 99.9 percent TPH removal). During this time its plume center of mass migrates only 156 ft downgradient, approximately 50 ft downgradient of the current monitoring network. The plume should remain on Hill AFB property, but residual mass would not be detectable with the current ground-water monitoring network.

### **Decision Making Regarding Intrinsic Remediation**

Decisions regarding the acceptability of an intrinsic remediation management approach for a given site should be made based on the potential impact a plume has on susceptible downgradient receptors, along with evidence that exists regarding the presence and rate of intrinsic attenuation reactions taking place at a site that provide contaminant plume containment and control. Evidence of contaminant degradation is provided through plume analysis and degradation rate estimates described above. Additional evidence related to the potential aquifer assimilative capacity estimated from an analysis of electron acceptor conditions existing upgradient of the plume is summarized below.

### **Impacted Receptors**

As indicated above, the long-term behavior of the contaminant plumes existing at the Hill AFB site projected from contaminant degradation and transport data suggest that the maximum extent of any plume of interest will only be 50 ft downgradient of the existing ground-water monitoring network. This limited extent of potential contaminant migration indicates that no downgradient receptors will be impacted by contamination at the Hill AFB site over the projected lifetime of the ground-water plume that exists there.

### **Potential Aquifer Assimilative Capacity**

Final evidence related to the feasibility of an intrinsic remediation management approach is the quantification of the potential assimilative capacity existing in uncontaminated ground-water at a site. When quantities of electron acceptors moving onto a site equal or exceed the levels of dissolved contaminant in the plume, it can be assumed that the availability of electron acceptors will not limit contaminant degradation and plume attenuation at the site in the future. Table 4-6 summarizes the hydrocarbon assimilative capacity relationships for electron acceptors quantified throughout the Hill AFB site. These relationships were used along with electron acceptor concentrations measured in the background ground-water (Appendixes



**Table 6-3. Potential Ground-Water Aquifer Assimilative Capacity at the Hill AFB Site Based on Ground-Water Data Collected from March 1992 to January 1994**

Electron Acceptor	Background Concentration (mg/L)	Mean HC Equivalent Stoichiometry (g/g HC Equivalent)	HC Equivalent Assimilative Capacity (mg/L)
DO	2.2	3.3	0.66
NO <sub>3</sub> <sup>-</sup>	5.8	1.1	5.40
SO <sub>4</sub> <sup>2-</sup>	53.2	5.0	10.70
ΔFe	1.4	23.1	0.06
ΔMn	0.45	20.0	0.02
CH <sub>4</sub>	Not Measured	NA	NA
Potential Assimilative Capacity ≈			16.90

**Table 6-4. Proposed Long-Term Sampling Schemes for Annual Compliance and Process Monitoring at the Hill AFB Site**

Compliance Monitoring		Intrinsic Remediation Process Monitoring					
Purpose	Location	Centerline	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
Background	MW-2	MW-3	MW-4	CPT-02	CPT-43	CPT-14	CPT-16
Downgradient	MW-5	CPT-18	CPT-28	CPT-03	CPT-34	CPT-33	CPT-15
	CPT-15	CPT-09	CPT-42	CPT-26	CPT-08	CPT-32	CPT-17
	CPT-30	CPT-12	CPT-31	CPT-05	CPT-11		
		CPT-29	CPT-25	CPT-20	CPT-10		
		CPT-30			MLP-35		

H and L) to estimate the potential assimilative capacity existing within the aquifer below the Hill AFB site.

The potential assimilative capacity results for the Hill AFB site are summarized in Table 6-3. The assimilative capacities related to dissolved oxygen, nitrate, and sulfate are based on the lowest observed concentration in background Monitoring Well 2 (MW-2) during the study. For iron and manganese, their assimilative capacities were estimated based on the smallest increase in the soluble concentrations of these solid-phase electron acceptors observed between MW-2 and CPT-08 within the center of the plume during the study. The lowest concentration changes for iron and manganese were observed in January 1994, where MW-2 concentrations were 0.181 and 0 mg/L, while those in CPT-08 were 1.6 and 0.45 mg/L, respectively.

As indicated in Table 6-3, sulfate is the most significant electron acceptor at the Hill AFB site, accounting for more than 60 percent of the potential assimilative capacity at the site. With a maximum TPH concentration of 184 µg/L and a maximum BTEX concentration of 40.5 µg/L observed at sampling point CPT-05 (Appendix F), the potential assimilative capacity projected in Table 6-3 is more than 90 times greater than that required to assimilate the TPH remaining at the site. This result provides additional evidence that an intrinsic remediation management option for the Hill site would be protective of public health and the environment.

#### **Long-Term Site Monitoring Program**

As indicated in Chapter 4, long-term monitoring at the Hill AFB site should be focused on two primary objectives. First, monitoring should be carried out for compliance purposes to ensure no impact to a

downgradient receptor. This should involve annual monitoring of the most downgradient sampling points to ensure that significant changes in plume degradation and transport have not occurred at the site. Second, intrinsic remediation monitoring is perhaps more critical at this site since no nearby receptors exist. In terms of monitoring for intrinsic remediation process evaluation, monitoring at four to six locations along the plume centerline on an annual basis should provide adequate data to ensure that unexpected plume migration has not taken place at the site. To validate degradation rates, which are presented above, additional cross-plume sampling point measurements are also necessary so that a representative determination of residual dissolved plume mass can be made. Based on the ground-water monitoring network at the Hill AFB site as shown in Figure 5-6, a sampling scheme for both compliance and intrinsic process validation monitoring purposes during long-term monitoring at the site is presented in Table 6-4.

Specific analyses for samples collected during the long-term monitoring phase should be similar to those used in this study. The analytes specified by the State of Utah Department of Environmental Quality for compliance monitoring purposes would be expected to include: ground-water elevation; field ground-water dissolved oxygen concentrations; and BTEX, naphthalene, and

purge-and-trap TPH ground-water concentrations. In addition, other electron acceptors (nitrate, sulfate, and dissolved iron and manganese) should be quantified for intrinsic remediation process evaluation along with general ground-water quality parameters such as pH, temperature, and total dissolved solids (TDS).

### **Summary of Intrinsic Remediation Evaluation at the Hill Site**

As indicated in the data presented and discussed above, there appears to be ample evidence that intrinsic remediation has effectively contained the hydrocarbon plume at the Hill AFB Building 1141 former UST site. Significant specific compound and TPH degradation rates, coupled with large pools of electron acceptor moving onto the site, support the implementation of an intrinsic remediation management option. Degradation rates for the most potentially mobile species, TPH and naphthalene, suggest that contaminant levels will fall below detection limits by early 1996, and that the maximum extent of contaminant migration will be contained completely within Hill AFB boundaries. Additional monitoring should take place at the site to verify that contaminant degradation has continued at the rates observed in this study so that complete contaminant assimilation at the site can be verified, and site closure actions can be initiated.

## Chapter 7

### Results and Discussion—Site 2 Blaine Jensen RV Site, Layton, Utah

#### Site Description and Site History

The Blaine Jensen R.V. facility was used as a recreational vehicle sales and service facility during the study and consisted of a service shop, an R.V. sales building, and associated sales and display lots (Figure 7-1). The majority of the site is covered by asphalt, and several underground utilities are present as indicated in Figure 7-1. The ground surface slopes gently toward the southwest and toward U.S. Interstate Highway 15 which borders the site directly to the west.

The property was in agricultural production until approximately 1958, at which time it was leased to Sinclair Oil for retail gasoline sales from a newly constructed gasoline station building (the present service shop). The fuel storage and dispensing system consisted at that time of four USTs (2,000 gallons each) located in the area labeled "Excavation 1" in Figure 7-1, with suction pumps located to the west of the tanks. The property was subsequently utilized for camper sales between 1968 and 1974, followed by a lease to DBA By-Rite Distributing for retail gasoline sales until 1984. The site was upgraded in 1974 by By-Rite Distributing with a fifth UST (6,000 gallons) installed in the "Excavation 1" area and two additional USTs (8,000 and 10,000 gallons) placed in the area labeled "Excavation 2" in Figure 7-1. These last three tanks were equipped with pressurized dispenser systems. The tanks were reportedly emptied in 1984, and the property was subsequently utilized for the recreational vehicle sales and service facility that occupied the site during the study.

The site is located within the Weber Delta Hydrologic District near the south central portion of Section 28, Township 4 North, Range 1 West. The area surrounding the site is characterized as mixed residential and agricultural. Only one active water right was encountered within this area, a shallow (10-ft completion depth) well used for irrigation purposes. This well is located to the northeast, upgradient from the site. The water right search was subsequently expanded to a radius of one mile (Wasatch Geotechnical, 1991).

Several wells were located within this larger area; none, however, were used as municipal water supply wells.

#### Geologic Setting

Ground-water in the Weber Delta Hydrologic District occurs in a shallow, unconfined aquifer as well as under artesian conditions in a multi-aquifer reservoir (Wasatch Geotechnical, 1991). Most of the production wells in the Weber Delta district are completed in the two major artesian aquifers: the Sunset Aquifer lying between 250 and 400 ft, and the more productive Delta Aquifer lying between 500 and 700 ft below land surface. Between the shallow ground-water and deeper artesian aquifers lies a thick confining layer of clay and mud. Recharge to the artesian aquifers is mostly from precipitation along the Wasatch Range front, with ground-water moving generally westward toward the Great Salt Lake.

Soils encountered at the site are primarily sands in the southern portion of the site and silts and clays in the northern half of the site. Ground-water is encountered at approximately 8 to 10 ft below grade at the site. The direction of shallow ground-water flow is predominantly southwest (Wasatch Geotechnical, 1991), although a westerly and northwesterly flow were observed at the site during the study. There are no streams or other occurrences of surface water within 1,000 ft of the site.

No regional hydraulic conductivity data were reported in original site reports; however, hydraulic conductivity values of the shallow soils at the Layton site, determined by slug tests performed during this study, indicate conductivity values ranging from 0.78 to 3.1 ft/d, with an average of 1.5 ft/day.

#### Previous Site Activities

A soil-gas survey was performed between November 2 and 6, 1990, at a depth of approximately 4 ft below ground surface. The organic vapor content of soil-gas samples was measured with a portable organic vapor monitor (OVM) equipped with a photoionization detector

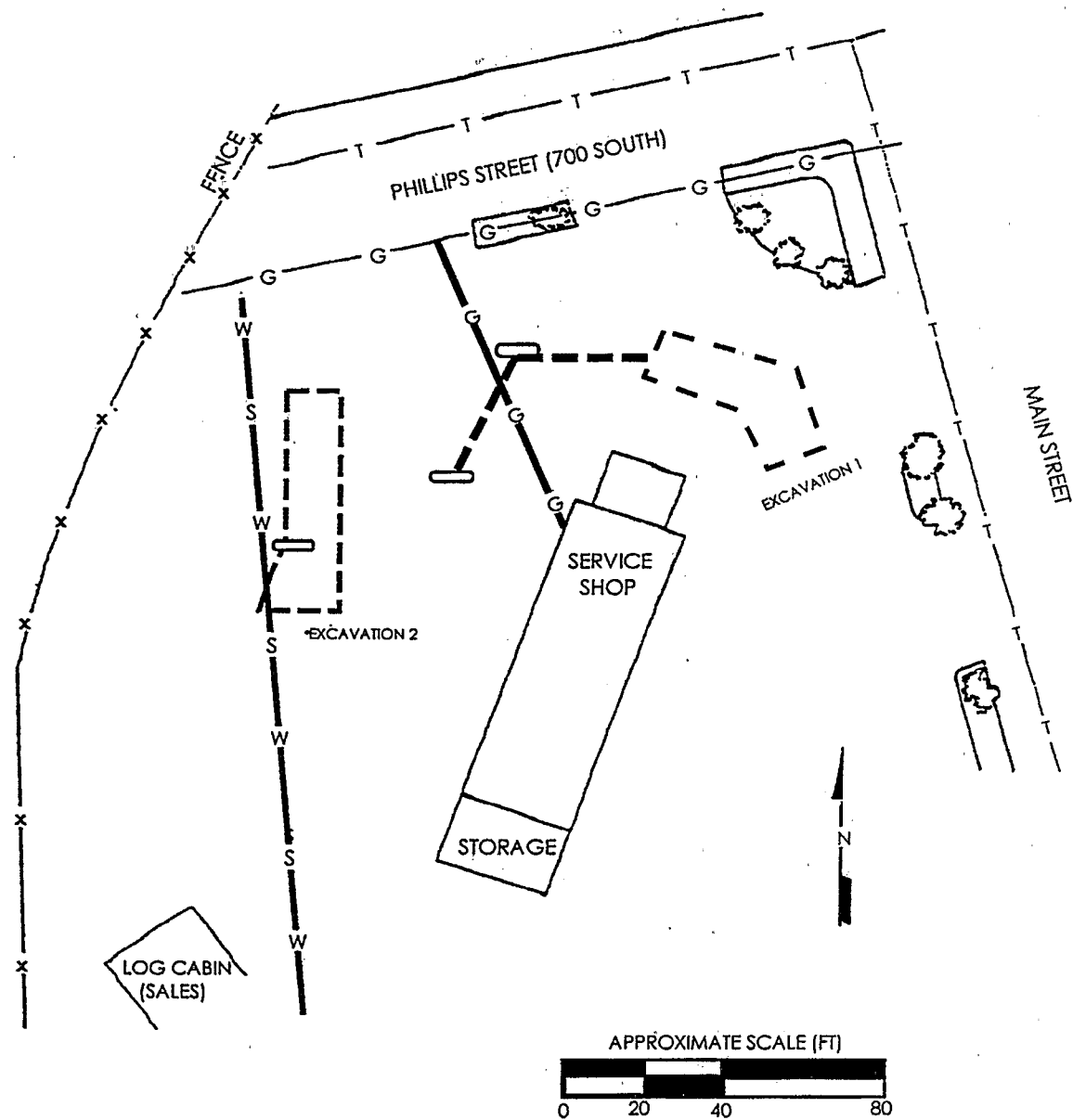


Figure 7-1. Map for Blaine Jensen RV, Layton, UT, site (Wasatch Geotechnical, 1991).

(PID). The portable instrument was calibrated to a 100 part per million by volume (ppmv) isobutylene standard, with a reporting range of 0.1 to 2,000 ppmv.

A total of 36 locations were surveyed for volatile organic vapors with detected concentrations up to 1,975 ppmv. The projected plume footprint based on measured vapor concentrations was constructed by Wasatch Geotechnical (1991) as indicated in Figure 7-2. Elevated vapor concentrations covered much of the north and west portions of the property. The highest vapor concentrations (from 250 to 1,975 ppmv) were found in the two tank excavations and in the dispenser island area between the former tanks. An outer area of lower vapor concentrations (from 0 to 250 ppmv) extended to the west and southwest. Overall, results of the survey defined an area of elevated vapor concentrations of approximately 18,400 ft<sup>2</sup> in horizontal extent. This area of vapor contamination appeared elongated in the direction of shallow ground-water flow (Wasatch Geotechnical, 1991).

The vertical and horizontal extent of petroleum hydrocarbon migration was investigated by Wasatch Geotechnical with six exploratory soil borings. Boring locations were selected based upon the results of the soil-gas survey. Four of the borings were drilled on January 7, 1991, with a CME 55 truck-mounted drill rig utilizing a hollow-stem auger. The other two borings (B5 and B6 in Figure 7-2) were drilled with a hand auger.

Soils encountered in the borings consisted of mostly sands, with discontinued layers of silt and clay. Product odor was noted in several of the samples. Results of OVM screening of boring soil samples qualitatively agreed with results of the soil-gas survey. The highest readings (620 ppmv) were recorded in samples from B2, between the excavations and below the north dispenser island, while the lowest OVM readings were from B4, at the mapped edge of soil-vapor contamination. Vapor concentrations were observed to be highest immediately above the water table.

Three ground-water monitoring wells were installed to evaluate shallow ground-water quality and flow direction at the site. Two wells were installed into the UST excavations at locations B1 and B3, while a third well was installed in location B4. The wells were constructed of 4-in diameter, schedule 40 PVC pipe, and screened across the water table from 7 to 17 ft below ground surface. The wells were developed (pumped) until the discharge was clear to remove sand and silt that had accumulated in them. Prior to ground-water sampling with disposable PVC bailers, a minimum of three well volumes were pumped from each of the wells to ensure that a sample representative of water quality within the formation was actually collected.

The wells were surveyed to allow the determination of water depths and the direction of surface flow. Results of well completion and ground-water level data are presented in Table 7-1 and indicate that the water table was approximately 8 to 10 ft below grade in January 1991. The ground-water flow was toward the southwest at that time.

### ***UWRL Site Activities***

As indicated in Chapter 5, site investigation protocols utilizing CPT soil textural data collection and small diameter ground-water piezometer sample placement for detailed plume delineation were evaluated in July and August 1992 at the Layton site. CPT data were collected at 27 locations throughout the Layton site (Figure 7-3) to augment the existing monitoring network consisting of three conventional ground-water monitoring wells.

This detailed site investigation effort provided soil textural features existing from the surface to a depth of 22 ft. Figure 7-3 shows these CPT data collected at the ground-water table. CPT data generally confirmed the site subsurface characterization data originally developed from soil boring information. This CPT information did, however, suggest a finer grained material than was indicated from soil boring data and identified a clay to silty clay lens 2 to 6 ft thick covering most of the Layton site 12 to 14 ft below ground surface (Figure 7-4).

The rapid screening-level site investigation data collected in this study from the Layton site generally confirmed the site conceptual model shown in Figure 7-2. There were times during the study, however, when the downgradient well, MW4, was actually upgradient of the site based on localized ground-water flow conditions. During this field study, the ground-water flow was generally more westerly than southwesterly as had been originally suggested from previous site investigation activities.

A total of seven sampling events were part of this study at the Layton site to describe the distribution and movement of contaminants and electron acceptors taking place at the site between April 1992 and January 1994. These sampling events included: April 1992 limited sample collection prior to installation of the piezometer network; July 1992 immediately following installation of the piezometer sampling network; December 1992; March 1993; June 1993; September 1993; and January 1994. In addition, BTEX, naphthalene, and TPH ground-water concentration data were collected from the Layton site in February 1995 as part of a separate EPA-sponsored field evaluation of in-situ air sparging and in-well aeration technology. These 1995 data were made available to this project to allow an

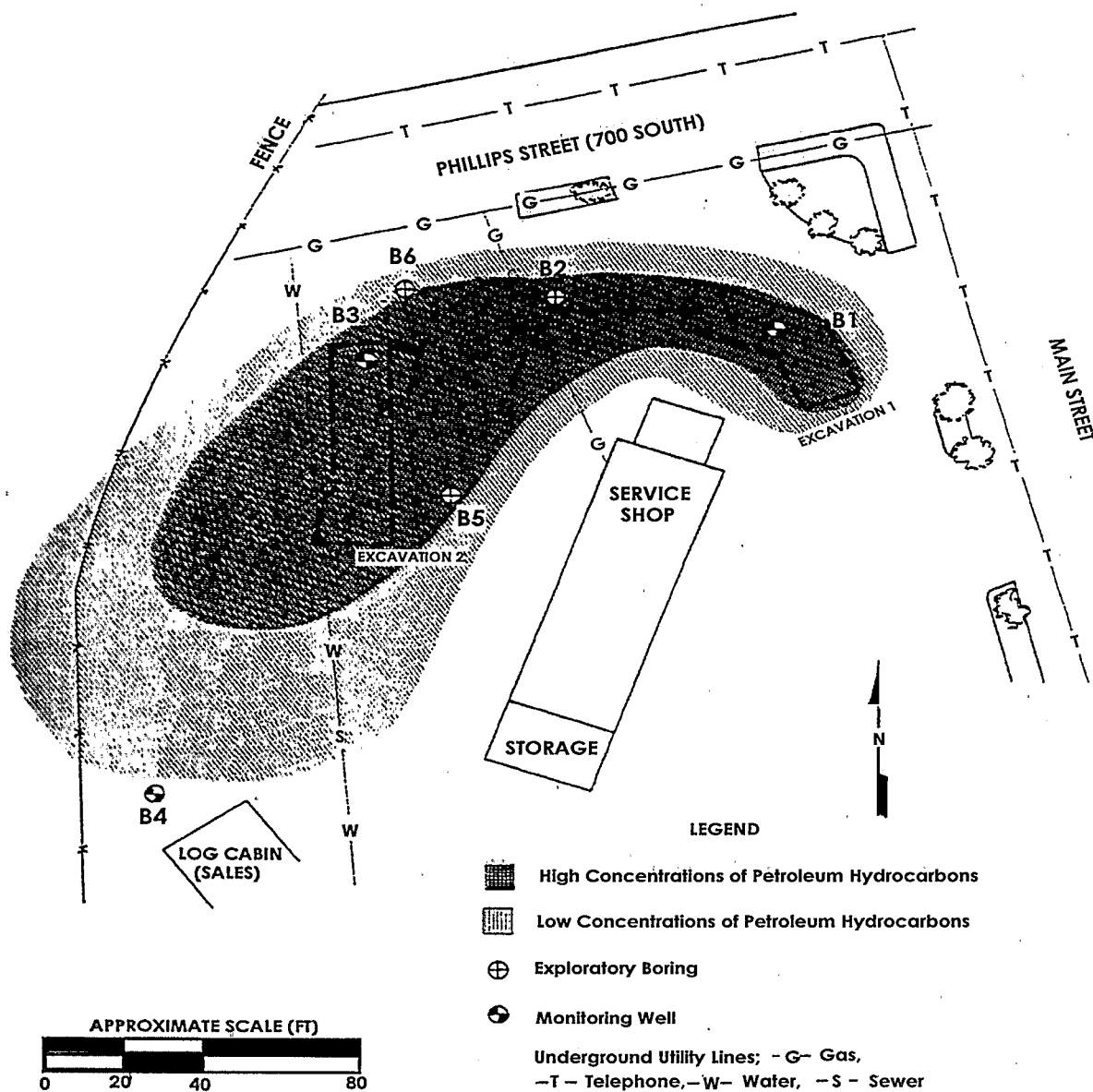
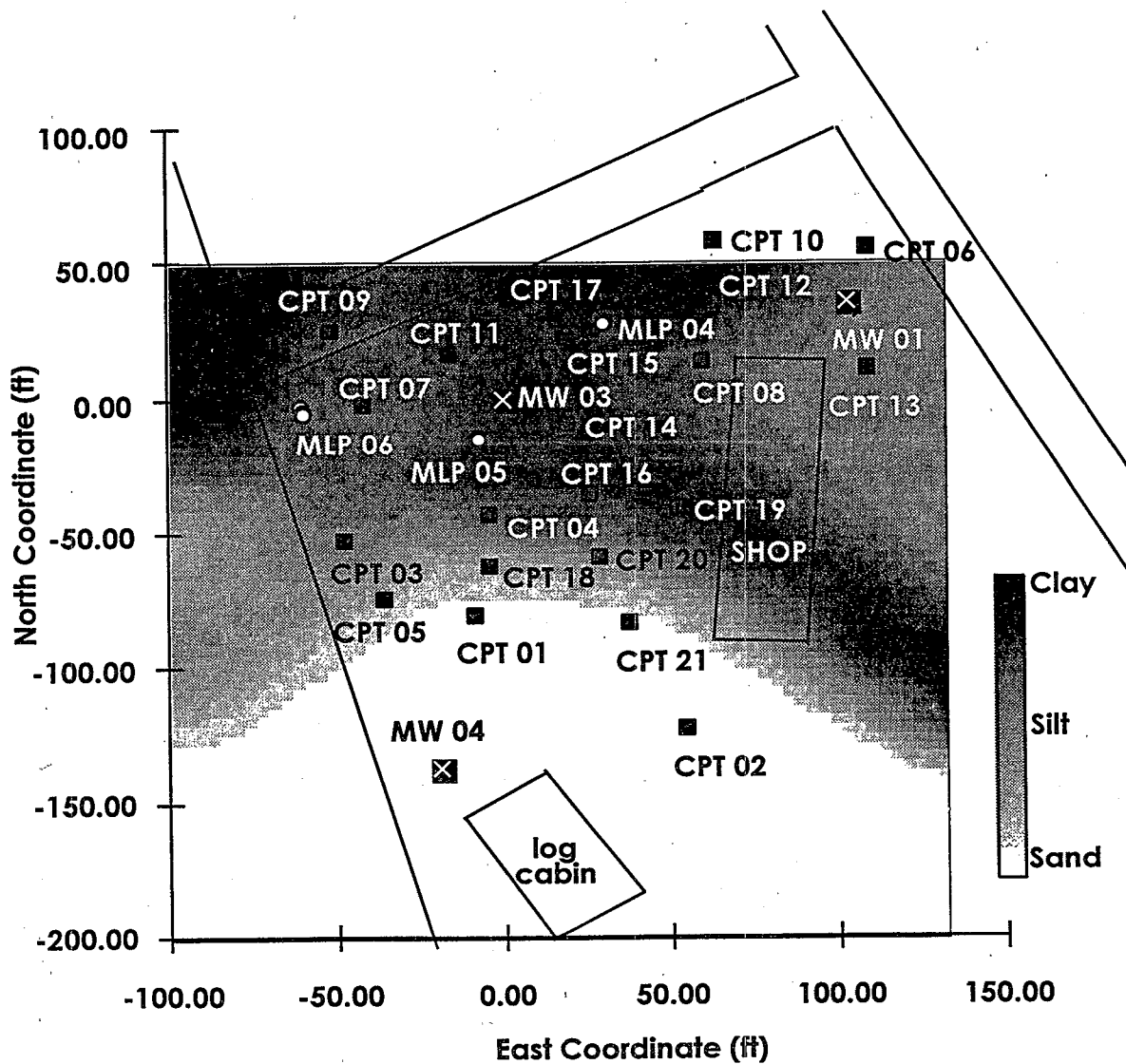


Figure 7-2. Conceptual site map for Blaine Jensen RV, Layton, UT. Soil and ground-water contamination based on field and laboratory soil, soil-gas, and ground-water data available 1990 to 1991 (Wasatch Geotechnical, 1991).

**Table 7-1. Summary of Well Completions and Measured Water Levels at the Layton, UT, Field Site\***

Well No.	Depth (ft)	Screened Interval (ft)	Elevation (TOC in ft)	Water Elevation (ft) January 11, 1989	Water Elevation (ft) January 25, 1991
B1	17	7 to 17	101.53	91.38	91.71
B3	17	7 to 17	100.00	91.08	91.58
B4	17	7 to 17	99.12	90.40	91.29

\*All elevations are relative to an assigned datum of 100.00 ft at the top of casing (TOC) elevation for Well B3.



**Figure 7-3. Soil textural profile observed at the ground-water table from CPT data collected at the Layton, UT, site in July 1992.**

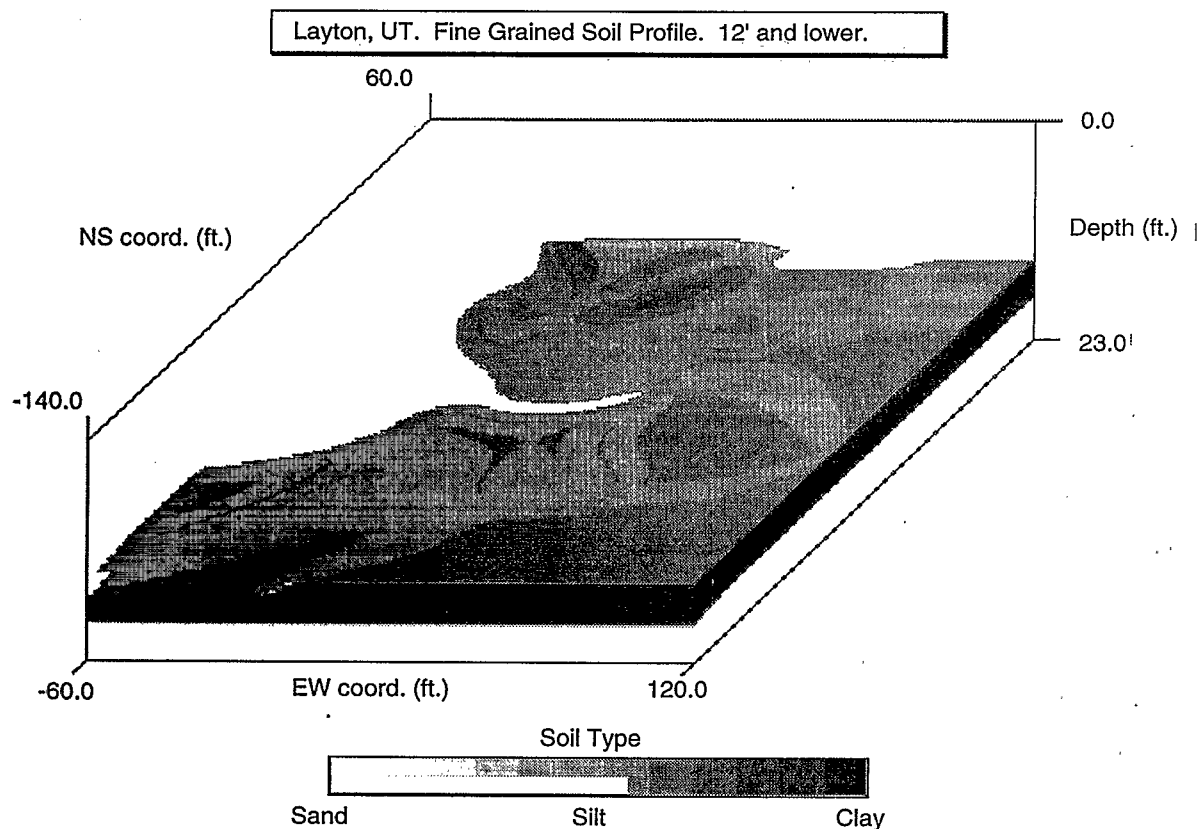


Figure 7-4. Fine-grained soil profile observed at the Layton, UT, site at the 12 to 16 ft depth from CPT data collected in July 1992.

update of plume information for the Layton site and have been incorporated in the data reduction and summary information included in this report.

Ground-water hydrocarbon composition data for the 1992 through 1994 sampling events are summarized in Appendix I, while all nutrient, iron, and manganese data collected at the Layton site are summarized in Appendix L. These data were used to determine steady-state plume conditions and to estimate total mass and mass center values for these various analytes at the Layton site over time as prescribed by the intrinsic remediation assessment protocol described in Chapter 4.

## Determination of Steady-State Plume Conditions

### *Contaminant Centerline Concentrations*

Once the plume centerline position was verified during site assessment activities in July 1992, a westerly centerline transect was used to make a determination

regarding steady-state plume conditions at the Layton site over time. This centerline transect was composed of data collected from the following single and multi-level ground-water piezometers (see Figure 7-3 for their specific locations throughout the site): CPT-19, CPT-20, and CPT-16 in the source area, and downgradient locations within the dissolved plume at CPT-04, MLP-05, CPT-07, and MLP-06.

The traditional compounds of concern from a health and fate-and-transport perspective include BTEX and naphthalene. These compounds were used along with TPH to generate centerline concentration profiles for each sampling event to evaluate plume steady-state conditions at the site. Appendix I contains summarized BTEX, naphthalene, and TPH data for each sampling event conducted in this study from July 1992 to January 1994, along with the data from February 1995. Figures 7-5 and 7-6 show plume centerline concentration data for combined BTEX and TPH concentrations at the Layton site from July 1992 to February 1995, respectively.



It appears from these figures that pseudo-steady-state centerline concentrations for both BTEX components and TPH occurred in the dissolved plume below the Layton site. Both BTEX and TPH concentrations increased and decreased along the plume centerline transect shown in Figures 7-5 and 7-6. No consistent pattern in transect concentrations downgradient of the source over time was evident, again suggesting that this criteria for steady-state was satisfied at the Layton site.

### **Dissolved Contaminant Plume Mass and Center of Mass Calculations**

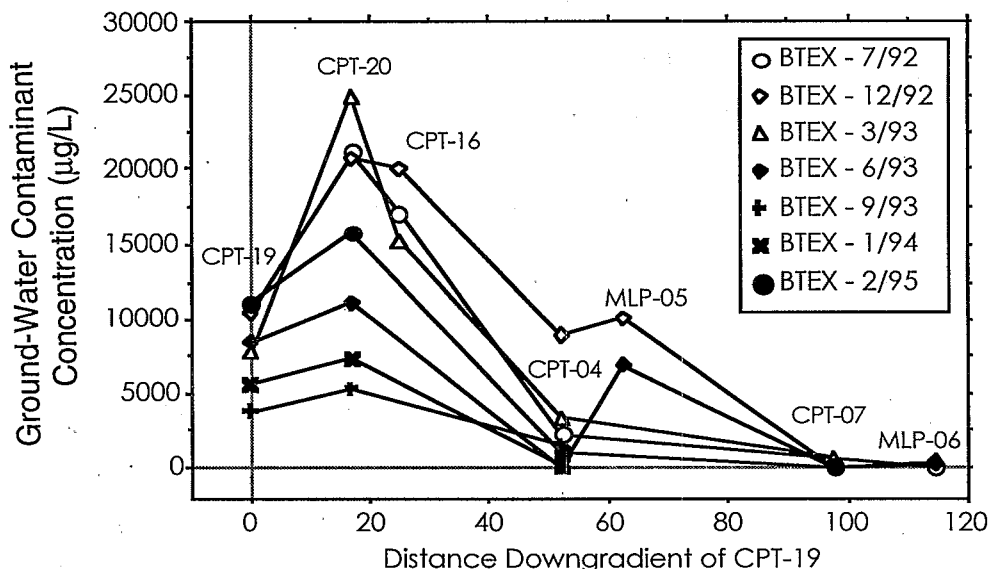
As indicated in Chapter 4, Thiessen areas were generated for each sampling event using a fixed outer plume boundary and individual areas were determined based on the actual sampling locations used in a given sampling event. This outer plume boundary for the Layton site is shown in Figure 7-7 along with Thiessen areas based on the July 1993 sampling event. A summary of specific Thiessen area calculations for each sampling event is provided in Appendix C.

Based on the Thiessen areas associated with each sampling point used for plume monitoring at each sampling time, estimates of the total dissolved plume mass and center of mass of BTEX, naphthalene, and TPH were made following the procedures described in Chapter 4. The results of the total mass and center of mass calculations are provided in detail in Appendix J.

Summary data are provided in Table 7-2. April 1992 data were not included in these calculations as this sampling period occurred before the installation of the piezometer network, and data resulted from only four existing large-diameter monitoring wells.

Upon inspection of Table 7-2, it becomes apparent that long-term monitoring of intrinsic bioremediation sites should be carried out due to the variability in dissolved mass that can occur from natural ground-water table fluctuations. Despite the decline in dissolved contaminant mass that was observed at the Layton site from July 1992 to September 1993, further sampling in January 1994 and particularly in February 1995 indicated that the mass of the specific contaminants of interest, as well as TPH, have remained essentially constant over the 2.5-year project period. The contaminant mass data in Table 7-2 are graphically represented in Figures 7-8 and 7-9, which again clearly show that despite the decline in contaminant mass after March 1993, significant dissolved mass persists within the plume below the Layton site.

Figures 7-10 to 7-15 show the position of the center of mass for each analyte over time at the Layton site and provide additional information regarding steady-state conditions within the plume over time. As indicated in all of these figures, the mobility of the center of mass of all of the specific contaminants of interest and



**Figure 7-5. Combined BTEX plume centerline concentration data collected at the Layton, UT, site from July 1992 to February 1995.**

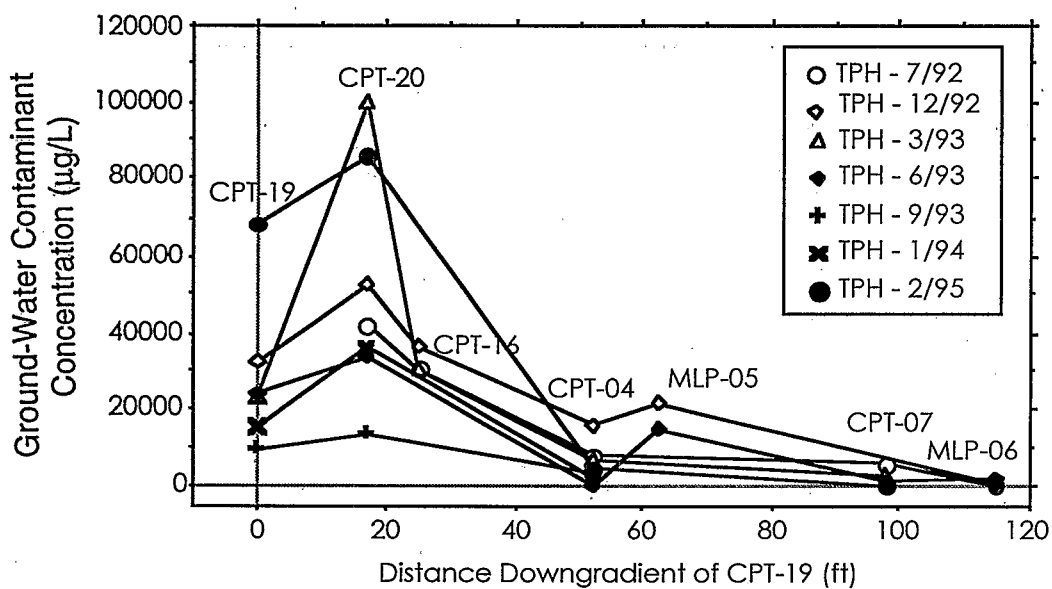


Figure 7-6. TPH plume centerline concentration data collected at the Layton, UT, site from July 1992 to February 1995.

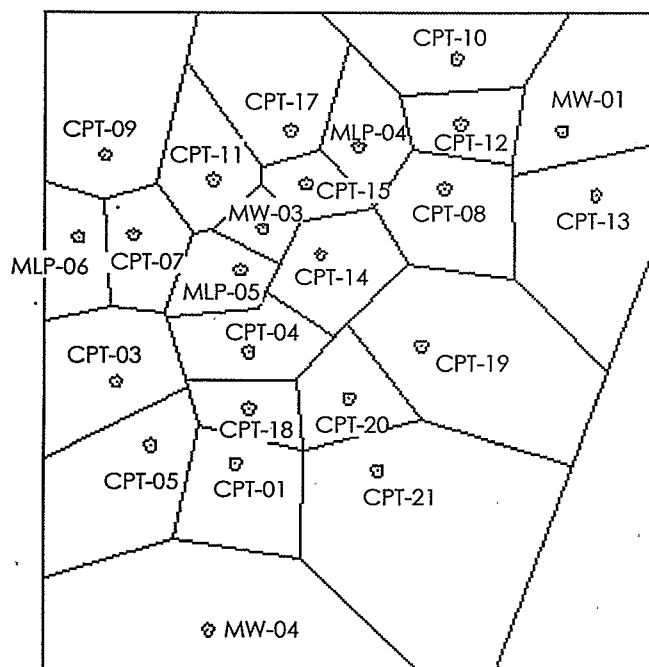
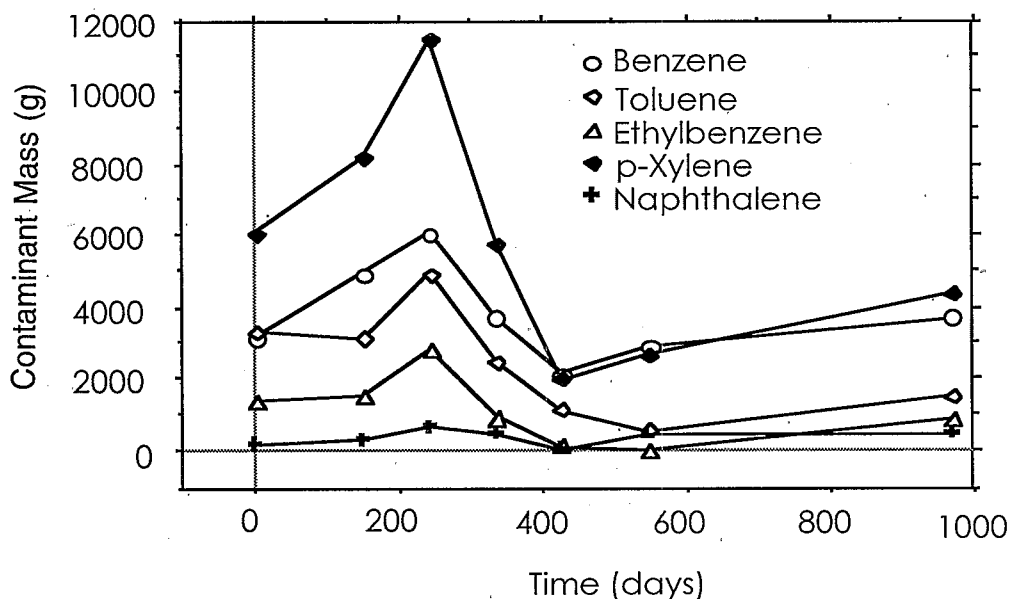


Figure 7-7. Outer plume boundary used for Layton site plume total mass and mass center calculations. Thiessen areas for the July 1993 sampling event are shown.

**Table 7-2. Summary Total Mass and Center of Mass Coordinate Data for BTEX, Naphthalene, and TPH Estimated from Data Collected at the Layton Site from July 1992 to February 1995**

Parameter	7/92	12/92	3/93	6/93	9/93	1/94	2/95
Benzene Mass (g)	3,139.9	4,926.2	6,057.5	3,689.0	2,147.8	2,864.3	3,695.5
Toluene Mass (g)	3,309.0	3,120.7	4,922.6	2,461.0	1,130.8	550.7	1,556.4
Ethylbenzene Mass (g)	1,372.3	1,527.6	2,822.1	956.9	141.2	9.3	867.8
p-Xylene Mass (g)	6,093.3	8,169.9	11,457.0	5,732.3	1,986.3	2,648.3	4,371.1
Naphthalene Mass (g)	191.6	296.3	650.0	500.1	61.3	454.8	531.8
TPH Mass (g)	34,849.3	48,766.7	86,469.1	34,165.6	13,792.2	18,689.0	78,194.1
Benzene-x (ft)	54.9	45.5	62.3	70.3	54.8	65.0	66.5
Benzene-y (ft)	-17.6	-11.4	-7.1	-4.8	-15.3	-12.2	-17.2
Toluene-x (ft)	71.9	53.2	70.5	89.6	69.8	68.1	78.3
Toluene-y (ft)	-8.1	-10.0	-3.2	5.9	-5.9	-13.9	-5.3
Ethylbenzene-x (ft)	54.3	47.3	47.1	72.6	48.7	-10.7	50.5
Ethylbenzene-y (ft)	-8.0	-4.6	-6.1	-6.8	-33.8	4.0	-27.7
p-Xylene-x (ft)	59.1	51.3	60.9	71.9	72.2	69.8	62.5
p-Xylene-y (ft)	-9.1	-10.9	-3.6	-4.3	-0.3	-9.9	-17.4
Naphthalene-x (ft)	31.4	44.0	45.2	66.9	55.4	66.0	42.9
Naphthalene-y (ft)	-19.3	-15.5	-13.2	-2.9	0.6	-5.7	-12.1
TPH-x (ft)	55.4	53.2	69.4	70.0	66.3	64.6	46.0
TPH-y (ft)	-3.0	-7.4	-3.3	-4.3	-7.0	-14.1	-6.2



**Figure 7-8. Time course of total dissolved plume mass estimates for BTEX and naphthalene contaminants at the Layton site during the study.**

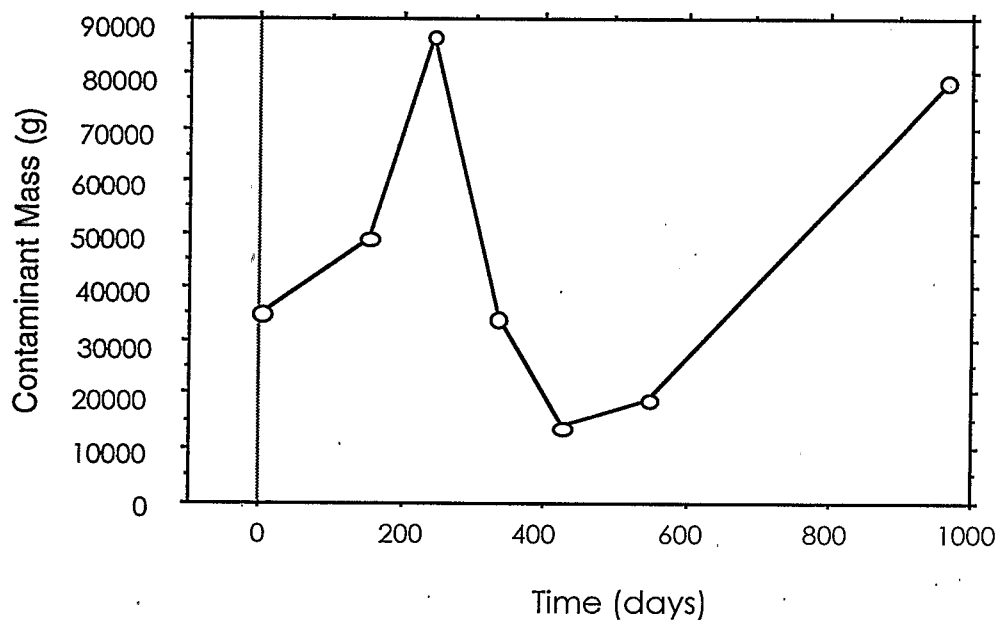


Figure 7-9. Time course of total dissolved plume mass estimates for TPH at the Layton site during the study.

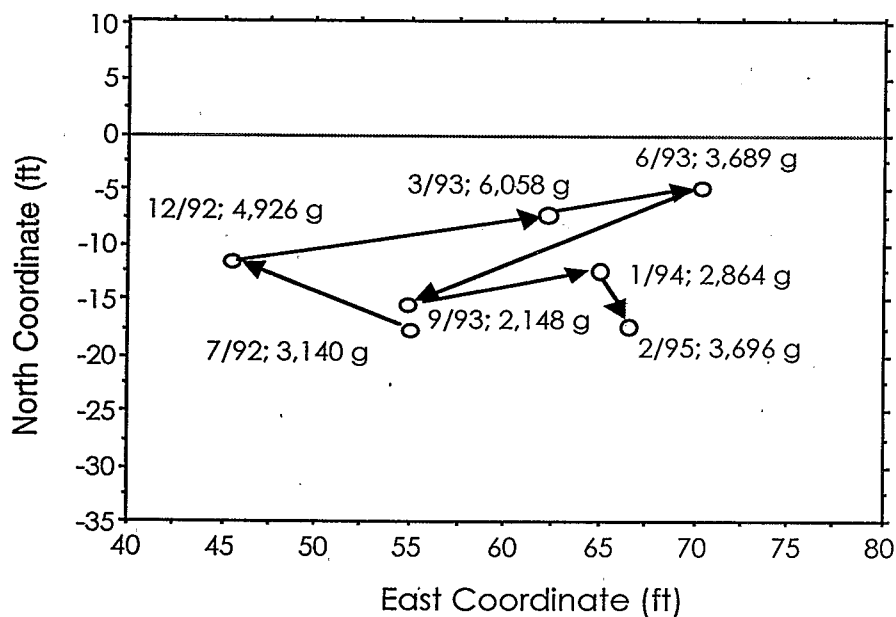


Figure 7-10. Center of mass positions for benzene at the Layton site during the study.

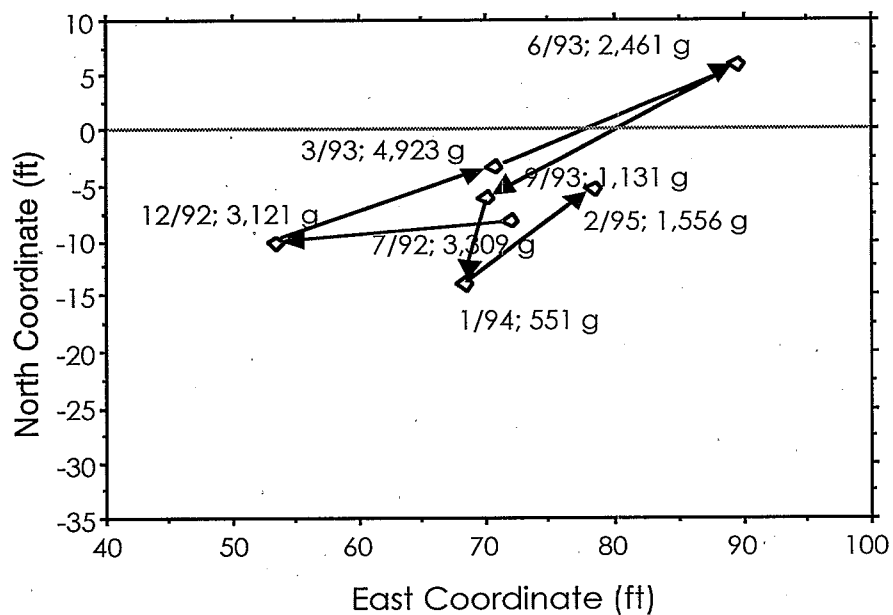


Figure 7-11. Center of mass positions for toluene at the Layton site during the study.

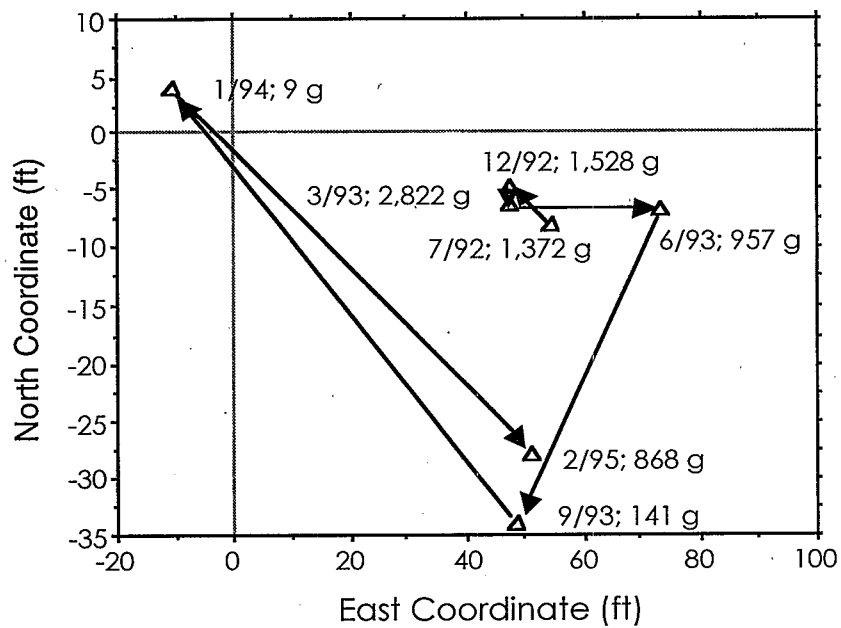


Figure 7-12. Center of mass positions for ethylbenzene at the Layton site during the study.

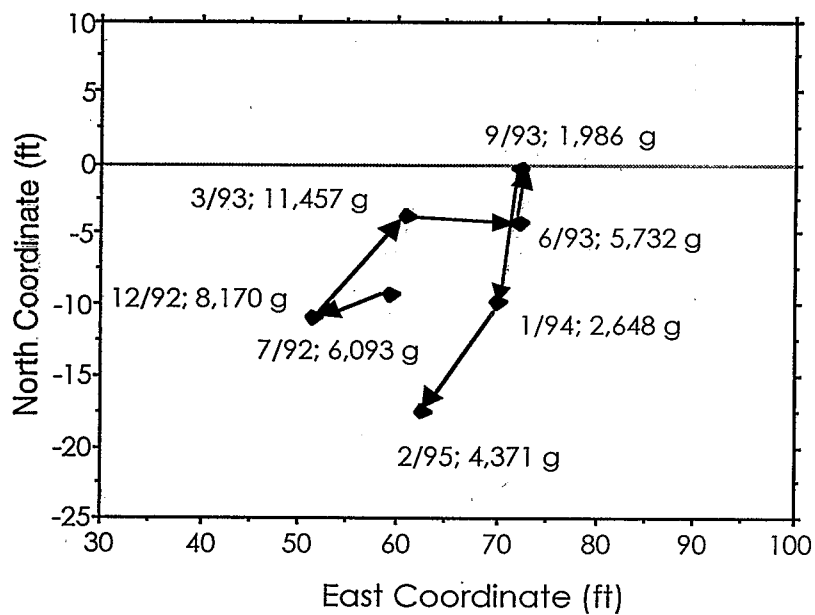


Figure 7-13. Center of mass positions for p-xylene at the Layton site during the study.

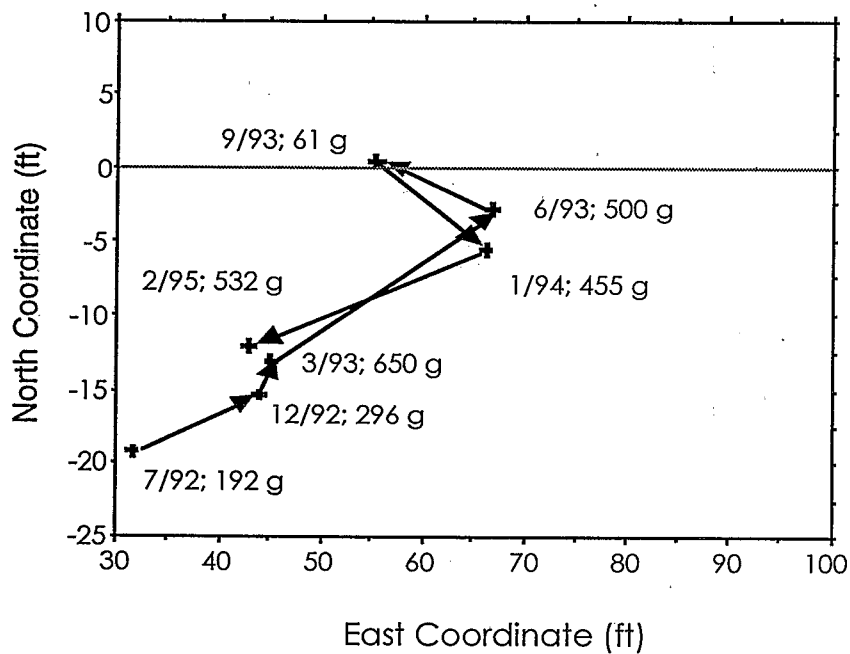


Figure 7-14. Center of mass positions for naphthalene at the Layton site during the study.

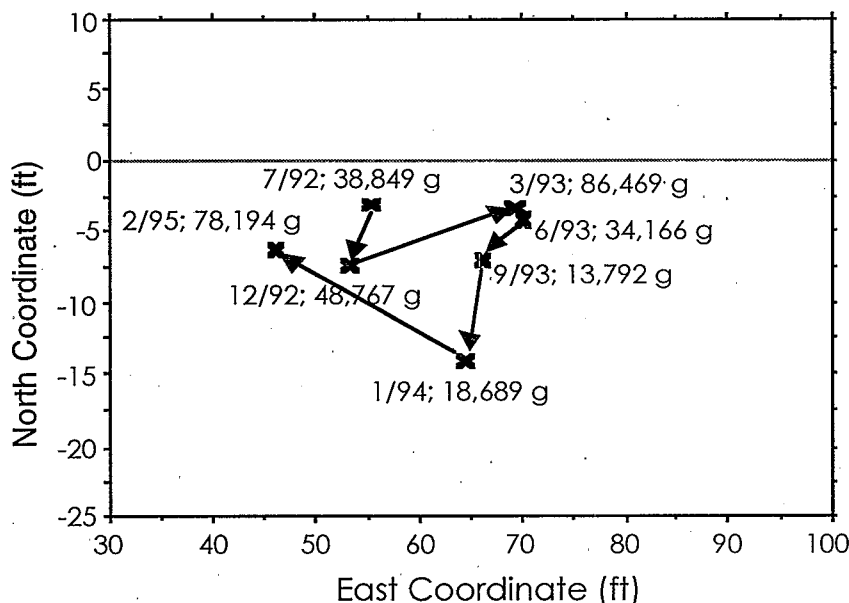


Figure 7-15. Center of mass positions for TPH at the Layton site during the study.

TPH was limited. Only TPH showed any actual downgradient movement of its center of mass, with only 10 ft movement over the two and one-half year field study (Table 7-3). Based on the interpretation of the changes observed in the center of mass and total mass values at the Layton site over time from Table 4-5, these pseudo-steady-state contaminant mass levels and limited center of mass movement downgradient suggest that a continuous source exists at the Layton site which reflects a plume stabilized by continuing intrinsic attenuation mechanisms.

### Estimation of Contaminant Degradation Rate

The estimation of contaminant degradation rates, with a steady-state mass within the plume, is carried out, according to the protocol developed in this study, either through the calibration of the fate-and-transport model described in Chapter 4 to field data collected from the site or from an analysis of plume centerline concentration data. Both of these contaminant degradation rate estimation procedures are highlighted below as applied to the Layton site.

### Plume Centerline Concentration Data

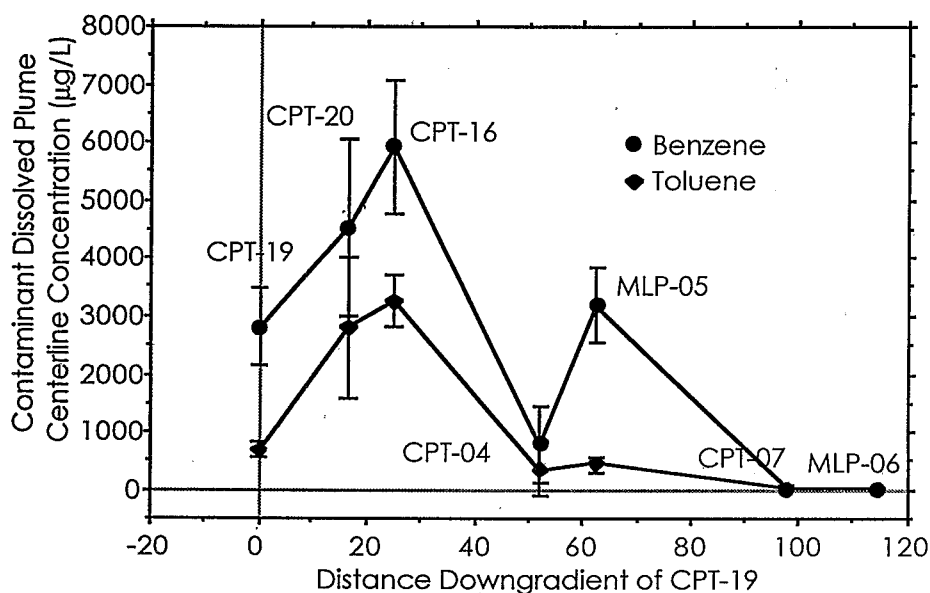
As indicated above, inspection of the centerline ground-water concentrations and dissolved plume mass changes over time indicated that over the life of the project the plume at the Layton site had reached apparent steady-state conditions. The BTEX and TPH concentration profiles shown in Figures 7-5 and 7-6,

respectively, and the naphthalene data for this plume centerline transect from CPT-20 to MLP-06 were averaged to generate a steady-state, time-averaged concentration profile that was used in further degradation rate estimations. These time-averaged center line concentration plots are shown in Figures 7-16 through 7-20, for individual BTEX components: naphthalene, combined BTEX components, and TPH, respectively, with 95-percent confidence intervals for the mean at each sampling location indicated on each figure. With these averaged data, first order degradation rates were estimated using the procedures described in Chapter 4. An example of the natural log transformed concentration data used to estimate a degradation rate for each compound of interest is shown for p-xylene in Figure 7-21, while the resultant estimated first order degradation rates are summarized in Table 7-4. Travel distance was converted to contaminant travel time using the retarded ground-water velocity for each compound (pore water velocity/contaminant retardation factors).

The data in Table 7-4 indicate that first order regression results for all specific compounds observed at the Layton site were statistically significant at the 95-percent confidence level ( $p$  value of regressions all  $< 0.05$ ). These first order degradation rates ranged from 0.00014 to 0.00087/d, with the highest molecular weight, lowest solubility compound, (naphthalene), having the slowest degradation rate. Benzene was found to be the most degradable of the compounds investigated at the Layton site.

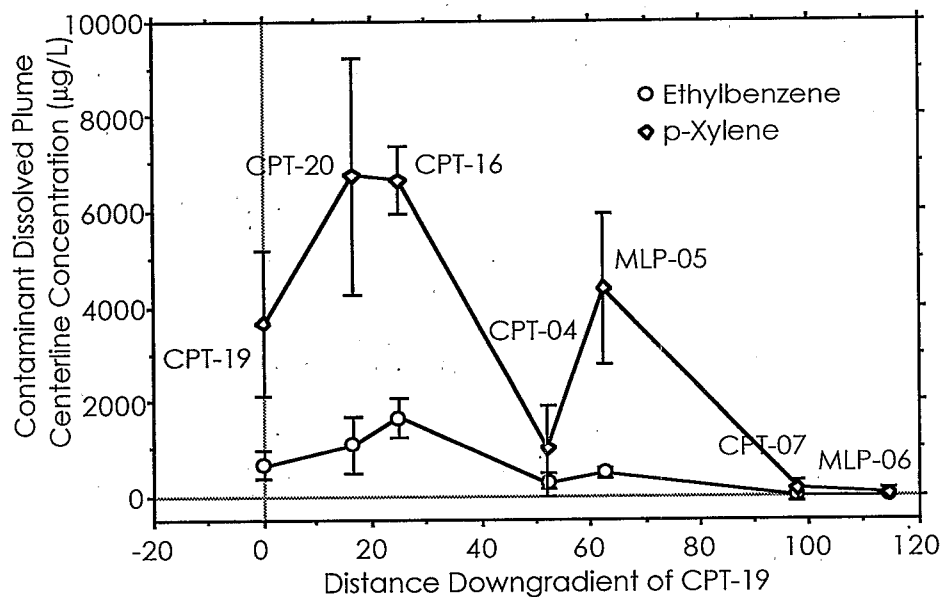
**Table 7-3. Contaminant Center of Mass Velocities Based on Ground-Water Data Collected at the Layton Site from July 1992 to February 1995.**

	Benzene	Toluene	Ethyl- benzene	p-Xylene	Naph- thalene	TPH
Distance Traveled (ft) =	11.64	6.94	20.08	8.97	13.54	9.93
Direction Traveled =	East	North East	South	South East	North East	South West
Contaminant Velocity (ft/d)=	0.01	0.01	0.02	0.01	0.01	0.01
Contaminant Velocity (ft/yr)=	4.39	2.62	7.57	3.38	5.11	3.75

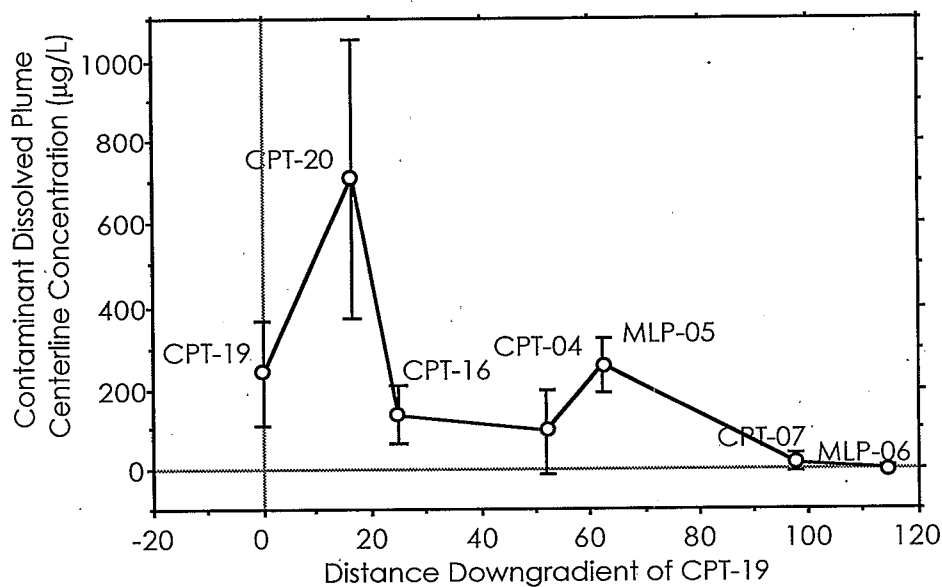


**Figure 7-16. Time-averaged dissolved plume centerline concentrations for benzene and toluene measured at the Layton site during the study.**





**Figure 7-17. Time-averaged dissolved plume centerline concentrations for ethylbenzene and p-xylene measured at the Layton site during the study.**



**Figure 7-18. Time-averaged dissolved plume centerline concentrations for naphthalene measured at the Layton site during the study.**

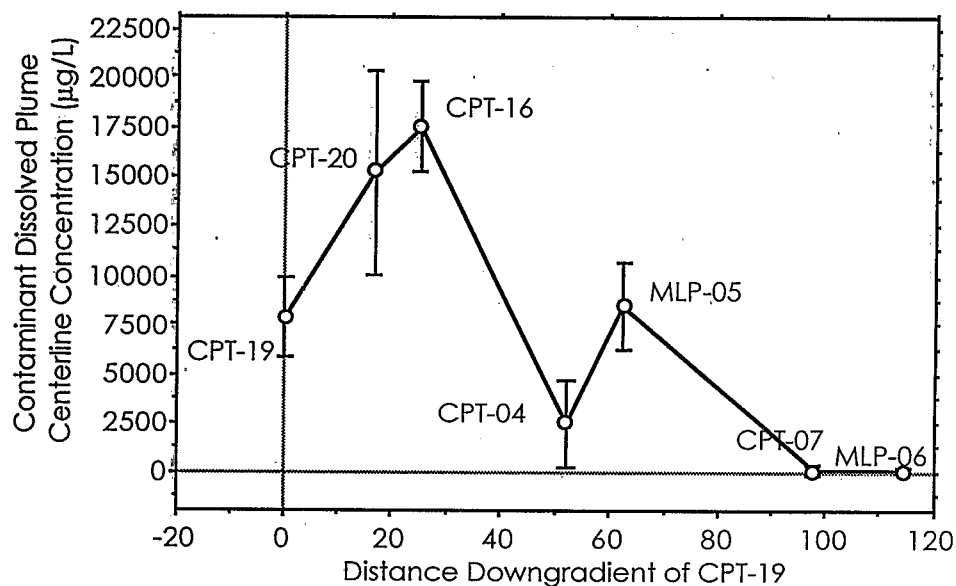


Figure 7-19. Time-averaged dissolved plume centerline concentrations for combined BTEX components measured at the Layton site during the study.

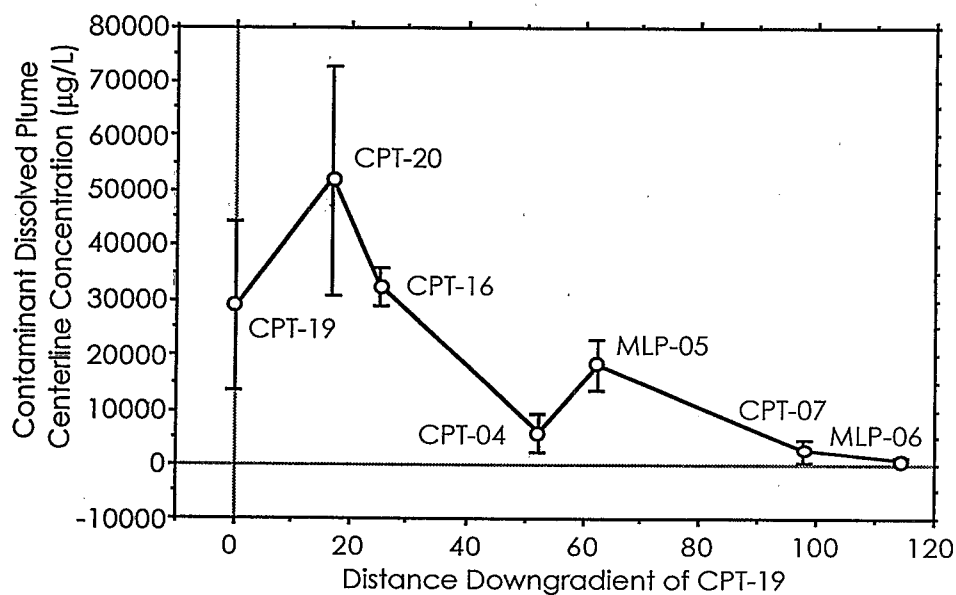
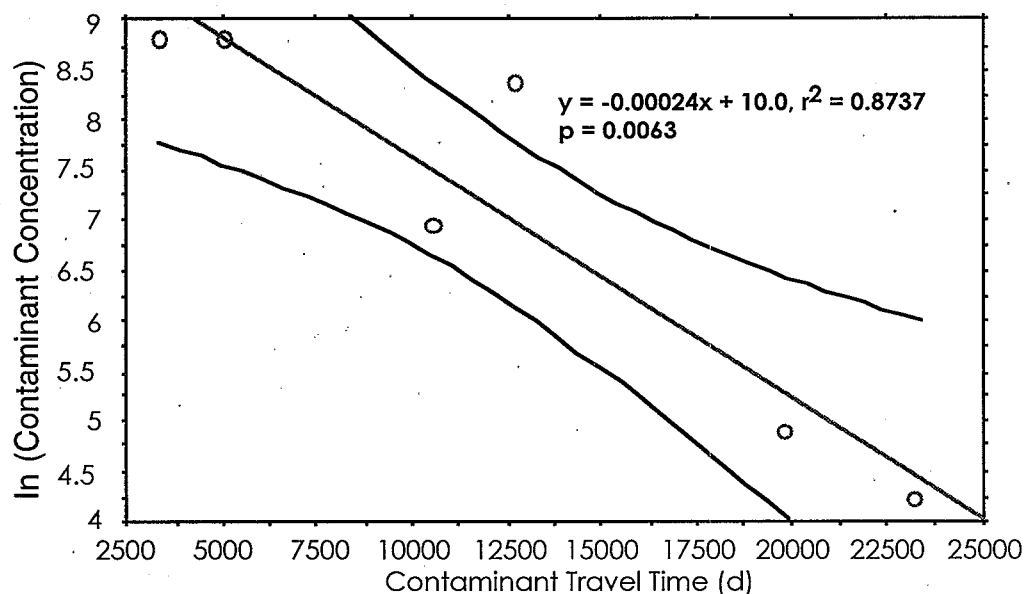


Figure 7-20. Time-averaged dissolved plume centerline concentrations for TPH measured at the Layton site during the study.



**Figure 7-21. Natural log transformed, time-averaged p-xylene plume-centerline concentrations versus contaminant travel time from the source area (measured at the Layton site during the study).**

**Table 7-4. Summary of Contaminant Degradation Rates Estimated from Time-Averaged Centerline Concentrations Measured at the Layton Site from July 1992 to February 1995 Corrected for Contaminant Retarded Velocity**

Compound	First Order Rate (1/d)	95% Percent Confidence Interval (1/d)	R <sup>2</sup>	p Value
Benzene	0.00087	0.00057	0.8204	0.0129
Toluene	0.00044	0.00010	0.9742	0.0003
Ethylbenzene	0.00026	0.00010	0.9263	0.0021
p-Xylene	0.00024	0.00013	0.8737	0.0063
Naphthalene	0.00014	0.00008	0.8243	0.0123

These degradation rates do not explicitly account for reductions in concentration due to dispersion and dilution (i.e., non-degradative) processes taking place within the Layton aquifer. The more preferred approach to estimate contaminant degradation, taking into account dilution/dispersion processes, involves the use of a ground-water fate-and-transport model that is calibrated to field-generated data.

### Ground-Water Model Calibration

As indicated in Chapter 4, an analytical solution for the advection-dispersion equation, with degradation, can be applied with site-specific physical/chemical input parameters to model the fate-and-transport of contaminants under actual field conditions so that "dilution-corrected" degradation rates for these compounds can be estimated. The modeling effort also allows the evaluation of long-term plume behavior based on the consideration of various source area management scenarios that may be applicable to a given site. The analytical solution for this transport with degradation problem was given in Equation 4-29 for a continuous source with one-dimensional ground-water flow, i.e., no vertical flow occurs within the flow field. Based on these assumptions, the following approach was used at the Layton site to generate a calibrated model for contaminant degradation estimates and long-term plume behavior analysis.

### Hydraulic and Chemical Model Input Parameters

Hydraulic and chemical properties affecting the transport of contaminants within the subsurface, and which are incorporated into the multidimensional transport model used in this study, include aquifer pore-water velocity

and dispersivity, and contaminant retardation. Site-specific values used for modeling plume transport and decay at the Layton site are summarized below.

Aquifer pore-water velocities were calculated based on measured values of hydraulic gradient and hydraulic conductivity and estimated values of total aquifer porosity using Darcy's Law. Hydraulic conductivity was estimated at 1.5 ft/day for the Layton site based on results of slug tests conducted in April 1992. Total aquifer porosity was assumed to be 0.38 at the Layton site. The hydraulic gradients, ground-water flow direction, and estimated pore-water velocities observed at the Layton site during the study are summarized in Table 7-5. The average hydraulic gradient observed during the study, 0.01 ft/ft, was used with the input data presented above to yield an average pore water velocity of approximately 0.037 ft/day at the Layton site during the study. As indicated in Chapter 4, details of the slug tests conducted at the Layton site can be found in Appendix D.

Contaminant retardation factors used in the modeling effort were estimated from Equation 4-31 with compound-specific values for the organic carbon normalized soil/water partition coefficient ( $K_{oc}$ ), and the soil organic carbon content, bulk density, and porosity values (assumed for the Layton aquifer) of 0.3%, 1.15 g/cm<sup>3</sup>, and 0.38, respectively.

Using the input data listed above, calculations of  $K_d$  and  $R$  for benzene, toluene, ethylbenzene, p-xylene, and naphthalene are summarized for the Layton site in Table 7-6. These data were used as input for the fate-and-transport modeling described below.

**Table 7-5. Summary of Ground-Water Head Gradient, Ground-Water Flow Direction, and Pore Water Velocity Results for the Layton Site Collected During This Study**

Sampling Date	Ground-Water Head Gradient (ft/ft)	Flow Direction	Estimated Pore Water Velocity (ft/d)
8/25/92	0.009	South Southwest	0.035
12/28/92	0.008	West	0.031
3/18/93	0.009	Northwest	0.035
6/10/93	0.014	Southwest	0.054
9/23/93	0.010	South Southwest	0.037
1/8/94	0.008	South Southwest	0.031
Average Values	0.010		0.037

**Table 7-6. Input Data and Estimated Sorption Coefficients/Retardation Factors Used for Model Input at the Layton Field Site.**

Compound	$K_{oc}^*$ (mL/g)	$K_d$ (mL/g)	R
Benzene	190	0.57	2.7
Toluene	380	1.14	4.4
Ethylbenzene	680	2.04	7.2
Xylenes	720	2.16	7.5
Naphthalene	1300	3.90	12.8

\*Compiled from U.S. EPA (1991) and API (1994l)

### Source Area Dimensions

As indicated in the model description, the analytical solution presented in Equation 4-29 assumes a constant plane source perpendicular to the direction of ground-water flow. Based on this assumption, the source vertical dimension, Z, was set equal to 10 ft, the approximate maximum thickness of the observed contaminated ground-water column in monitoring wells at the Layton site. The simulated plume elevation, z, was set to one ft, the approximate elevation of single-level ground probes below the ground-water table. The lateral source dimension, Y, was based on an inspection of contaminant concentration profiles perpendicular to ground-water flow near the source area. For the Layton site, the transect composed of CPT-21, CPT-19, CPT-08, CPT-12, and CPT-10 was used to make the determination of the appropriate cross-plume, Y-dimension value.

This transect is shown in Figure 7-22 and indicates that the plume width was relatively constant over the study period at approximately 100 ft. This 100-ft value was subsequently used in all plume modeling efforts.

### Simulation Times

The simulation time represents the length of time since the source release occurred. This is an important modeling parameter since model simulations are carried out from the source release time at  $t = 0$  to some designated point in time that corresponds to the data set used in the calibration process. Plumes grow over time until they reach a steady-state condition at which the assimilation rate of contaminant within the plume is equivalent to the release rate of the contaminant from the source area. If the simulation time is inappropriately selected, a different phase of the life of the plume may be described by the analytical solution and may produce incorrect degradation rates from the model. The release

at the Layton site could not have occurred before 1958 when the first tanks were placed at the site, and likewise it could not have occurred after 1984 when the last of the installed tanks were taken out of service. No contaminated soil and system leaks were identified during the placement of pressurized dispenser systems in a portion of the site in 1974. This suggests that major releases of product occurred after that time. From this site history, a range of simulation times from 10 to 25 years was used for model calibration efforts.

As indicated in the protocol (Chapter 4),  $\lambda$  and  $t$  were varied over ranges applicable for each contaminant to evaluate the sensitivity of model output to these parameter values and to determine those combinations of parameters producing the smallest MSE values. All compounds of interest in the study were evaluated together so that one common set of model parameters was generated from calibration of the model to the field data. Table 7-7 summarizes results of a portion of the calibration effort, presenting MSE values for various combinations of simulation time and  $\lambda$  for the BTEX compounds and naphthalene. Data from the March 1993 sampling event were chosen for model calibration for all compounds except naphthalene, as they appear to be representative of mean conditions existing at the site during the course of the field study (Figures 7-5 and 7-6).

The naphthalene data set appeared anomalous as concentrations observed for this compound along most of the March 1993 transect were higher than 1 mg/L, a concentration above the expected ground-water concentration in equilibrium with gasoline of 200 to 500  $\mu\text{g/L}$ . Because of the high and persistent concentrations of naphthalene observed in March 1993, concentration data averaged over the study period were used for the naphthalene calibration data set. Based on

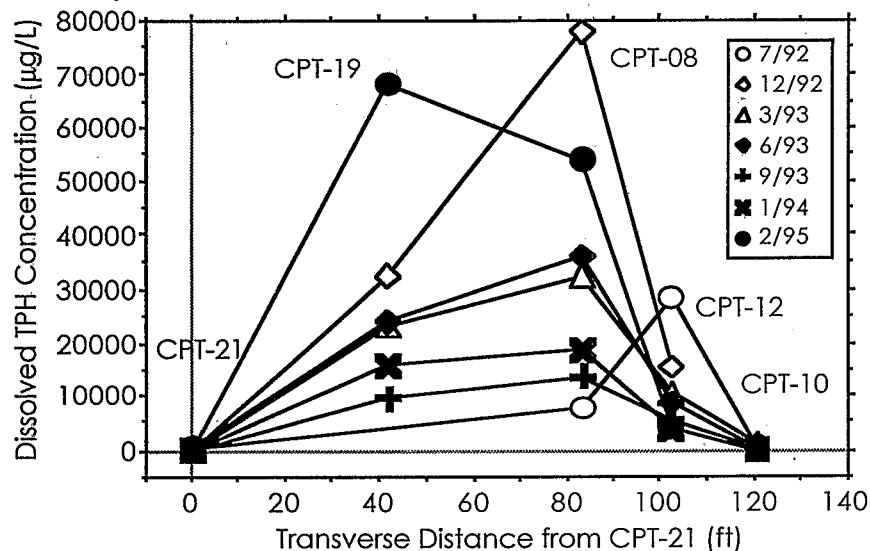


Figure 7-22. Dissolved TPH concentrations in transverse transect of plume at the Layton site measured from July 1992 to February 1995.

this time-averaged data, concentrations of naphthalene downgradient of the source area were not found below the equilibrium aqueous concentration until reaching monitoring point MLP-05. The transect used for naphthalene model calibration, outside of the apparent supersaturated naphthalene area, included only points MLP-05, CPT-07, and MLP-06 for model calibration purposes.

### Model Calibration Results

From the model calibration effort, a source simulation lifetime of 25 years resulted in the best overall model fit. Figures 7-23 through 7-27 show the results of the calibration effort and reflect the optimal model fit that is represented by the last entry for each compound in Table 7-7. It is interesting to note that in all cases the results from the plume centerline approach summarized in Table 7-4 overlap those from the model calibration results in Table 7-7 for all compounds at the 95-percent confidence level. It appears then that the plume centerline concentration approach provides statistically equivalent results to that of the fate-and-transport modeling approach when the plume has reached steady-state conditions.

### Estimation of Source Mass/Lifetime

As indicated in Chapter 4, when a continuous source is identified at a site, the estimation of source mass and source lifetime is based on the total mass of contaminant at the site both above and below the ground-water table. This mass is generally estimated from soil-core concentration data collected within the source area at

the site. Since the plume at the Layton site was identified as a continuous source with steady-state dissolved mass, lifetime calculations of contaminant mass were estimated from soil core and ground-water concentration measurements along with contaminant degradation rates.

### Mass Based on Soil Core Data

Soil core data from a variety of locations throughout the Layton site were used to develop an estimate of the contaminant mass within the source area below the site. These soil data included nine soil core locations from which five to 11 samples from each core were obtained over soil depths from 2.5 to 10.5 ft below ground surface. Cores were collected adjacent to MW-01 and CPT locations 03, 04, 05, 06, 07, 08, 09, and 10. Soil concentrations of BTEX, naphthalene, and TPH, ranging from non-detect to a high of only 430 µg TPH/g dry wt. soil, were lower than expected based on high ground-water measurements from ground-water monitoring probes. Source area BTEX, naphthalene, and TPH concentration and total-mass estimates were made by calculating an average concentration across the site for each core depth, then calculating a depth-averaged concentration across the entire site. These depth-averaged concentrations were then applied to the entire area of the site (41,072 ft<sup>2</sup>) over a sampling depth of 11.5 ft to yield the total mass values shown in Table 7-8. The estimated residual source area masses appear under predicted by the soil core data as the dissolved plume masses (measured in February 1995)

**Table 7-7. Summary of Model Calibration Results For BTEX Centerline Concentrations Measured at the Layton Site in March 1993, and Time-Averaged Naphthalene Centerline Concentration Data.**

Compound	Simulation Time (yr)	$\lambda$ (1/d)	MSE
Benzene	10	0.0000	20,792,893
	10	0.0009	2,577
	20	0.0000	62,577,557
	20	0.0009	10,305
	<b>25</b>	<b>0.0009</b>	<b>10,320</b>
Toluene	10	0.0000	3,763,063
	10	0.0006	17,235
	20	0.0000	16,730,551
	20	0.0006	37,014
	<b>25</b>	<b>0.0006</b>	<b>32,984</b>
Ethylbenzene	10	0.0000	196,102
	10	0.0002	195,623
	20	0.0000	631,985
	20	0.0000	11,622
	<b>25</b>	<b>0.0002</b>	<b>12,706</b>
p-Xylene	10	0.0000	16,054,755
	10	0.0004	775,097
	20	0.0000	45,526,903
	20	0.0004	604,452
	<b>25</b>	<b>0.0004</b>	<b>430,043</b>
Naphthalene	10	0.0000	166
	10	0.0001	159
	20	0.0000	69
	20	0.0002	102
	<b>25</b>	<b>0.0001</b>	<b>17</b>

were generally 10 to 25 percent of the masses predicted from the soil cores. The soil-core data collected from the Layton site do not appear to yield representative estimates of source-area residual mass, and an alternative method of source-mass estimation was used based on the maximum residual saturation that can be expected to exist within the soil at the Layton site.

### **Mass Based on Residual Product Estimate**

Estimates of the maximum product residual saturation can be made (based on the characteristics of the soil existing at a given site) by using quantitative relationships by Parker et al. (1987) and Mobil Oil Corporation (1995). These relationships describe the typical residual hydrocarbon saturations within a smear zone at and below the ground-water table as a function

of soil texture. Using these residual saturation data for the clay to silty clay soils below the Layton site suggests that approximately 10 percent of the subsurface porosity could be expected to be occupied by non-aqueous phase product material (Mobil Oil Corporation, 1995).

Based on ground-water data collected in February 1995, the aerial extent of potential residual phase material was approximated by the shaded polygon shown in Figure 7-28 and represents approximately 8,360 ft<sup>2</sup>. It should be noted that only two of the nine soil borings collected during the site investigation phase of this study were included in this area.

The volume of soil below the site which contains this residual saturation was estimated from the area shown in Figure 7-28 and the vertical extent of potentially

**Table 7-8. Summary of Average Contaminant Concentration, Estimated Total Residual Soil Mass, and Dissolved Plume Mass in February 1995 Measured at the Layton Site**

Depth (ft)	Average Soil Concentration ( $\mu\text{g/g}$ dry wt. soil)					TPH
	Benzene	Toluene	Ethyl- benzene	p-Xylene	Naph- thalene	
2 to 3	1.90	4.40	4.50	4.00	0.00	97
5 to 6	0.21	0.57	0.49	1.10	0.31	20
6 to 7	0.15	0.62	0.33	0.52	0.24	26
7 to 8	0.09	0.41	1.70	3.20	1.20	87
8 to 9	0.21	0.44	0.34	0.46	0.01	3
9 to 10	0.80	3.10	1.80	3.00	0.74	97
10 to 11.5	0.10	0.41	0.22	0.38	0.01	7
Average Concentration Across the Site ( $\mu\text{g/g}$ dry wt. soil)						
2 to 11.5	0.49	1.30	1.30	1.60	0.25	41
Total Mass of Contaminant in Soil Across the site (lb)						
2 to 11.5	12.80	35.20	33.50	41.30	6.70	1,072
Total Mass of Contaminant in Dissolved Plume February 1995 (lb)						
	8.10	3.40	1.90	9.60	1.20	172

contaminated soil of 13.5 ft (10 ft of ground-water contamination and 3.5 ft of capillary fringe and smear zone). It was further assumed that 10 percent of the pore volume of soil contained this residual product (112,900 ft<sup>3</sup> soil volume, 42,900 ft<sup>3</sup> pore volume) yielding an estimated residual product volume of 4,290 ft<sup>3</sup>, or approximately 241,000 lb of TPH.

From this estimate of the mass of residual product remaining below the site, the mass of BTEX and

naphthalene components associated with the product was determined using Raoult's Law, Equation 7-1, and associated relationships shown in Equations 7-2 through 7-4. In using these equations, a molecular weight of the residual product of 120 lb/lbmol was assumed. Contaminant ground-water measurements in February 1995 were used as measured values of the Equilibrium Concentration in Equations 7-1 and 7-2.

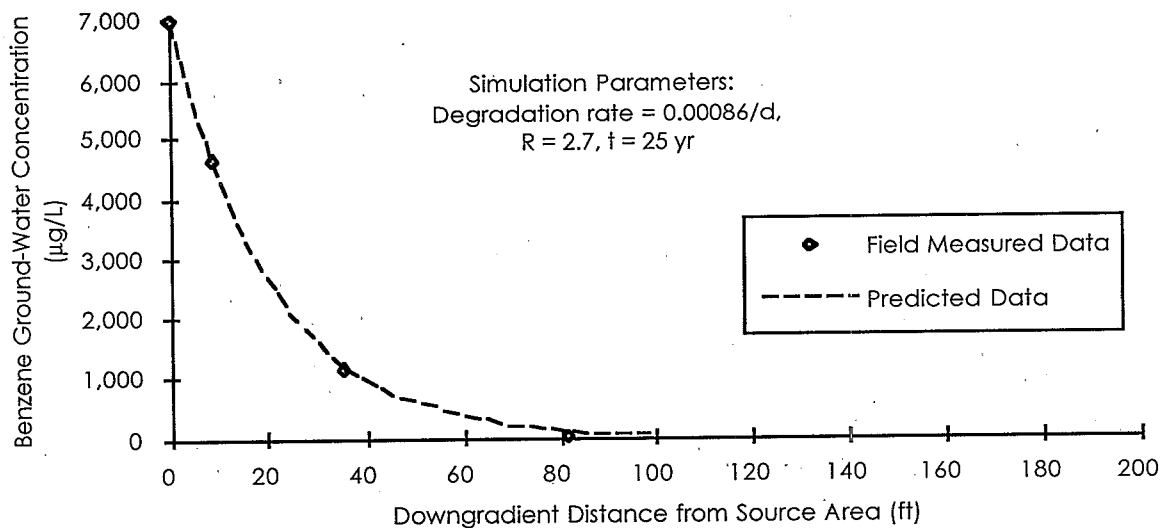
$$\text{Equilibrium Concentration} = (\text{Mole Fraction}) (\text{Aqueous Solubility}) \quad (7-1)$$

$$\text{Mole Fraction} = (\text{Equilibrium Concentration}) / (\text{Aqueous Solubility}) \quad (7-2)$$

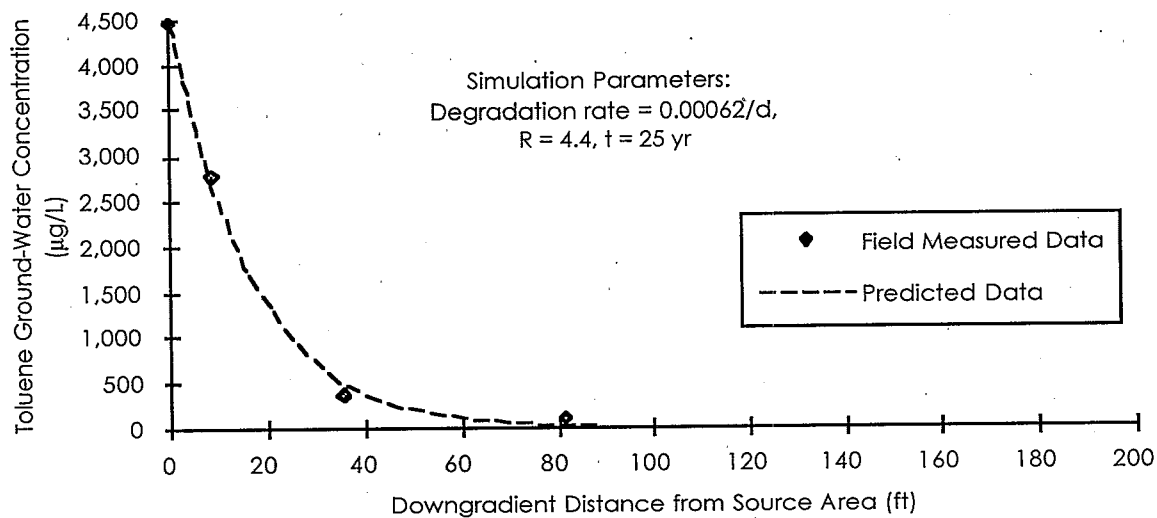
$$\text{Moles in Product} = (\text{Mole Fraction}) (\text{Mass of TPH}) / (\text{MWTPH}) \quad (7-3)$$

$$\text{Mass in Product} = (\text{Moles in Product}) (\text{MWcompound}) \quad (7-4)$$





**Figure 7-23. Results of benzene plume centerline calibration at the Layton site using data collected in March 1993.**



**Figure 7-24. Results of toluene plume centerline calibration at the Layton site using data collected in March 1993.**

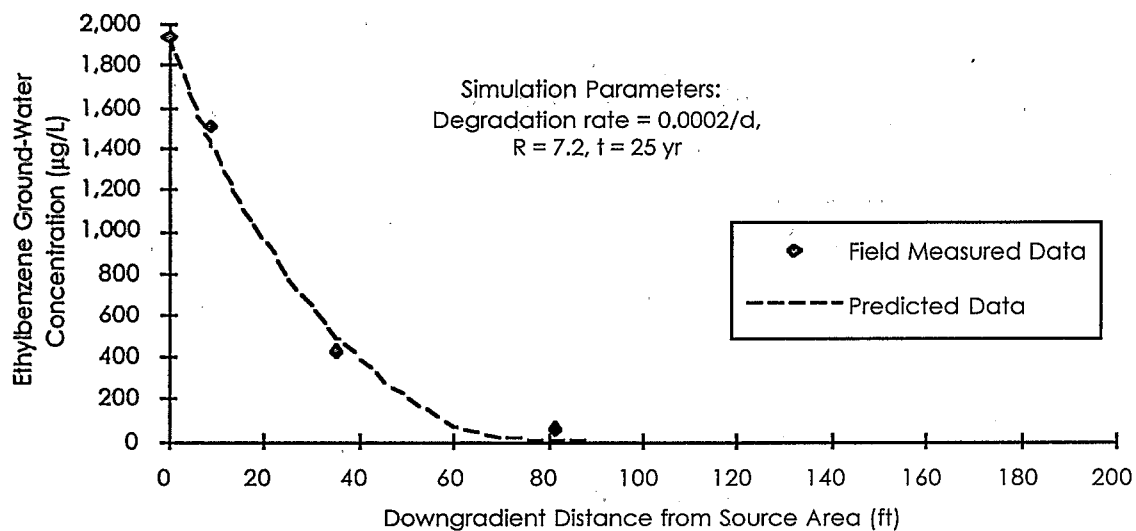


Figure 7-25. Results of ethylbenzene plume centerline calibration at the Layton site using data collected in March 1993.

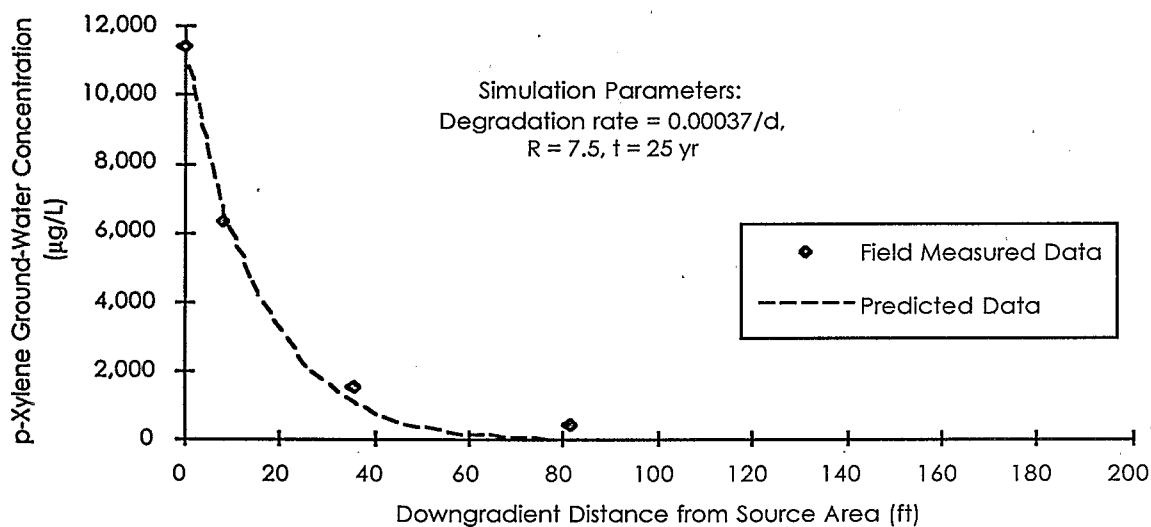
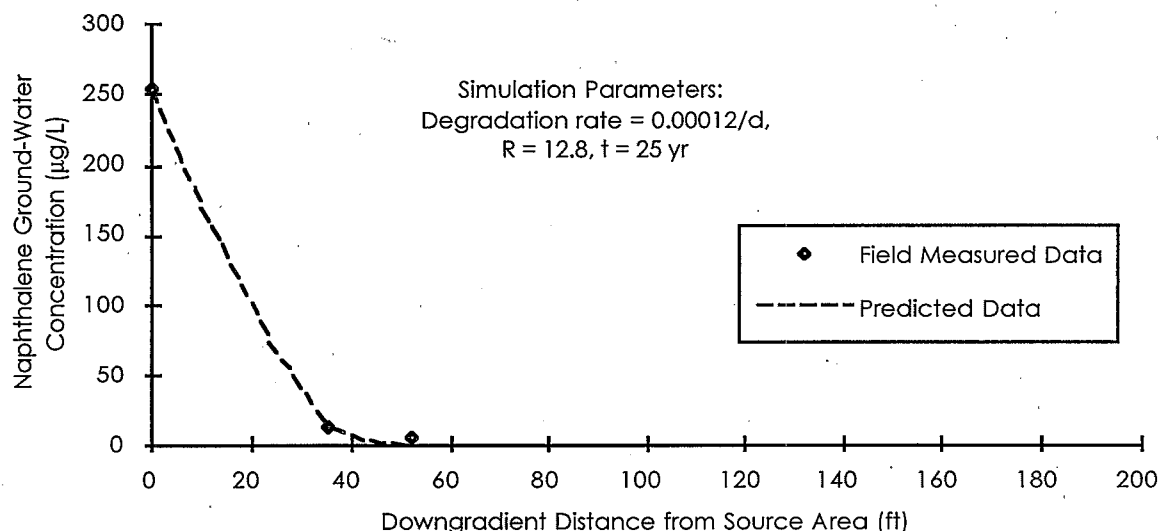


Figure 7-26. Results of p-xylene plume centerline calibration at the Layton site using data collected in March 1993.



**Figure 7-27. Results of naphthalene plume centerline calibration at the Layton site using project time-averaged concentration data for transect beginning at MLP-05.**

where MWTPH = molecular weight of TPH  $\approx$  120 lb/lbmol; and MWcompound = molecular weight of individual BTEX components and naphthalene, lb/lbmol.

These calculations are summarized in Table 7-9 along with the mass of BTEX and naphthalene in the dissolved plume at the site in February, 1995. As indicated in Table 7-9, estimates of masses of BTEX and naphthalene within the residual phase at the site are significantly higher than those presented in Table 7-8 using the site soil core data. These higher residual soil mass data are consistent with the dissolved-phase BTEX and naphthalene mass values determined to be in the plume in February 1995. They are thought to provide a more representative picture of site conditions than that generated from the soil core results. If the data in Table 7-9 are correct, the source area can be expected to last for a significant time into the future if no source removal action is taken. The dissolved-phase mass is only a small fraction of the mass of contaminant remaining within the source area. Source area lifetime considerations are addressed in the following section.

### Contaminant Mass Lifetime

The lifetime for the mass of contaminant, estimated to be remaining at the Layton site can be determined according to the procedures described in Chapter 4 with the use of Equation 4-16 and the model-calibrated first order degradation rates for the BTEX and naphthalene components of the residual-phase material.

Equation 4-16 indicates that for a continuous source that shows first order degradation, the time for a specific

mass or concentration of contaminant to be reached (based on initial values) is:

$$T\% = -\ln[\% \text{remaining}] / k_1 \quad (7-5)$$

where T% = the time required to yield a given percentage of remaining mass or concentration; %remaining = mass or concentration remaining at time T%; and  $k_1$  = model calibrated first order degradation rate constant for the compound, 1/d. Using Equation 7-5, the length of time for the destruction of the residual mass, 99.9 percent of the total mass at the Layton site, and the time to achieve 10 x and 1 x the MCL with and without source removal are summarized in Table 7-10. It should be noted that the total time associated with the assimilation of a contaminant plume is the sum of the time for source-area mass assimilation plus the time required for assimilation of the dissolved plume. With source removal, the time for the assimilation of the contaminant plume is then only related to destruction of mass in the dissolved plume. The results (summarized in Table 7-10) reflect this effect of source removal on the projected time to reach contaminant MCLs below the Layton site. Without source removal, the large mass of contaminant within the source area could require more than 100 years before MCLs are reached--based on the ethylbenzene MCL of 700 µg/L and a source-area ethylbenzene ground-water concentration of approximately 1,900 µg/L measured in February 1995. With source removal, the time to reach the ethylbenzene MCL requirement is reduced to 14 years. Benzene becomes the limiting contaminant, requiring an assimilation time of approximately 22 years before its

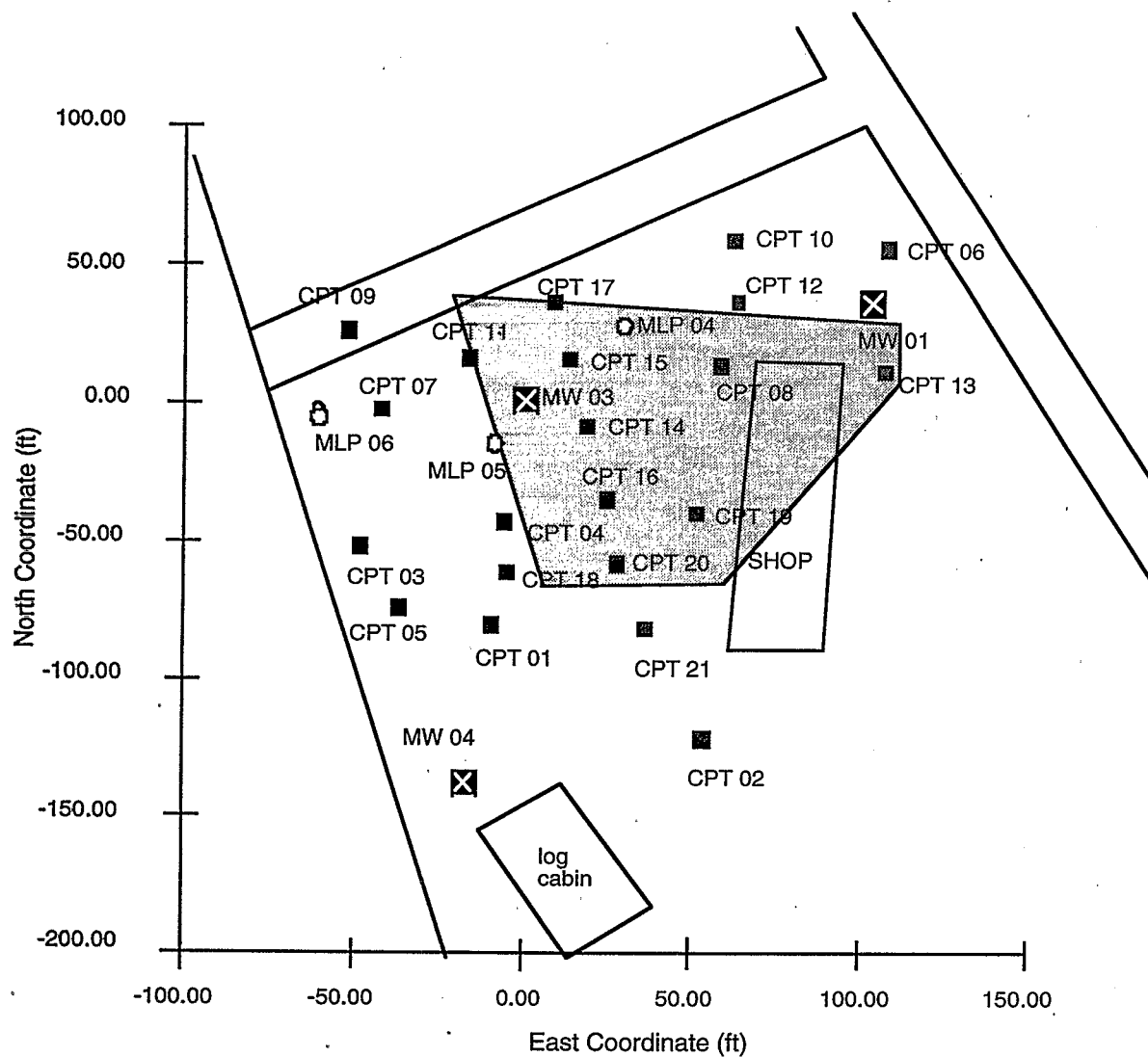


Figure 7-28. Estimated extent of residual contamination at the Layton site based on ground-water concentration data collected in February 1995.

**Table 7-9. Summary of Estimated Total Residual Contaminant Mass Based on Residual Product Volume Estimates, and Dissolved Plume Mass in February 1995, Measured at the Layton Site**

Compound	MW (lb/lbmol)	Aqueous Solubility (mg/L)	2/95 GW Concentration (mg/L)	Mole Fraction	lbmol in Product	Mass in Product (lb)	Mass in Plume 2/95 (lb)
Benzene	78.1	1,780	4.9	0.003	5.5	431	8.1
Toluene	92.1	759	3.2	0.004	8.5	782	3.4
Ethylbenzene	106.2	135	1.9	0.014	285.0	3,025	1.9
p-Xylene	106.2	221	6.3	0.029	57.5	6,111	9.6
Naphthalene	128.2	31	0.8	0.026	52.1	6,681	1.2
TPH	120.0		86.1			241,000	17.20

**Table 7-10. Summary of Estimated Residual Contaminant Mass Lifetime Based on Model Calibrated Degradation Rates Determined for the Layton Site.**

	Mass in Residual	Mass in Plume 2/95	Compound	Time for Residual Mass	Time for 99.9 Percent Total	Time to Reach 10 x MCL	Time to Reach MCL
Compound	(lb)	(lb)	First Order Rate (1/d)	Decay (yr)	Mass Decay (yr)	(yr)	(yr)
Benzene	431	8.1	0.00086	12.7	22.0	27.3	34.7
Toluene	782	3.4	0.00062	24.0	30.5	NA	29.2
Ethylbenzene	3,025	1.9	0.00020	101.0	94.6	NA	115.0
p-Xylene	6,111	9.6	0.00037	47.8	51.1	NA	NA
Naphthalene	6,681	1.2	0.00012	196.9	157.7	NA	NA
TPH	241,000	172.0					
	Percent Total	Percent Total		with 100 percent Residual Product Removal			
	Mass in Residual	Mass in Plume	Compound	Time for Specified Percent	Mass Removal (yr)	Time to Reach 10 X MCL	Time to Reach MCL
			First Order Rate (1/d)	99	99.9	(yr)	(yr)
Benzene	98.2	1.84	0.00086	1.9	9.3	14.6	21.9
Toluene	99.6	0.43	0.00062	NA	6.5	NA	5.1
Ethylbenzene	99.9	0.06	0.00020	NA	NA	NA	14.0
p-Xylene	99.8	0.16	0.00037	NA	3.3	NA	NA
Naphthalene	100.0	0.02	0.00012	NA	NA	NA	NA
TPH	99.9	0.07					

MCL is reached below the site. Source removal greatly reduces the length of time for assimilation of the mass of all contaminants at the Layton site, suggesting the need for some source removal effort for this site, making the duration of site management more acceptable.

### Predicting Long-Term Behavior of Plume

Since the Layton site has been shown to contain a significant source area, which produces a continuous source plume, long-term plume behavior can be evaluated based on various source removal scenarios. If source removal does not occur, a worst-case scenario develops in terms of the length of time the plume will persist. Table 7-10 indicates that this time frame could be approximately 100 years -- based on ethylbenzene MCL requirements. If 100 percent of the contaminant source were removed, Table 7-10 indicates that the overall time for site remediation is reduced significantly, by a factor of nearly ten for ethylbenzene, nearly six for toluene, and by a factor of nearly two for benzene.

As indicated in Chapter 4, the long-term behavior of a contaminant plume can be predicted for a variety of source removal options. This is carried out by the superposition of a continuous-source plume (with a source concentration equal to  $-C_0$ ) with the steady-state plume concentration profile (at a point in time corresponding to the time of source removal). If it is assumed that site management will be required as long as the plume at the Layton site exceeds the MCL values for any of the constituents of public health concern, e.g., BTEX, then a time to reach the MCL (following source depletion) can be predicted for each component using the fate-and-transport model described in this report, calibrated to the Layton field data, using this superposition approach. This modeling approach is more rigorous than the simple first order decay

approximation described by Equation 7-5 and presented in Table 7-10, since it accounts quantitatively for sorption, dilution and dispersion in addition to biodegradation mechanisms taking place at the site.

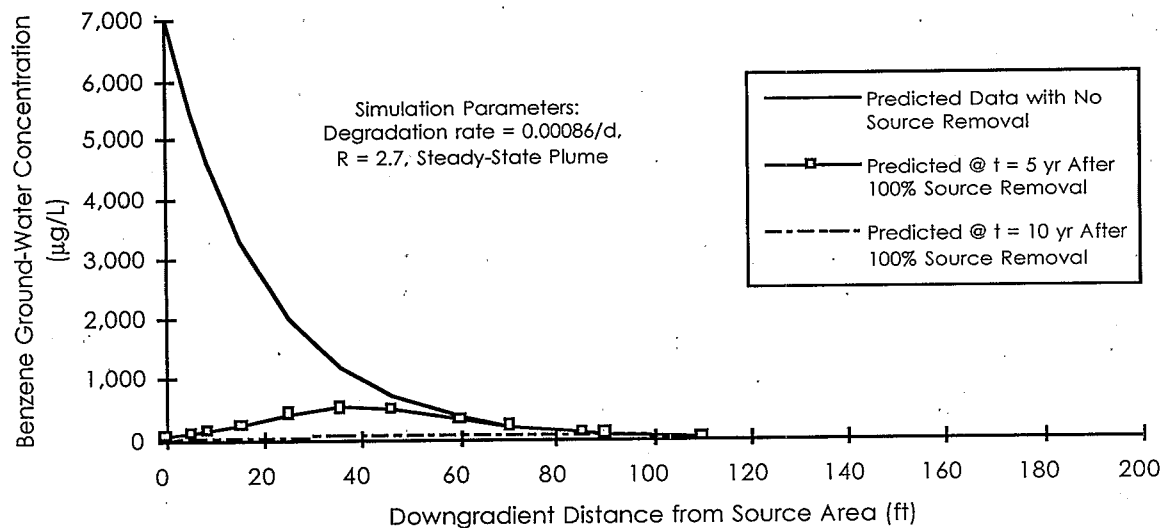
Table 7-11 presents a summary of this modeling effort. Figures 7-29 through 7-33 show the simulation runs for BTEX for simulation times from 0 to 18 years after 100 percent source removal/depletion depending upon the contaminant being modeled. These results are slightly lower than those presented in Table 7-1. This would be expected from the additional mechanisms that act to reduce contaminant concentration and that are accounted for in this fate-and-transport modeling approach. Results from both the approximate first order and the more rigorous modeling approach do suggest, however, that once source removal or depletion is complete at the Layton site, the persistence of the plume and the duration of site management will be controlled by benzene. A benzene plume of greater than the MCL of 5  $\mu\text{g/L}$  is projected to persist for 18 years following source removal/depletion, while all other contaminants of concern are projected to reach their MCL values everywhere within the plume in only 1.5 days to 7.5 years after source removal.

### Decision Making Regarding Intrinsic Remediation

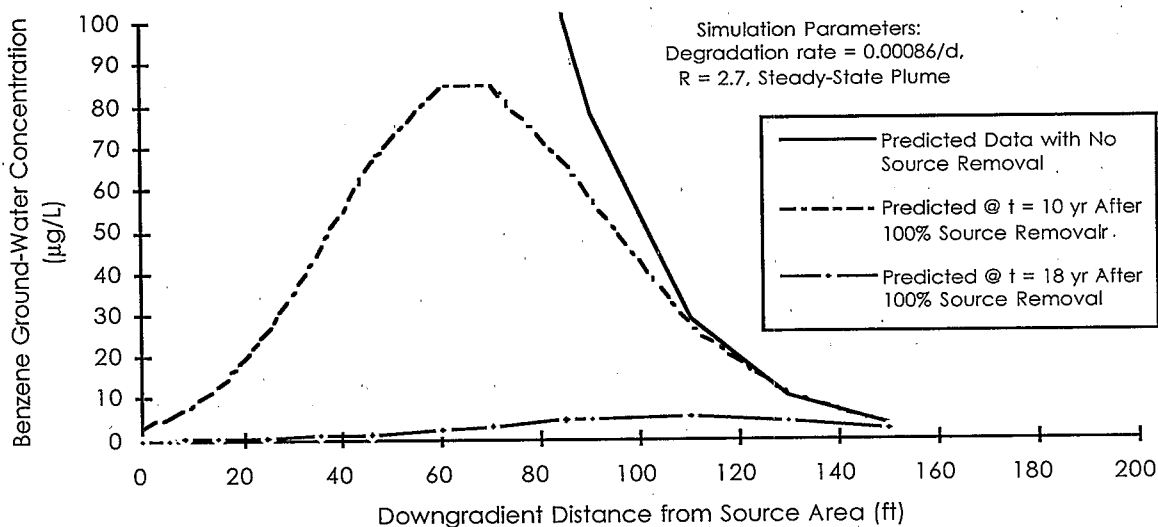
Decisions regarding the acceptability of natural attenuation for a given site should be based on the potential impact a plume has on susceptible downgradient receptors, and evidence regarding the presence and rate of intrinsic attenuation reactions that occur at a site that provide contaminant plume containment and control. Evidence of contaminant degradation is provided through plume analysis and the degradation-rate estimates described in this report. Assessment of the potential aquifer assimilative

**Table 7-11. Summary of Estimated Time to Reach MCL Levels within the Contaminant Plume at the Layton Site for BTEX, Naphthalene and TPH Compounds Based on Field Calibrated Fate-and-Transport Model Results**

Compound	MCL ( $\mu\text{g/L}$ )	Aqueous Solubility ( $\text{mg/L}$ )	3/93 GW Concentration ( $\mu\text{g/L}$ )	Time to Reach MCL Following Source Removal (yr)
Benzene	5	1,780	6,996	18.00
Toluene	1,000	759	4,473	3.25
Ethylbenzene	700	135	1,946	7.50
p-Xylene	10,000	221	11,441	0.01 (1.50 d)
Naphthalene	NA	31	1,544	NA
TPH	NA		99,832	NA



**Figure 7-29.** Predicted impact on plume centerline benzene concentrations 5 and 10 years after 100 percent source removal based on the field data calibrated fate-and-transport model for the Layton site.



**Figure 7-30.** Predicted impact on plume centerline benzene concentrations 10 and 18 years after 100 percent source removal based on the field data calibrated fate-and-transport model for the Layton site.

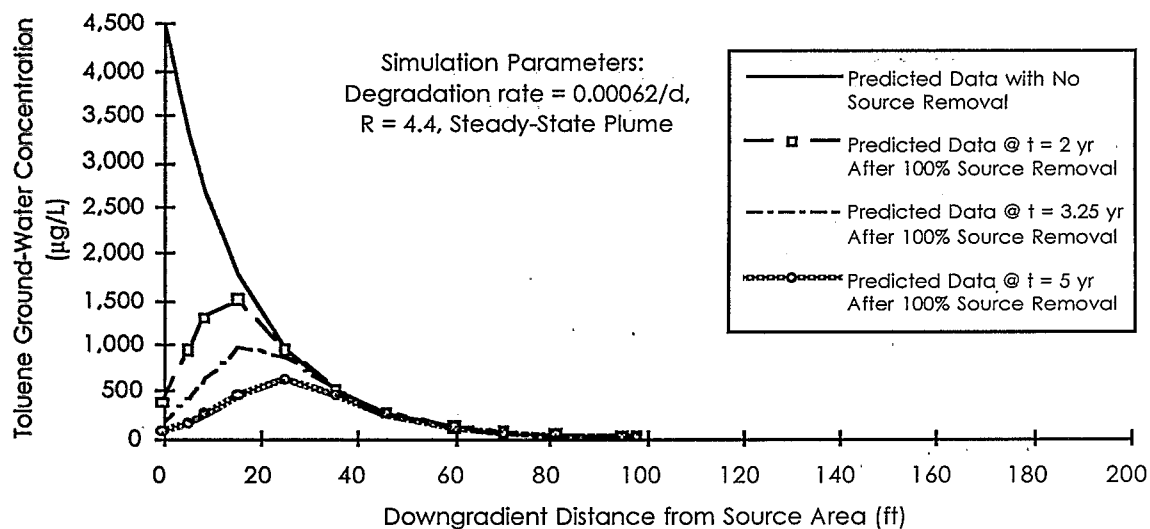


Figure 7-31. Predicted impact on plume centerline toluene concentrations 2, 3.25, and 5 years after 100 percent source removal based on the field data calibrated fate-and-transport model for the Layton site.

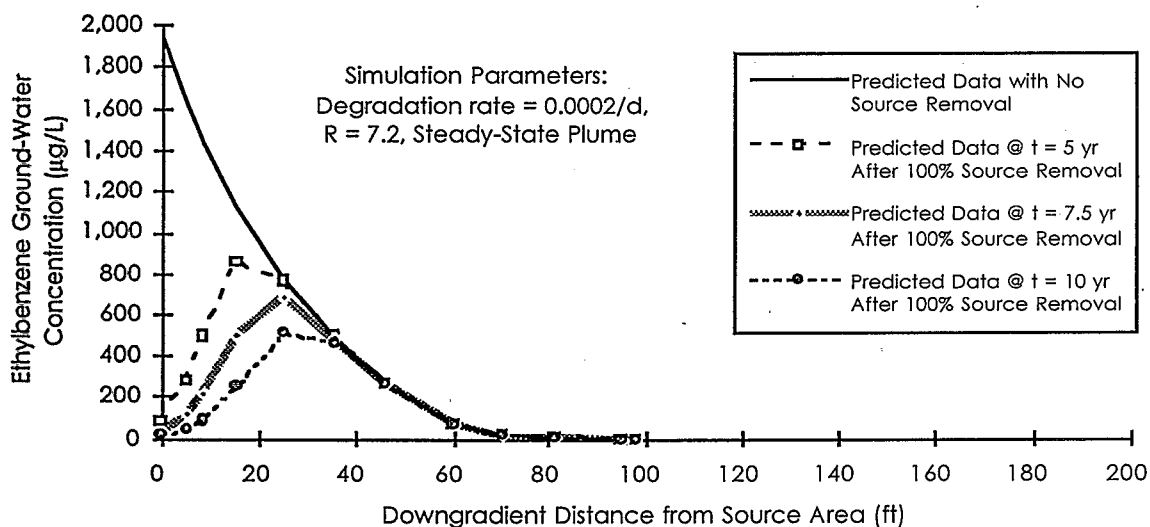
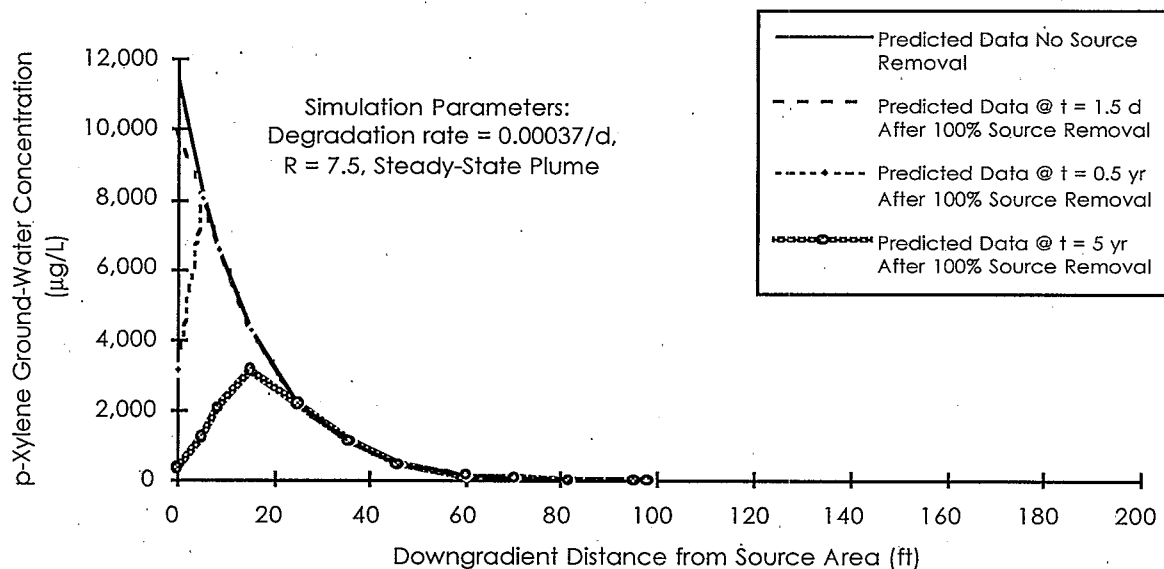


Figure 7-32. Predicted impact on plume centerline ethylbenzene concentrations 5, 7.5, and 10 years after 100 percent source removal based on the field data calibrated fate-and-transport model for the Layton site.





**Figure 7-33. Predicted impact on plume centerline p-xylene concentrations 1.5 d, and 0.5 and 5 years after 100 percent source removal based on the field data calibrated fate-and-transport model for the Layton site.**

capacity, estimated from an analysis of electron-acceptor conditions upgradient of the plume, is summarized below.

### **Impacted Receptors**

The long-term behavior of the contaminant plumes existing at the Layton site (projected from contaminant degradation and transport data) suggest that the plume has stabilized and is not expected to migrate from the site as long as existing hydraulic conditions persist. This limited extent of potential contaminant migration ensures that no downgradient receptors will be impacted by contamination at the Layton site over the projected lifetime of the existing ground-water plume.

### **Potential Aquifer Assimilative Capacity**

Feasibility of an intrinsic remediation management approach for a given site is provided from the quantification of the potential assimilative capacity existing in uncontaminated ground-water at the site. When quantities of electron acceptors moving onto a site equal, or exceed, the stoichiometric requirements for the degradation of dissolved contaminant, it can be assumed that the availability of electron acceptors will not limit contaminant degradation and plume attenuation at the site in the future. Table 4-6 summarizes the hydrocarbon assimilative capacity relationships for electron acceptors that are based on the stoichiometry of contaminant degradation. These relationships were used along with electron-acceptor concentrations measured in the background ground-water (Appendices

K and L) to estimate the potential assimilative capacity within the aquifer below the Layton site.

The potential assimilative capacity for the Layton site is summarized in Table 7-12. The assimilative capacity related to dissolved oxygen was based on average values observed in MW-04 during the course of the study. The sulfate and nitrate assimilative capacity was based on concentrations in the background monitoring location CPT-02 at the beginning of the study. The assimilative capacities of iron and manganese were estimated based on increases in the soluble concentrations of these solid-phase electron acceptors observed between MW-04 and MW-03 within the center of the plume. Iron and manganese concentrations observed in July 1993 in MW-04 were 0.07 and 0.04 mg/L, while those in MW-03 were 1.46 and 0.63 mg/L, respectively.

As indicated in Table 7-12, sulfate is the most significant electron acceptor at the Layton site, and accounts for nearly 60 percent of the potential assimilative capacity there. With a maximum TPH concentration of nearly 100 mg/L and a maximum BTEX concentration of nearly 25 mg/L observed during the study, the potential assimilative capacity projected in Table 7-12 is marginal. This result provides additional evidence that an intrinsic remediation management option, with some form of source removal to reduce contaminant mass flux into the impacted ground-water, is the preferred approach for the Layton site. Without additional contaminant source

**Table 7-12. Potential Aquifer Assimilative Capacity at the Layton Site Based on Ground-Water Data Collected from March 1992 to January 1994**

Electron Acceptor	Background Concentration (mg/L)	Mean HC Equivalent Stoichiometry (g/g HC Equivalent)	HC Equivalent Assimilative Capacity (mg/L)
DO	2.5	3.3	0.76
NO <sub>3</sub> <sup>-</sup>	21.0	1.1	19.63
SO <sub>4</sub> <sup>2-</sup>	148.5	5.0	30.00
ΔFe	1.4	23.1	0.06
ΔMn	0.6	20.0	0.03
CH <sub>4</sub>	Not measured	NA	NA
Potential Assimilative Capacity =			50.47

removal, intrinsic remediation appears marginally protective of public health and the environment.

### Long-Term Monitoring Program for Site

As indicated in Chapter 4, long-term monitoring at the Layton site should be focused on two primary objectives. First, monitoring should be carried out for compliance purposes to ensure no impact to a downgradient receptor. This should involve monitoring of downgradient sampling points on a three- to five-year sampling frequency to ensure that significant changes in plume degradation and transport have not occurred at the site. Second, intrinsic remediation monitoring for remediation process evaluation is perhaps more critical at this site since no nearby receptors exist. Monitoring at four to six locations along the plume centerline on a three- to five-year sampling frequency should provide adequate data to ensure that unexpected plume migration has not taken place at the site. To validate degradation rates that are presented above, additional cross plume sampling point measurements are also necessary so that a representative determination of residual dissolved plume mass can be made. Based on the ground-water monitoring network in place at the Layton site (Figure 5-6) a sampling scheme for both compliance and intrinsic remediation process monitoring purposes at the site is presented in Table 7-13.

Specific analyses for samples collected during the long-term monitoring phase should be similar to those used in this study. The analytes specified by the State of Utah DEQ for compliance monitoring purposes would be expected to include: ground-water elevation; field ground-water dissolved oxygen concentrations; and BTEX, naphthalene, and purge-and-trap TPH ground-water concentrations. In addition, other electron acceptors (nitrate, sulfate, and dissolved iron and

manganese) should be quantified for intrinsic remediation process evaluation along with general ground-water quality parameters such as pH, temperature, and TDS.

The proposed sampling frequency of three to five years is based on the projected lifetime of the source and dissolved plume of 35 to 115 years without source removal (Table 7-10). As indicated in Table 7-10, with complete source removal, the projected lifetime is reduced significantly, (being only slightly greater than 20 years). If source removal activities were carried out at the Layton site, a monitoring frequency of every two to three years would be recommended to account for the reduced source/plume lifetime.

### Summary of Intrinsic Remediation Evaluation at the Layton Site

As indicated in the data presented and discussed above, there appears to be ample evidence that intrinsic remediation has stabilized the hydrocarbon plume at the Layton site. The efficacy of intrinsic remediation alone, however, is questionable because of the significant mass of contaminant existing at the site, the relatively low contaminant degradation rates (one order of magnitude lower than those observed at the Hill AFB site), and the limited pools of electron acceptors moving onto the site.

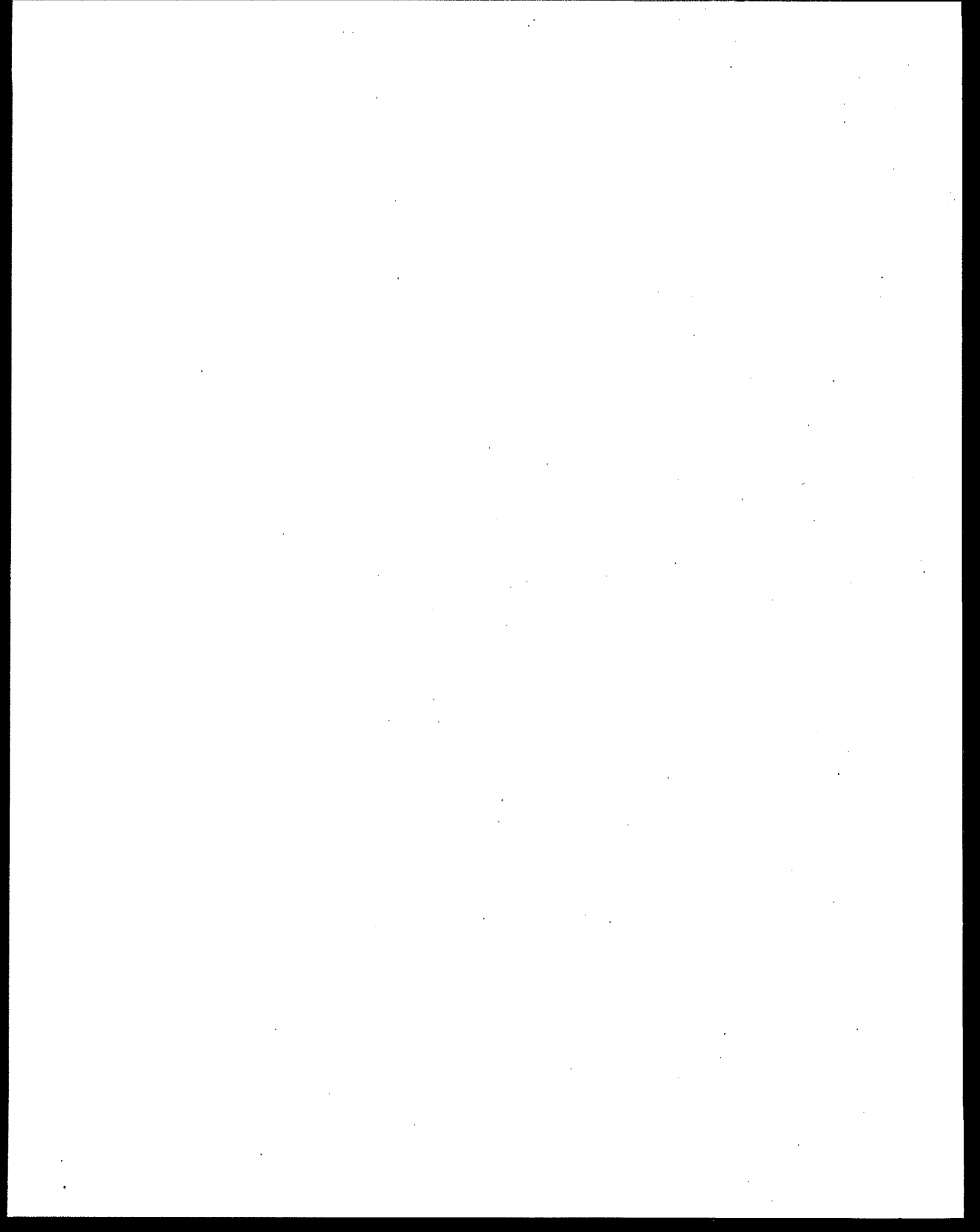
The contaminant plume appears to be stabilized for all contaminants of concern; however, the time for residual mass assimilation (without some form of source removal and controlled by the ethylbenzene MCL value), is estimated to exceed 100 years. This estimate is significantly reduced with the removal of mass from the source area; however, reduction of benzene below the MCL across the site may still require more than 20 years

with 100 percent source mass removal. Additional monitoring should be carried out to develop a better estimate of the residual mass existing within the source area and to verify that contaminant degradation has continued at the rates observed in this study.

Finally, investigation of the effectiveness of active remediation alternatives for contaminant removal at and below the ground-water table should be conducted in an effort to accelerate the removal of hydrocarbon contamination below the Layton site and to reduce the duration of site management and plume monitoring activities to reasonable levels.

**Table 7-13. Proposed Long-Term Sampling Schemes for Compliance and Intrinsic Process Monitoring at the Layton Site**

Compliance Monitoring		Intrinsic Remediation Process Monitoring			
Purpose	Location	Centerline	Transect 1	Transect 2	Transect 3
Background	MW-04	MW-01	CPT-21	CPT-01	CPT-05
Downgradient	MW-03	CPT-19	CPT-08	CPT-18	CPT-03
	CPT-07	CPT-20	CPT-12	CPT-15	CPT-11
	CPT-09	CPT-16	CPT-10	CPT-17	
		CPT-04			
		MLP-06			



## Chapter 8

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## Appendix A

### Cone Penetrometer QA/QC Procedures Implemented by Terra Technologies-Southwest, Inc., at the Hill and Layton Field Sites

#### Field Quality Assurance/Quality Control (QA/QC)

The following QA/QC program can be initiated for the field portion of this project.

- Step: Hydrologic measurement.  
Goal: Establish static water level to determine depth correction for soil gas analysis.  
Action: Measure the water level to 0.03 cm (0.1 foot).
- Step: Well purging.  
Goal: Removal of stagnant water which could bias ground water chemistry results. This is an option which would aid in the initial setting of the analytical instrument.  
Action: Pump water until purging parameters such as pH, Temperature, Ohms, Eh, or chemistry stabilize to  $\pm 10\%$  over at least two well volumes.
- Step: Soil gas sample collection.  
Goal: Collection of samples with minimal disturbance of sample chemistry.  
Action: Dedicated sample containers, Vacutainer samples where possible and pumping rates less than 10 ml/min for volatile organics.
- Step: Soil gas sample collection.  
Goal: To minimize cross-contamination between samples.  
Action: Where possible, dedicated sampling equipment should be used. All samples are to be placed in sterile containers. All non-dedicated sampling equipment should be thoroughly decontaminated by steam cleaning or other approved method.
- Step: Field determinations.  
Goal: Field analysis of samples will avoid bias in determinations of samples which are highly volatile or do not keep well.  
Action: Where possible, field screening should be conducted. A minimum of an initial volatile

organic compound (VOC) scan should be conducted on all samples.

- Step: Field analytical test equipment.  
Goal: To accurately monitor organic compounds.  
Action: Equipment used during the screening process is to be calibrated in a clean environment with specialty samples of organic compounds known to exist in the soil and ground water in the area.
- Step: Field blanks/standards.  
Goal: To permit the correction of analytical results for changes which may occur after sample collection, preservation, storage, and transport.  
Action: Where appropriate, at least one blank and one standard should be made up in the field during sampling. Spiked samples should also be sent to the laboratory for analysis, if required.
- Step: Sample storage/transport.  
Goal: To minimize any chemical alteration of samples prior to analysis.  
Action: All samples shall be either refrigerated or placed on ice immediately upon collection. Guidelines for maximum sample holding times or storage periods shall be adhered to. It should be noted that soil gas samples are very photosensitive and that holding times should be kept to a minimum.
- Step: Sample documentation.  
Goal: To determine the handling and liability of samples during shipment and analysis.  
Action: If samples are transported off-site, they need to be accompanied by a completed Chain of Custody form, properly signed and dated.

#### Analytical Quality Assurance/Quality Control QA/QC

1. Calibration of GC System - The system calibration is conducted after all tuning criteria

have been met and before any samples or blanks are analyzed. The calibration is also verified for each 12 hour period.

- a. Linearity Response - The system is calibrated at various concentrations to determine the linearity response by use of standards. The calibration also requires that the relative retention time of each calibration compound in each calibration run is within reason based on retention time units. The percent relative standard deviation for each calibration check compound is also checked for variance against standards.
- b. Performance Check - The system performance check is performed each 12 hours during analyses using a known calibration standard.
- c. Initial Calibration Check - The validity of the initial calibration is checked using calibration check compounds. Minimum

difference are reviewed for various compounds to have a valid calibration.

- d. Method Blank Analysis - Blank analyses of deionized water or pure sample matrix is performed before sample analyses to minimize artifacts due to contaminants in solvents, reagents, glass ware, etc.
2. Internal Standard Response - Internal standard responses are evaluated in all samples so that the changes in retention times are not more than a factor of two.
  3. Concentration Readjustment - The sample is diluted and the internal standard concentration readjusted if any compound in the sample exceeds the initial calibration range. If dilution causes any compound to be undetectable, the results of both analyses are considered.
  4. Qualitative Analyses - The elution of the sample component must be at the same GC relative retention time as the standard component. Peak identification will also be conducted and must agree within 20 percent of the standard.

## Appendix B

### Detailed Analytical Methods for Ambient Headspace Measurements

#### Appendix B-1. UWRL Procedure

The UWRL method is carried out as follows. Water and headspace are placed in a Ziplock® freezer bag which has a septa bonded to the outside with adhesive tape. Forty mL of water are placed in the bag through the zipper opening and 0.75 L air headspace is injected

from a sample pump through the septa. Figure B-1 shows the Ziplock bag system for the UWRL method. The system is allowed to equilibrate in a 20°C incubator for 15 to 30 minutes before the headspace is routed to the detector through the septa for analysis.

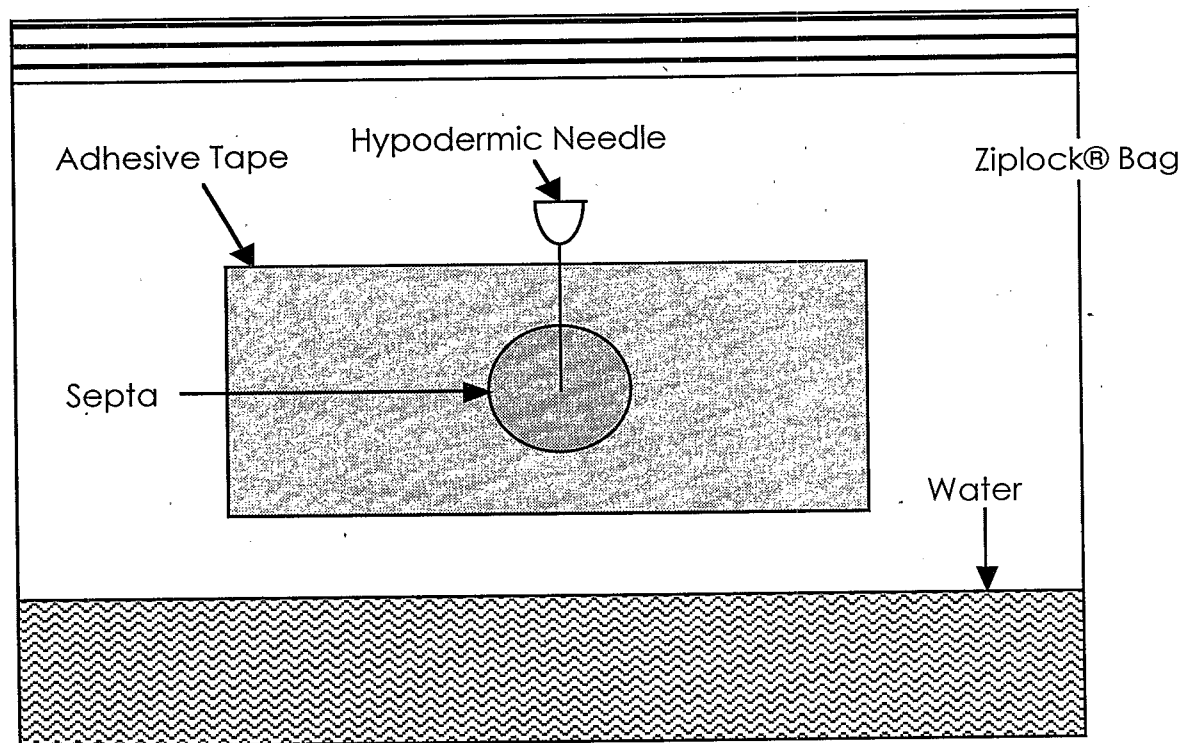


Figure B-1. Schematic of Ziplock® bag system for UWRL Method

## Appendix B-2. Lab-In-A-Bag (LIB) Procedure (In-Situ, Inc., 1991)

The LIB apparatus operates on a principal similar to that of the UWRL method, but the device automates many of the sample handling tasks involved in headspace analysis. A nipple at the top of the device penetrates the bag and seals to the side of the polyethylene bag. The point of bag penetration is connected to a system of valves, tubing, and a pump which is capable of:

1. Filling the bag with headspace air. A pressure sensitive switch automatically turns off the compressor when the bag is full. This allows the operator to fill bags with a consistent headspace volume.
2. Isolating the bag while phases equilibrate.
3. Routing the headspace gases to sampling point.
4. Purging the apparatus of residual vapors from the previous sample prior to the next sample preparation sequence.

The apparatus is also equipped with a magnetic stirrer which can stir the bag contents while the bag is attached to the unit. Speed and time of agitation are adjusted before beginning agitation. Agitation is used to speed equilibration of the phases (water/air or soil/water/air).

The procedure for analysis of samples using LIB is as follows.

1. Attach and seal a bag to the penetrator. A hole must first be cut in the side of the bag with the hole cutter supplied with the LIB kit.

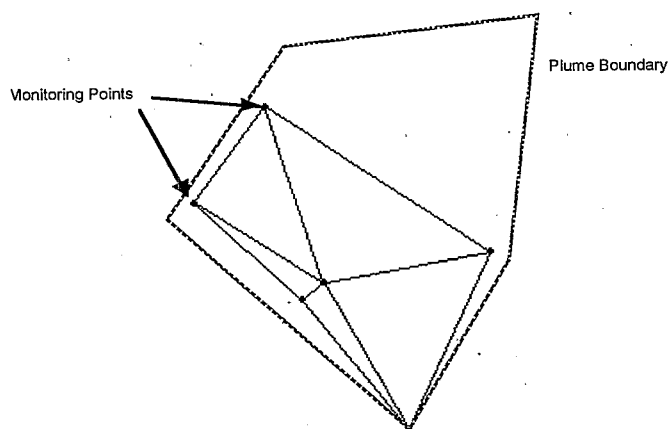
2. Check the bag and connection to the apparatus for leaks. Seal the opening of the bag, adjust valves for filling the bag with air, and start the pump. A short time after the pump stops, start the pump again. The amount of time the pump is on the second time is an indication of how leaky the bag and/or the connection to the apparatus is (are). Replace the bag with a new one if necessary.
3. To minimize loss of volatiles, prepare the bag for sample introduction. Put a magnetic stir bar in the bag. If a soil sample is to be analyzed, put 100 mL DDW in the bag.
4. Fill the bag with sample and headspace. The sample can be 100 mL water or 25 grams soil. Fill the bag with headspace.
5. Isolate the bag and agitate the sample. Adjust valves to isolate the bag and start magnetic stirrer. Stir time can be adjusted on the apparatus between 1 and 11 minutes in 1 minute increments. Unlike the UWRL method, the sample equilibrates at ambient temperature.
6. Analyze the headspace with a detector. Connect the detector inlet to the sample port on the LIB apparatus and adjust valves to route headspace gases to the sample port.
7. Dispose of the sample and bag and purge the system. Remove the bag from the penetrator. Adjust valves to purge the system and turn the pump on. Purge until the detector reaches background readings with the valves in the sampling position.

## Appendix C

### Thiessen Polygon Method for Assignment of Areas to Ground-Water Monitoring Points for Plume Mass Estimates

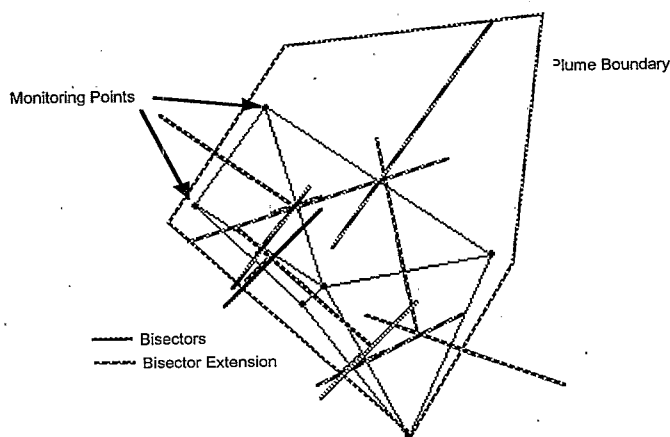
The Thiessen Method is borrowed from the water resources discipline, where it is routinely used to assign areas associated with rain gauge measurements in the determination of integrated rainfall values. The method involves the identification of specific sampling locations within a sampling network (monitoring well and gravel point sampling locations in this study) and the determination of associated areas based on the construction of polygons surrounding these sampling points. The method for polygon construction is as follows:

1. The outer boundary of the sampling network is identified based on logical, physical boundaries of the problem. When applied to ground-water contamination in this study, the area boundary was assigned based on site characteristics and plume delineation provided from monitoring points and interpolated isoconcentration plots.
2. Each sampling location is then connected to all adjacent points to form a series of polygons with the sampling point as their corners.

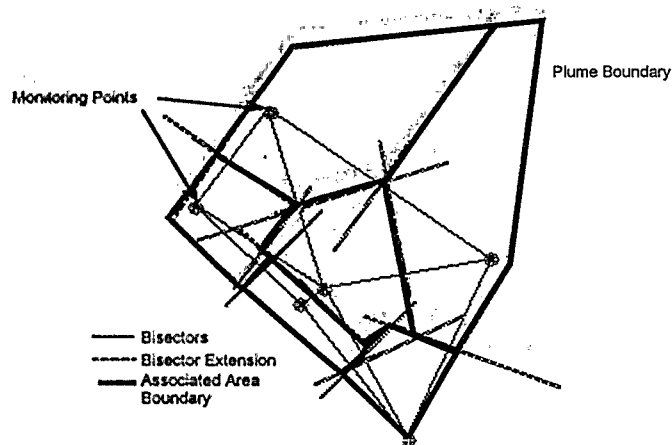


3. The lines between these sampling points are then bisected, and perpendicular lines are

drawn at the bisection points. These perpendicular lines are then extended so that they intersect one another.



4. Finally, the intersecting lines are connected to form polygons associated with each original sampling location to yield arbitrary, but unbiased and consistently generated areas associated with sampling points. These areas are then used in the generation of associated ground-water and soil volumes that allow the determination of the mass of contaminant within the assigned plume boundary and the changes in that mass over time.



During the 2-year field study described in this report, the actual sampling points used for data collection varied at each sampling event due to various reasons (freezing, dry sampling point, etc.). When sampling locations did change, the procedures above were repeated to redistribute area within the plume boundaries to those sampling points for which data were collected. A check on the accuracy of the method was carried out by comparing the sum of the areas assigned to each sampling point with the total area calculated using the entire sampling network. If the difference in total areas was more than 5 percent, the procedure was repeated and areas were recalculated until the 5 percent criteria was met. Summaries of the actual areas associated with each sampling point are provided in Tables C-1 and C2.



Table C-1. Thiessen Polygon Areas Determined for the Hill AFB, UT, Site During the Course of the Field Study. Blank Entries Indicate Sampling Locations that Could Not Be Sampled Due to Freezing, Being Above the Ground-Water Table, etc.

4/92 Sampling Event					7/92 Sampling Event				12/92 Sampling Event				
Well Number	X (ft)	Y (ft)	Area (ft^2)		Well Number	X (ft)	Y (ft)	Area (ft^2)		Well Number	X (ft)	Y (ft)	Area (ft^2)
MW 1	74.3	24.3	10,419		MW 2	63.6	-112.7	2,496		MW 2	63.6	-112.7	2,498
MW 2	63.6	-112.7	2,352		MW 3	16.7	32.9	610		MW 3	16.7	32.9	682
MW 3	16.7	32.9	2,459										
MW 4	-21.2	60.0	1,680		MW 5	33.7	126.7	1,385		MW 5	33.7	126.7	1,697
MW 5	33.7	126.7	8,843		MW 6	20.8	35.6	265		MW 6	20.8	35.6	406
MW 6	20.8	35.6	2,351		CPT 1	38.2	-11.6	3,201					
					CPT 2	-1.0	70.7	992					
					CPT 3	8.2	52.3	341					
					CPT 4	22.7	82.2	281		CPT 4	22.7	82.2	1,038
					CPT 5	23.1	48.5	189					
					CPT 6	27.5	59.0	244					
					CPT 7	38.0	44.2	374		CPT 7	38.0	44.2	888
					CPT 8	35.4	77.5	250		CPT 8	35.4	77.5	561
					CPT 9	52.4	43.9	283					
					CPT 10	50.2	74.7	155					
					CPT 11	42.3	93.4	150		CPT 11	42.3	93.4	237
					CPT 12	63.6	79.1	120		CPT 12	63.6	79.1	1,403
					CPT 13	68.2	39.5	260		CPT 13	68.2	39.5	2,431
					CPT 14	50.6	99.4	620		CPT 14	50.6	99.4	612
					CPT 15	99.0	132.2	890					
					CPT 16	84.9	153.4	1,025					
					CPT 17	113.7	110.7	545					
					CPT 19	128.0	165.9	328					
					CPT 20	85.4	36.3	703					
					CPT 21	110.8	147.7	702		CPT 21	110.8	147.7	2,787
					CPT 22	126.4	89.2	1,226					
					CPT 25	84.5	22.7	2,092					
					CPT 26	18.3	67.7	244					
					CPT 27	67.1	54.8	354					
					CPT 28	2.4	38.3	855		CPT 28	2.4	38.3	1,608
					CPT 29	73.6	95.7	979		CPT 29	73.6	95.7	3,216
					CPT 30	119.5	159.0	444		CPT 30	119.5	159.0	774
					CPT 31	60.6	27.0	575		CPT 31	60.6	27.0	2,012
					CPT 32	87.2	50.8	1,140					
					CPT 33	79.7	77.7	801					
					CPT 34	30.6	97.9	237		CPT 34	30.6	97.9	310
					MLP 35d	59.4	73.8	159		CPT 42	42.7	6.3	4,172
					MLP 36s	46.3	84.6	120		CPT 43	23.1	95.0	625
					MLP 36d	46.3	84.6						
					MLP 37d	51.7	61.2	256					

Table C-1. (Continued)

2/6/93 Sampling Event				6/9/93 Sampling Event				9/21/93 Sampling Event				1/94 Sampling Event			
Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )	Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )	Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )	Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )
MW 2	63.6	-112.7	2,498	MW 2	63.6	-112.7	2,484	MW 2	63.6	-112.7	2,484	MW 2	63.6	-112.7	2,484
MW 3	16.7	32.9	917	MW 3	16.7	32.9	509	MW 3	16.7	32.9	509	MW 3	16.7	32.9	672
MW 4	-21.2	60.0	728	MW 4	-21.2	60.0	476	MW 4	-21.2	60.0	476	MW 4	-21.2	60.0	482
MW 5	33.7	126.7	1,353	MW 5	33.7	126.7	1,385	MW 5	33.7	126.7	1,385	MW 5	33.7	126.7	1,385
MW 6	20.8	35.6	171	MW 6	20.8	35.6	164	MW 6	20.8	35.6	164	MW 6	20.8	35.6	175
				CPT 2	-1.0	70.7	448	CPT 2	-1.0	70.7	448	CPT 2	-1.0	70.7	692
CPT 3	8.2	52.3	413	CPT 3	8.2	52.3	317	CPT 3	8.2	52.3	317	CPT 3	8.2	52.3	324
CPT 4	22.7	82.2	400	CPT 4	22.7	82.2	398	CPT 4	22.7	82.2	398				
CPT 5	23.1	48.5	155	CPT 5	23.1	48.5	188	CPT 5	23.1	48.5	243	CPT 5	23.1	48.5	243
CPT 6	27.5	59.0	125	CPT 6	27.5	59.0	135	CPT 6	27.5	59.0	280	CPT 6	27.5	59.0	280
				CPT 8	35.4	77.5	249	CPT 8	35.4	77.5	320	CPT 8	35.4	77.5	320
CPT 9	52.4	43.9	212	CPT 9	52.4	43.9	208	CPT 9	52.4	43.9	350	CPT 9	52.4	43.9	464
CPT 10	50.2	74.7	151	CPT 10	50.2	74.7	153	CPT 10	50.2	74.7	400	CPT 10	50.2	74.7	551
CPT 11	42.3	93.4	153	CPT 11	42.3	93.4	153	CPT 11	42.3	93.4	153	CPT 11	42.3	93.4	161
CPT 12	63.6	79.1	392	CPT 12	63.6	79.1	199					CPT 12	63.6	79.1	241
CPT 13	68.2	39.5	190	CPT 13	68.2	39.5	208	CPT 13	68.2	39.5	708				
CPT 14	50.6	99.4	350	CPT 14	50.6	99.4	578	CPT 14	50.6	99.4	578	CPT 14	50.6	99.4	549
CPT 15	99.0	132.2	673	CPT 15	99.0	132.2	914	CPT 15	99.0	132.2	914	CPT 15	99.0	132.2	914
CPT 16	84.9	153.4	1,031	CPT 16	84.9	153.4	1,028	CPT 16	84.9	153.4	1,028	CPT 16	84.9	153.4	1,036
CPT 17	113.7	110.7	1,007	CPT 17	113.7	110.7	1,969	CPT 17	113.7	110.7	1,969	CPT 17	113.7	110.7	2,042
CPT 18	37.9	30.9	1,743	CPT 18	37.9	30.9	441	CPT 18	37.9	30.9	465	CPT 18	37.9	30.9	465
CPT 19	128.0	165.9	555												
CPT 20	85.4	36.3	705	CPT 20	85.4	36.3	685					CPT 20	85.4	36.3	730
CPT 21	110.8	147.7	884	CPT 21	110.8	147.7	588	CPT 21	110.8	147.7	588	CPT 21	110.8	147.7	588
CPT 25	84.5	22.7	3,386	CPT 25	84.5	22.7	2,866	CPT 25	84.5	22.7	2,866	CPT 25	84.5	22.7	2,866
CPT 26	18.3	67.7	434	CPT 26	18.3	67.7	329	CPT 26	18.3	67.7	329	CPT 26	18.3	67.7	346
CPT 27	67.1	54.8	227	CPT 27	67.1	54.8	123	CPT 27	67.1	54.8	175				
CPT 28	2.4	38.3	685	CPT 28	2.4	38.3	691	CPT 28	2.4	38.3	691	CPT 28	2.4	38.3	681
CPT 29	73.6	95.7	1,663	CPT 29	73.6	95.7	933	CPT 29	73.6	95.7	933	CPT 29	73.6	95.7	913
				CPT 30	119.5	159.0	773	CPT 30	119.5	159.0	773	CPT 30	119.5	159.0	773
CPT 31	60.6	27.0	1,798	CPT 31	60.6	27.0	523	CPT 31	60.6	27.0	523	CPT 31	60.6	27.0	672
CPT 32	87.2	50.8	1,522	CPT 32	87.2	50.8	1,373	CPT 32	87.2	50.8	1,553	CPT 32	87.2	50.8	1,546
				CPT 33	79.7	77.7	822	CPT 33	79.7	77.7	884	CPT 33	79.7	77.7	884
CPT 34	30.6	97.9	300	CPT 34	30.6	97.9	257					CPT 34	30.6	97.9	258
MLP 35s	59.4	73.8	157	MLP 35s	59.4	73.8	204	MLP 35s	59.4	73.8	380	MLP 35dr	59.4	73.8	380
MLP 36s	46.3	84.6	191	MLP 36m	46.3	84.6	163	MLP 36m	46.3	84.6	163				
MLP 37s	51.7	61.2	274	MLP 37s	51.7	61.2	322	MLP 37s	51.7	61.2	322				
MLP 38s	30.7	56.5	206	MLP 38s	30.7	56.5	182								
MLP 39s	39.4	41.5	225	MLP 39s	39.4	41.5	217								
MLP 40m	61.5	43.9	123	MLP 40s	61.5	43.9	123	MLP 40s	61.5	43.9	223				
MLP 41m	78.5	56.2	361	MLP 41s	78.5	56.2	250								
				CPT 42	42.7	6.3	3,535	CPT 42	42.7	6.3	3,535	CPT 42	42.7	6.3	3,424
CPT 43	23.1	95.0	637	CPT 43	23.1	95.0	637	CPT 43	23.1	95.0	719	CPT 43	23.1	95.0	719
MLP 44s	113.3	110.7	1,007												
TOTAL				TOTAL				TOTAL				TOTAL			
28,264				28,201				28,247				28,257			

Table C-2: Thiessen Polygon Areas Determined for the Layton, UT, Site During the Course of the Field Study. Blank Entries Indicate Sampling Locations that Could Not Be Sampled Due to Freezing, Being Above the Ground-Water Table, etc.

7/92 Sampling Event					12/92 Sampling Event					3/93 Sampling Event				
Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )		Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )		Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )	
CPT 1	-8.4	-80.6	1,464		CPT 1	-8.4	-80.6	3,344		CPT 1	-8.4	-80.6	1,464	
CPT 2	54.6	-122.4	3,777											
CPT 3	-47.5	-52.8	1,723		CPT 3	-47.5	-52.8	1,671		CPT 3	-47.5	-52.8	1,753	
CPT 4	-4.5	-42.8	1,194		CPT 4	-4.5	-42.8	945		CPT 4	-4.5	-42.8	1,185	
CPT 5	-36.3	-74.6	2,168		CPT 5	-36.3	-74.6	3,586		CPT 5	-36.3	-74.6	2,168	
CPT 6	108.7	55.4	1,270											
										CPT 7	-41.9	-2.2	1,738	
CPT 8	59.4	13.7	1,969		CPT 8	59.4	13.7	1,719		CPT 8	59.4	13.7	1,565	
CPT 9	-51.3	24.9	3,814		CPT 9	-51.3	24.9	3,482		CPT 9	-51.3	24.9	2,724	
CPT 10	63.4	58.1	1,386							CPT 10	63.4	58.1	1,578	
										CPT 11	-16.0	16.5	1,108	
CPT 12	64.7	35.9	899		CPT 12	64.7	35.9	2,699		CPT 12	64.7	35.9	795	
CPT 13	108.7	11.5	3,266		CPT 13	108.7	11.5	2,538		CPT 13	108.7	11.5	2,538	
CPT 14	19.0	-8.9	850		CPT 14	19.0	-8.9	956		CPT 14	19.0	-8.9	956	
CPT 15	14.3	15.4	1,470		CPT 15	14.3	15.4	2,884		CPT 15	14.3	15.4	536	
CPT 16	26.2	-35.4	1,495		CPT 16	26.2	-35.4	849		CPT 16	26.2	-35.4	849	
										CPT 17	9.1	33.8	2,009	
CPT 18	-4.3	-61.9	672		CPT 18	-4.3	-61.9	672		CPT 18	-4.3	-61.9	672	
					CPT 19	52.0	-40.6	3,227		CPT 19	52.0	-40.6	3,296	
CPT 20	28.5	-58.4	1,655		CPT 20	28.5	-58.4	772		CPT 20	28.5	-58.4	815	
CPT 21	37.8	-82.8	2,874		CPT 21	37.8	-82.8	6,253		CPT 21	37.8	-82.8	5,387	
MLP 4 - 9.0	31.2	28.1	3,584							MLP 4 - 9.5	30.5	27.4	962	
					MLP 5 - 9.5	-7.3	-14.3	761						
MLP 6 - 9.0	-59.9	-3.2	1,502		MLP 6 - 8.5	-59.9	-4.2	1,713						
MW 1	103.0	35.7	899		MW 1	103.0	35.7	2,158		MW 1	103.0	35.7	2,097	
MW 3	0.0	0.0	1,414							MW 3	0.0	0.0	791	
MW 4	-17.2	-137.5	1,795		MW 3	-17.2	-137.5	846		MW 4	-17.2	-137.5	4,086	
			TOTAL 41,140					TOTAL 41,072					TOTAL 41,072	

Table C-2. (Continued)

6/93 Sampling Event					9/93 Sampling Event					1/94 Sampling Event				
Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )		Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )		Well Number	X (ft)	Y (ft)	Area (ft <sup>2</sup> )	
CPT 1	-8.4	-80.6	1,464							CPT 1	-8.4	-80.6	1,491	
CPT 3	-47.5	-52.8	1,671		CPT 3	-47.5	-52.8	2,259		CPT 3	-47.5	-52.8	2,238	
CPT 4	-4.5	-42.8	1,102		CPT 4	-4.5	-42.8	1,375		CPT 4	-4.5	-42.8	1,345	
CPT 5	-36.3	-74.6	2,168		CPT 5	-36.3	-74.6	2,352		CPT 5	-36.3	-74.6	2,152	
CPT 7	-41.9	-2.2	953											
CPT 8	59.4	13.7	1,556		CPT 8	59.4	13.7	1,556		CPT 8	59.4	13.7	1,867	
CPT 9	-51.3	24.9	2,601		CPT 9	-51.3	24.9	3,466		CPT 9	-51.3	24.9	3,411	
CPT 10	63.4	58.1	1,618		CPT 10	63.4	58.1	1,578		CPT 10	63.4	58.1	1,622	
CPT 11	-16.0	16.5	1,101		CPT 11	-16.0	16.5	1,458		CPT 11	-16.0	16.5	1,452	
CPT 12	64.7	35.9	839		CPT 12	64.7	35.9	795		CPT 12	64.7	35.9	1,037	
CPT 13	108.7	11.5	2,538		CPT 13	108.7	11.5	2,538		CPT 13	108.7	11.5	2,492	
CPT 14	19.0	-8.9	1,221		CPT 14	19.0	-8.9	1,206		CPT 14	19.0	-8.9	1,195	
CPT 15	14.3	15.4	536		CPT 15	14.3	15.4	536		CPT 15	14.3	15.4	761	
CPT 17	9.1	33.8	2,009		CPT 17	9.1	33.8	2,009		CPT 17	9.1	33.8	2,430	
CPT 18	-4.3	-61.9	672		CPT 18	-4.3	-61.9	1,273		CPT 18	-4.3	-61.9	699	
CPT 19	52.0	-40.6	3,574		CPT 19	52.0	-40.6	3,539		CPT 19	52.0	-40.6	3,540	
CPT 20	28.5	-58.4	974		CPT 20	28.5	-58.4	991		CPT 20	28.5	-58.4	1,024	
CPT 21	37.8	-82.8	5,387		CPT 21	37.8	-82.8	5,743		CPT 21	37.8	-82.8	5,271	
MLP 4 - 9.5	30.5	27.4	962		MLP 4 - 9.5	30.5	27.4	962						
MLP 5 - 9.0	-7.3	-14.3	752											
MLP 6 - 9.0	-59.9	-3.2	863											
MW 1	103.0	35.7	2,013		MW 1	103.0	35.7	2,097		MW 1	103.0	35.7	2,043	
MW 3	0.0	0.0	413		MW 3	0.0	0.0	906		MW 3	0.0	0.0	914	
MW 4	-17.2	-137.5	4,086		MW 4	-17.2	-137.5	4,345		MW 4	-17.2	-137.5	4,086	
		TOTAL	41,072				TOTAL	40,985				TOTAL	41,070	

## Appendix D

### Ground-Water Slug Test Data and Conductivity/Ground-Water Velocity Calculations from the Layton and Hill AFB, Utah, Field Sites Collected April 8 to 10, 1992

The slug test data for the Layton and Hill AFB sites used in these calculations are presented in Tables D-1 and D-2, respectively.

#### Calculation of Hydraulic Conductivity

Two different methods were used in the calculation of hydraulic conductivity at each observation well, the Hvorslev method (Fetter, 1988) and the method from Bouwer and Rice (1976).

##### The Hvorslev Method

If the length of the piezometer is more than eight times the radius of the well screen ( $L/R$ ), the following formula applies:

$$K = \frac{r_c^2 \ln(L/R)}{2LT_o} \quad (1)$$

where  $K$  = the hydraulic conductivity,  $L/T$ ;  $r_c$  = the radius of the well casing;  $R$  = the radius of the well screen,  $L$ ;  $L$  = the length of the well screen,  $L$ ; and  $T_o$  = the time it takes for the water level to rise or fall to 37 percent of the initial change,  $T$ .

These results are presented in Table D-3.  $T_o$  can be calculated by plotting the log ( $h/h_o$ ) versus time, where  $h_o$  is the initial head, and  $h$  is the measured head at some time after the beginning of the slug test. These data for the determination of  $T_o$  for all of the slug tests conducted at the Layton and Hill sites are attached.

##### The Bouwer and Rice Method

The Bouwer and Rice method allows the estimation of the hydraulic conductivity of a formation using the following relationship:

$$K = \frac{r_c^2 \ln(R_e/r_w)}{2L_e t} \ln \frac{y_o}{y_t} \quad (2)$$

where  $r_c$  = the inside radius of the casing,  $L$ ;  $r_w$  = the effective radius of the well,  $L$ ;  $L_e$  = the effective aquifer thickness,  $L$ ;  $y_t$  = the drawdown in the well at time  $t$ ,  $L$ ; and  $y_o$  = the drawdown in the well at time zero,  $L$ .

The radius of influence can be computed by the empirical equation:

$$\ln \frac{R}{r_w} = 1 / \left( \frac{1.1}{\ln(L_w/r_w)} + \frac{A + B \ln((H - L_w)/r_w)}{(L_e/r_w)} \right) \quad (3)$$

where  $A$  and  $B$  = empirical constants;  $L_w$  = the length from the water table to the bottom of the aquifer,  $L$ ; and  $H$  = the thickness of the aquifer,  $L$ . The results of these calculations are presented in Table D-4.

#### Calculation of Pore Water Velocity

##### Geometric Hydraulic Conductivity

The geometric hydraulic conductivity is used to calculate the pore water velocity and can be calculated from the geometric mean of conductivities measured throughout a site using the following equation:

$$K = \left( \prod_{i=1}^n K_i \right)^{1/n} \quad (4)$$

where  $n$  = the number of observation wells.

From Table D-4 data using Equation 4, the mean hydraulic conductivities for the two sites are found to be:

for Layton:  $K = 1.20$  ft/d  
for Hill AFB:  $K = 1.53$  ft/d

### Pore Water Velocity

The pore water velocity is calculated using Darcy's Law:

$$V = \frac{K \partial h}{n \partial l} \quad (5)$$

where V = the pore water velocity, L/T; K = the hydraulic conductivity, L/T; n = the porosity; and  $\partial h / \partial l$  = the hydraulic gradient, L/L.

**Porosity.** For the Layton site, there are no data available for porosity, and the porosity of each observation well is estimated using typical values for the geologic materials described in boring logs from the site. These values were weighted based on the relative thickness of each geologic layer. The results of these porosity estimates are presented in Table D-5. The porosity used for the Layton site was 0.38 as shown in Table D-5. This is geometric average value of the porosity of all three observation wells for which slug tests were conducted.

For the Hill site, the porosity stated in the Corrective Action Plan report from Engineering-Science of 0.25 was used for all calculations.

**Hydraulic Gradient.** For Layton, the coordinate system was set to originate at Well B4 with the North direction being Y, X being in the East direction, and using water table data from the January 25, 1991, Corrective Action Plan report prepared by Wasatch Geotechnical, Inc. The observed piezometer head distribution data were used to develop a regression equation relating head to piezometer location. Well B4 (0,0) water level was equal to 91.29', while Well B3 (55,131) and Well B1 (163,140) had water levels at 91.58' and 91.71', respectively. The equation of piezometer head as a function of X, Y position was determined to be the following:

$$h \text{ (ft)} = 0.00106 X + 0.00177 Y + 91.29 \quad (6)$$

So,

$$\frac{\partial h}{\partial x} = 0.00106 \quad \frac{\partial h}{\partial y} = 0.00177 \quad (7)$$

$$\frac{\partial h}{\partial l} = \sqrt{\left(\frac{\partial h}{\partial x}\right)^2 + \left(\frac{\partial h}{\partial y}\right)^2} = 0.002 \text{ (ft / ft)} \quad (8)$$

For the Hill site from the Engineering Science Corrective Action Plan report, the hydraulic gradient was found to be:

$$\frac{\partial h}{\partial l} = 0.03 \text{ (ft / ft)} \quad (9)$$

From these hydraulic gradient and site permeability data determined above, the pore water velocity can be easily calculated for each site and were found to be:

$$\begin{aligned} \text{for Layton: } V &= 0.006 \text{ ft/d} \\ \text{for Hill AFB: } V &= 0.183 \text{ ft/d} \end{aligned}$$

### References

1. Bouwer, H. and R.C. Rice. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Res. Research, 12:423-428.
2. Fetter, C.W. 1988. Applied Hydrogeology. Macmillan Publishing Company, New York, New York.
3. Engineering-Science. 1991. Corrective Action Plan Building 1141 Release Response. October.
4. Wasatch Geotechnical, Inc. 1991. Compliance Report for Release Site, Blaine Jensen R.V., Layton, Utah. July.

Table D1: Layton slug test sampling							
Well #1		Well #3	(Rep. 1)	Well #3	(Rep. 2)	Well #4	
Time	GWT	Time	GWT	Time	GWT	Time	GWT
(min.)	(ft)	(min.)	(ft)	(min.)	(ft)	(min.)	(ft)
0.00	19.20	0.00	17.20	0.00	17.32	0.00	19.36
1.02	19.10	1.50	17.19	0.07	17.31	0.55	19.22
2.30	19.00	2.22	17.17	0.17	17.30	0.85	19.15
3.47	18.95	3.30	17.16	0.28	17.29	1.07	19.10
4.47	18.90	4.50	17.15	0.80	17.25	1.50	19.00
5.62	18.85	6.32	17.14	1.73	17.20	1.75	18.95
7.02	18.80	7.08	17.13	3.57	17.15	1.98	18.90
8.97	18.75	8.75	17.12	5.67	17.12	2.22	18.85
11.33	18.70			8.28	17.10	2.47	18.80
				10.43	17.09	2.93	18.70
						3.50	18.60
						4.08	18.50
						4.68	18.40
						5.30	18.30
						6.07	18.20
						6.95	18.10
						7.52	18.00
						8.37	17.90
						9.28	17.80
						10.28	17.70
						11.35	17.60
						13.32	17.40
						16.07	17.20

Table D2: Hill AFB Slug Test Sampling									
Well #3		Well #4	(Rep. 1)	Well #4	(Rep. 2)	Well #5		Well #6	
Time	GWT	Time	GWT	Time	GWT	Time	GWT	Time	GWT
(min.)	(ft)	(min.)	(ft)	(min.)	(ft)	(min.)	(ft)	(min.)	(ft)
0.00	17.50	0.00	15.50	0.00	15.60	0.00	20.30	0.00	16.90
0.95	17.20	0.07	15.60	0.05	15.70	1.43	20.20	2.00	16.80
1.60	17.10	0.12	15.70	0.10	15.80	5.97	20.20	5.08	16.80
2.58	17.00	0.15	15.80	0.17	15.90	6.98	20.20	21.05	16.80
3.10	17.00	0.20	15.90	0.23	16.00	13.32	20.14		
3.88	16.90	0.28	16.00	0.28	16.10				
5.12	16.90	0.33	16.10	0.40	16.20				
7.23	16.80	0.45	16.20	0.62	16.30				
14.00	16.80	0.65	16.30	1.12	16.40				
		1.07	16.40	2.07	16.50				
		3.10	16.50	3.72	16.50				
		3.63	16.50	5.00	16.50				

Table D3: Hydraulic conductivity calculated from The Hvorslev Method.

Well	r (in)	L (ft)	R (in)	To (min)	K (ft/day)
Layton #1	2	10	2	5.18	1.58
Layton #3	2	10	2	4.64	1.77
Layton #3 (rep. 2)	2	10	2	2.60	3.15
Layton #4	2	10	2	7.29	1.12
Hill AFB #3	1	5	1	2.17	1.89
Hill AFB #4	1	5	1	0.42	9.70
Hill AFB #4 (rep. 2)	1	5	1	0.42	9.63
Hill AFB #5	1	5	1	3.30	1.24
Hill AFB #6	1	5	1	5.30	0.77

Table D4: Hydraulic conductivity calculated from The Bouwer &amp; Rice Method.

Well	rw (ft)	Lw (ft)	Le (ft)	Le/rw	A	B	$\ln[(H-Lw)/rw]$	R	K (ft/d)
Layton #1	1/6	17.0	10	60	4.05	0.6875	6	86.9	1.11
Layton #3	1/6	17.0	10	60	4.05	0.6875	6	86.9	1.25
Layton #3 (rep. 2)	1/6	17.0	10	60	4.05	0.6875	6	86.9	2.00
Layton #4	1/6	17.0	10	60	4.05	0.6875	6	86.9	0.78
Hill AFB #3	1/12	13.1	5	60	4.05	0.6875	6	202.4	1.45
Hill AFB #4	1/12	13.2	5	60	4.05	0.6875	6	203.2	7.62
Hill AFB #4 (rep. 2)	1/12	13.2	5	60	4.05	0.6875	6	203.2	7.10
Hill AFB #5	1/12	11.7	5	60	4.05	0.6875	6	194.9	0.86
Hill AFB #6	1/12	26.0	5	60	4.05	0.6875	6	253.7	0.61

Table D5: Porosity calculation for Layton.

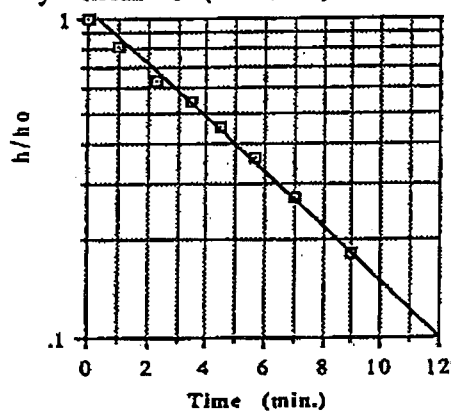
Well No.	Depth (ft)	Interval (ft)			Screen	Porosity for Wells	Porosity for Site
		SP	SC	CL			
B1	17	10.1-11	11-17		7-17	0.44	0.38
B2	17	8.9 - 10.5	10.5 - 17		7-17	0.46	
B3	17	10.0 - 17		8.9 - 10.0	7-17	0.31	



# Figures:

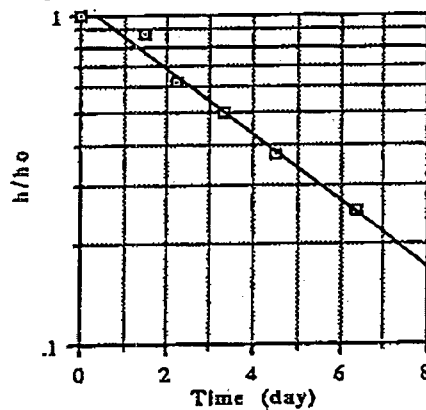
Slug Test for Layton Well #1

$$y = 1.0612 * 10^{(-8.8389e-2x)} \quad R^2 = 0.989$$



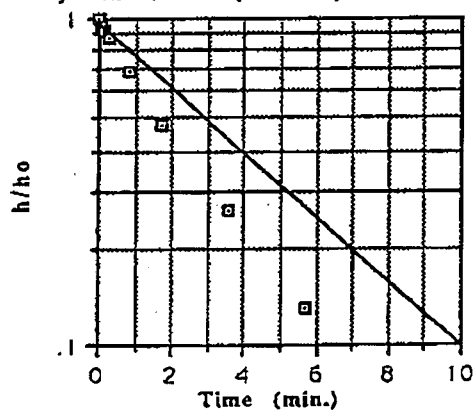
Slug Test for Layton Well#3 (Rep.1)

$$y = 1.0776 * 10^{(-0.10011x)} \quad R^2 = 0.981$$



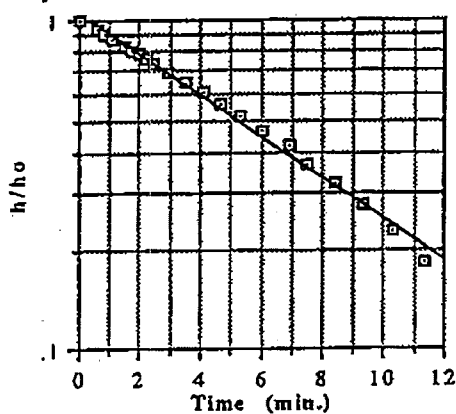
Slug Test for Layton Well#3 (Rep.2)

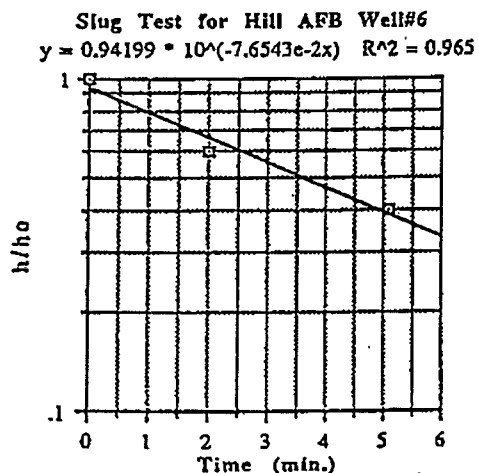
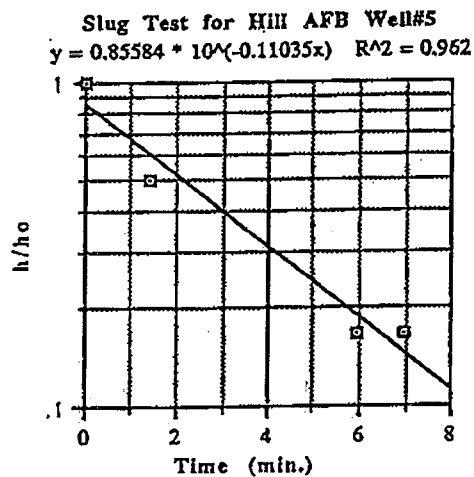
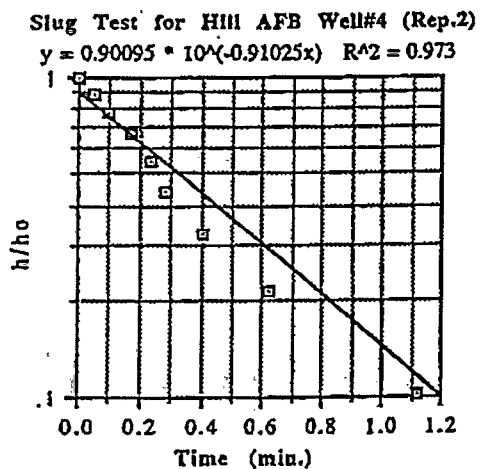
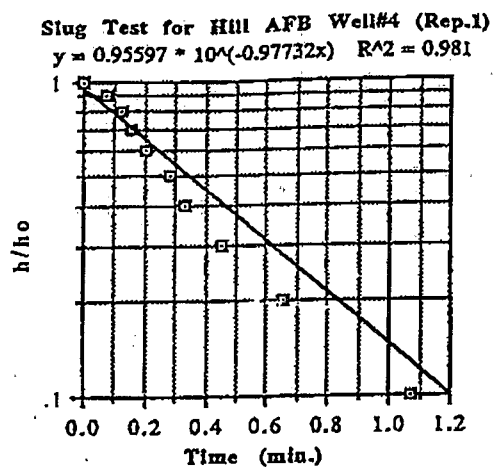
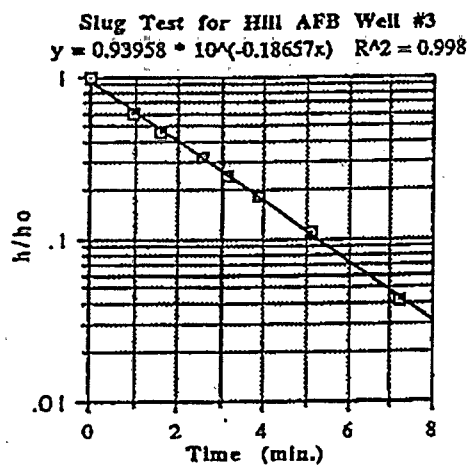
$$y = 0.96698 * 10^{(-0.16024x)} \quad R^2 = 0.998$$



Slug Test for Layton Well #4

$$y = 1.0477 * 10^{(-6.2036e-2x)} \quad R^2 = 0.993$$





## Appendix E

### Raw Data for Field ATH Versus Laboratory TPH Data Comparison

Hill AFB - 7/92				Hill AFB - 12/92			
	Field	Lab			Field	Lab	
Sample	ATH Results (µg/L)	P&T Results (µg/L)	Lab/Field Response	Sample	ATH Results (µg/L)	P&T Results (µg/L)	Lab/Field Response
CPT-01	326	60	0.18				
CPT-02	326	0	0.00				
CPT-03	326	41	0.13	CPT-03	16	58	3.73
CPT-04	326	172	0.53	CPT-04	1,505	213	0.14
CPT-05	3,711	544	0.15	CPT-05	292	57	0.20
CPT-06	1,196	992	0.83	CPT-06	191	257	1.34
CPT-07	25,080	40,135	1.60				
CPT-08	1,382	653	0.47	CPT-08	1,675	103	0.06
CPT-09	2,868	6,196	2.16				
CPT-10	1,729	124	0.07				
CPT-11	2,301	107	0.05	CPT-11	1,675	227	0.14
CPT-12	2,397	736	0.31	CPT-12	2,014	1,198	0.59
CPT-13	1,765	1,234	0.70	CPT-13	16	157	10.09
CPT-14	1,298	141	0.11	CPT-14	1,844	409	0.22
CPT-15	574	294	0.51				
CPT-16	2,354	8	0.00				
CPT-17	1,832	8	0.00				
CPT-18	57,510	81,509	1.42	CPT-18	154	169	1.09
CPT-19	930	0	0.00				
CPT-20	1,197	2,517	2.10	CPT-20	16	63	4.06
CPT-21	1,053	0	0.00	CPT-21	16	149	9.55
CPT-22	326	3	0.01				
CPT-25	667	0	0.00	CPT-25	16	193	12.37
CPT-26	682	0	0.00	CPT-26	16	107	6.84
CPT-27	1,447	266	0.18	CPT-27	16	523	33.50
CPT-28	336	25	0.08	CPT-28	16	62	3.98
CPT-29	1,725	18	0.01				
CPT-30	558	0	0.00	CPT-30	16	17	1.12
CPT-31	1,190	29	0.02	CPT-31	16	946	60.63
CPT-32	1,995	186	0.10	CPT-32	601	662	1.10
CPT-33	5,969	10,362	1.74				
CPT-34	1,331	0	0.00	CPT-34	1,505	68	0.05
CPT-42	4,282	962	0.22	CPT-42	16	97	6.24
CPT-43	805	180	0.22	CPT-43	1,675	667	0.40
MLP38(9.6)	2,339						
MLP38(10.1)	1,285						
MLP39(9.7)	1,951						
MLP39(10.2)	1,175						
MLP40(10.25)	21,585						
MLP44(12.9)	94,460	12,003	0.13				
				MW2	16	813	52.10
MW3	3,714	4,351	1.17	MW3	973	18	0.02
MW4	326	24	0.07				
MW5	326	6	0.02	MW5	1,675	271	0.16
MW6	326	4	0.01	MW6	16	67	4.32
Method Blanks	902			Method Blanks	16		
		Average	0.39			Average	8.23
		St.Dev.	0.61			St.Dev.	15.81
		C.V (%)	156.48			C.V (%)	192.10

Layton - 7/92				Layton - 12/92			
	Field	Lab			Field	Lab	
	ATH Results	P&T Results	Lab/Field		ATH Results	P&T Results	Lab/Field
Sample	(µg/L)	(µg/L)	Response	Sample	(µg/L)	(µg/L)	Response
CPT-01	1,343	0	0.00	CPT-01	2,047	2	0.00
CPT-02	1,774	0	0.00				
CPT-03	5,409	0	0.00	CPT-03	2,616	392	0.15
CPT-04	64,425	7,840	0.12	CPT-04	57,130	15,923	0.28
CPT-05	73	4	0.05	CPT-05	1,067	33	0.03
CPT-06	0	3					
CPT-07	23,955	5,993	0.25				
CPT-08	25,513	7,661	0.30	CPT-08	1,067	78,090	73.19
CPT-09	1,798	796	0.44	CPT-09	4,277	148	0.03
CPT-10	1,313	313	0.24				
CPT-11	10,744						
CPT-12	25,493	28,269	1.11	CPT-12	34,407	15,341	0.45
CPT-13	42,526	43,478	1.02	CPT-13	100,852	34,394	0.34
CPT-14	51,514	23,351	0.45	CPT-14	402	41,841	104.08
CPT-15	45,418	24,504	0.54	CPT-15	26,138	8,532	0.33
CPT-16	22,934	30,322	1.32	CPT-16	56,024	36,698	0.66
CPT-17	15,279	3,537	0.23	CPT-17	27,052		
CPT-18	1,329	17	0.01	CPT-18	2,538	136	0.05
CPT-19	2,010			CPT-19	35,269	32,583	0.92
CPT-20	85,026	41,899	0.49	CPT-20	131,845	52,403	0.40
CPT-21	897	135	0.15	CPT-21	1,067	13	0.01
MLP4(9.0)	2,096	15,472	7.38				
MLP4(9.5)	1,755	3,785	2.16				
MLP6(9.0)	4,487	52	0.01				
MW1	5,107	397	0.08	MW1	5,107	3,313	0.65
MW3	30,842	3,354	0.11	MW3	30,842	2,111	0.07
MW4	56,470	4	0.00	MW4	56,470		
Method Blanks	902			Method Blanks	1,067		
		Average	0.69			Average	10.68
		St.Dev.	1.52			St.Dev.	29.84
		C.V (%)	221.31			C.V (%)	279.32

## Appendix F

### Summarized BTEX, Naphthalene, and TPH Ground-Water Concentration Data Used for Plume Centerline and Mass Calculations for the Hill AFB Site

#### Hill AFB Site 4/92 Ground-Water Data

		X-Coord	Y-Coord	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Well	No.	(ft)	(ft)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
MW	1	74.3	24.3	3.2	0.0	0.0	0.0	0.0	13.4
MW	2	63.6	-112.7	0.0	0.0	0.0	0.0	0.0	24.8
MW	3	16.7	32.9	36.3	21.2	29.2	95.3	29.6	1284.8
MW	4	-21.2	60.0	0.0	20.2	30.2	126.1	0.0	204.0
MW	5	33.7	126.7	0.0	0.0	0.0	0.0	0.0	12.3
MW	6	20.8	35.6	0.0	0.0	0.0	0.0	0.0	0.0

# Hill AFB Site 7/92 Ground-Water Data

Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
MW	1	74.3	24.3						
MW	2	63.6	-112.7	0.0	0.0	0.0	0.0	0.0	36
MW	3	16.7	32.9	8.6	30.5	28.4	11.8	30.0	2,586
MW	4	-21.2	60.0						
MW	5	33.7	126.7	0.0	0.0	0.0	0.0	0.0	0
MW	6	20.8	35.6	0.0	0.0	0.0	0.0	0.0	4
CPT	1	38.2	-11.6	11.0	9.3	9.8	0.0	0.0	60
CPT	2	-1.0	70.7	0.0	0.0	0.0	0.0	0.0	0
CPT	3	8.2	52.3	0.0	0.0	0.0	0.0	0.0	41
CPT	4	22.7	82.2	0.0	0.0	0.0	0.0	0.0	172
CPT	5	23.1	48.5	18.1	10.0	18.9	0.0	40.4	544
CPT	6	27.5	59.0	37.1	0.0	0.0	0.0	23.5	992
CPT	7	38.0	44.2	369.0	159.0	321.0	839.0	349.0	40,135
CPT	8	35.44	77.5	37.8	0.0	0.0	0.0	15.5	653
CPT	9	52.4	43.9	0.0	85.7	73.4	97.0	208.0	6,196
CPT	10	50.2	74.7	0.0	0.0	0.0	0.0	0.0	124
CPT	11	42.3	93.4	0.0	0.0	0.0	0.0	0.0	107
CPT	12	63.6	79.1	0.0	6.9	41.8	10.0	0.3	736
CPT	13	68.2	39.5	0.0	22.2	0.0	0.0	2.2	1,234
CPT	14	50.6	92.4	0.0	0.0	0.0	0.0	2.7	141
CPT	15	99.0	132.2	0.0	0.0	21.0	0.0	3.7	294
CPT	16	84.9	153.4	0.0	0.0	0.0	0.0	0.0	14
CPT	17	113.7	110.7	0.0	0.0	0.0	0.0	0.0	8
CPT	18	37.9	30.9						81,509
CPT	19	128.0	165.9	0.0	0.0	0.0	0.0	0.0	0
CPT	20	85.4	36.3	0.0	60.6	84.4	24.5	55.1	2,517
CPT	21	110.8	147.7	0.0	0.0	0.0	0.0	0.0	0
CPT	22	126.4	89.2	0.0	0.0	0.0	0.0	0.0	3
CPT	23	61.9	74.5						
CPT	24	99.5	134.6						
CPT	25	84.5	22.7	0.0	0.0	0.0	0.0	0.0	0
CPT	26	18.3	67.7	0.0	0.0	0.0	0.0	0.0	0
CPT	27	67.1	54.8	0.0	0.0	27.6	30.4	5.9	266
CPT	28	2.4	38.3	0.0	0.0	0.0	0.0	0.0	25
CPT	29	73.6	95.7	0.0	0.0	0.0	0.0	0.0	18
CPT	30	119.5	159.0	0.0	0.0	0.0	0.0	0.0	0
CPT	31	60.6	27.0	0.0	0.0	9.2	0.0	0.0	29
CPT	32	87.2	50.8	0.0	0.0	0.0	0.0	7.8	196
CPT	33	79.7	77.7	0.0	29.8	161.0	163.0	177.0	10,362
CPT	34	30.6	97.9	0.0	0.0	0.0	0.0	0.0	0
MLP	35s	59.4	73.8						
MLP	35m	59.4	73.8						
MLP	35d	59.4	73.8	0.0	0.0	0.0	0.0	0.0	16
MLP	35dr	59.4	73.8						
MLP	36s	46.3	84.6						6
MLP	36m	46.3	84.6						
MLP	36d	46.3	84.6	0.0	0.0	0.0	0.0	0.0	27
MLP	37s	51.7	61.2						
MLP	37m	51.7	61.2						
MLP	37d	51.7	61.2	0.0	0.0	0.0	0.0	0.0	4
MLP	38s	30.7	56.5						
MLP	38m	30.7	56.5						
MLP	38d	30.7	56.5						
MLP	39s	39.4	41.5						
MLP	39m	39.4	41.5						
MLP	39d	39.4	41.5						
MLP	40s	61.5	43.9						
MLP	40m	61.5	43.9						
MLP	40d	61.5	43.9						
MLP	41s	78.5	56.2						
MLP	41m	78.5	56.2						
MLP	41d	78.5	56.2						
CPT	42	42.7	6.3	0.0	50.1	18.0	0.0	0.6	962
CPT	43	23.1	95.0	0.0	0.0	0.0	0.0	0.0	180
MLP	44s	113.3	110.7						
MLP	44m	113.3	110.7						
MLP	44d	113.3	110.7	0.0	71.8	281.9	117.7	67.6	7,505

# Hill AFB Site 11 to 12/92 Ground-Water Data

Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (ug/L)	Toluene (ug/L)	Ethylbenzene (ug/L)	p-Xylene (ug/L)	Naphthalene (ug/L)	Total (ug/L)
MW	1	74.3	24.3						
MW	2	63.6	-112.7	36.6	0.0	24.4	29.8	0.0	241
MW	3	16.7	32.9	0.0	9.2	0.0	0.0	0.0	20
MW	4	-21.2	60.0						
MW	5	33.7	126.7	23.0	34.3	21.4	20.8	0.0	160
MW	6	20.8	35.6	0.0	0.0	0.0	0.0	0.0	44
CPT	1	38.2	-11.6						
CPT	2	-1.0	70.7						
CPT	3	8.2	52.3						
CPT	4	22.7	82.2	17.3	20.8	9.8	0.0	0.0	95
CPT	5	23.1	48.5						
CPT	6	27.5	59.0						
CPT	7	38.0	44.2	0.0	13.2	0.0	0.0	0.0	17
CPT	8	35.44	77.5	0.0	0.0	0.0	0.0	0.0	42
CPT	9	52.4	43.9						
CPT	10	50.2	74.7						
CPT	11	42.3	93.4	17.5	5.4	15.1	15.3	1.6	128
CPT	12	63.6	79.1	3.9	5.8	9.8	6.2	34.2	285
CPT	13	68.2	39.5	0.0	0.0	0.0	0.0	0.0	16
CPT	14	50.6	99.4	35.4	53.4	34.0	32.6	0.0	261
CPT	15	99.0	132.2						
CPT	16	84.9	153.4						
CPT	17	113.7	110.7						
CPT	18	37.9	30.9						
CPT	19	128.0	165.9						
CPT	20	85.4	36.3						
CPT	21	110.8	147.7	0.0	0.0	8.8	0.0	0.0	104
CPT	22	126.4	89.2						
CPT	23	61.9	74.5						
CPT	24	99.5	134.6						
CPT	25	84.5	22.7						
CPT	26	18.3	67.7						
CPT	27	67.1	54.8						
CPT	28	2.4	38.3	0.0	9.2	2.6	2.6	0.0	18
CPT	29	73.6	95.7	8.1	13.1	6.7	8.3	0.0	60
CPT	30	119.5	159.0	0.0	0.0	0.0	0.0	0.0	2
CPT	31	60.6	27.0	13.8	15.1	13.2	22.3	6.0	632
CPT	32	87.2	50.8						
CPT	33	79.7	77.7						
CPT	34	30.6	97.9	0.0	6.7	0.0	0.0	0.0	54
MLP	35s	59.4	73.8						
MLP	35m	59.4	73.8						
MLP	35d	59.4	73.8						
MLP	35dr	59.4	73.8						
MLP	36s	46.3	84.6						
MLP	36m	46.3	84.6						
MLP	36d	46.3	84.6						
MLP	37s	51.7	61.2						
MLP	37m	51.7	61.2						
MLP	37d	51.7	61.2						
MLP	38s	30.7	56.5						
MLP	38m	30.7	56.5						
MLP	38d	30.7	56.5						
MLP	39s	39.4	41.5						
MLP	39m	39.4	41.5						
MLP	39d	39.4	41.5						
MLP	40s	61.5	43.9						
MLP	40m	61.5	43.9						
MLP	40d	61.5	43.9						
MLP	41s	78.5	56.2						
MLP	41m	78.5	56.2						
MLP	41d	78.5	56.2						
CPT	42	42.7	6.3	8.5	6.1	3.0	3.5	0.0	31
CPT	43	23.1	95.0	9.4	89.5	6.9	7.7	0.0	142
MLP	44s	113.3	110.7						
MLP	44m	113.3	110.7						
MLP	44d	113.3	110.7						

# Hill AFB Site 2/93 Ground-Water Data

Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
MW	2	63.6	-112.7	0.0	0.0	0.0	0.0	0.0	0.7
MW	3	16.7	32.9	15.0	37.7	3.9	5.5	0.0	285.0
MW	4	-21.2	60.0	0.0	2.4	0.0	0.0	0.0	9.3
MW	5	33.7	126.7	0.0	0.0	0.0	0.0	0.0	0.0
MW	6	20.8	35.6	0.0	2.5	1.4	2.4	0.0	22.6
CPT	3	8.2	52.3	10.8	28.1	41.0	39.8	8.5	235.0
CPT	4	22.7	82.2	0.0	0.0	0.0	0.0	0.0	0.0
CPT	5	23.1	48.5	0.0	0.0	0.0	0.0	0.0	1.5
CPT	6	27.5	59.0	0.0	0.0	0.0	0.0	0.0	0.0
CPT	8	35.44	77.5	0.0	0.0	0.0	0.0	0.0	24.0
CPT	9	52.4	43.9	0.0	2.6	0.0	1.7	0.0	90.9
CPT	10	50.2	74.7	5.9	6.1	1.6	1.8	0.0	21.2
CPT	11	42.3	93.4	0.0	0.0	0.0	0.0	0.0	0.0
CPT	12	63.6	79.1	0.0	0.0	0.0	0.0	0.0	36.5
CPT	13	68.2	39.5	0.0	25.4	5.4	9.2	12.3	801.0
CPT	14	50.6	99.4	0.0	0.0	0.0	0.0	0.0	0.0
CPT	15	99.0	132.2	49.9	6.2	2.1	2.9	0.6	244.5
CPT	16	84.9	153.4	0.0	0.0	0.0	0.0	0.0	0.0
CPT	17	113.7	110.7	0.0	4.7	2.8	2.8	0.0	44.5
CPT	18	37.9	30.9	3.9	19.8	32.1	19.2	96.4	2910.0
CPT	20	85.4	36.3	0.0	6.5	3.3	3.7	0.0	31.2
CPT	21	110.8	147.7	0.0	0.0	0.0	0.0	0.0	9.3
CPT	25	84.5	22.7	0.0	0.0	0.0	0.0	0.0	9.1
CPT	26	18.3	67.7	0.0	0.0	0.0	0.0	0.0	0.0
CPT	27	67.1	54.8	2.5	3.3	2.2	3.2	0.0	122.0
CPT	28	2.4	38.3	0.0	0.0	0.0	0.0	0.0	175.0
CPT	29	73.6	95.7	0.0	0.0	0.0	0.0	0.0	2.6
CPT	31	60.6	27.0	0.0	0.0	0.0	0.0	0.0	0.0
CPT	32	87.2	50.8	3.1	6.8	3.6	3.6	0.0	34.2
CPT	34	30.6	97.9	0.0	1.9	0.0	0.0	0.0	2.8
MLP	35s	59.4	73.8	0.0	0.0	0.0	0.0	0.0	1.0
MLP	35m	59.4	73.8	0.0	0.0	0.0	0.0	0.0	16.8
MLP	35d	59.4	73.8	0.0	2.9	6.9	3.9	51.8	1386.0
MLP	35dr	59.4	73.8	0.0	12.5	19.8	12.3	170.0	4668.0
MLP	36s	46.3	84.6	3.3	4.7	3.2	3.3	0.0	18.2
MLP	36m	46.3	84.6	0.0	0.0	0.0	0.0	0.0	0.0
MLP	36d	46.3	84.6	0.0	0.0	0.0	0.0	3.3	8.6
MLP	37s	51.7	61.2	7.4	7.7	2.0	2.9	0.0	190.0
MLP	37m	51.7	61.2	4.0	9.9	5.5	6.1	1.5	84.8
MLP	37d	51.7	61.2	0.0	2.7	0.0	1.5	0.0	7.8
MLP	38s	30.7	56.5	0.0	6.4	17.4	7.6	59.5	1928.0
MLP	38m	30.7	56.5	0.0	12.2	7.3	11.8	0.0	170.0
MLP	38d	30.7	56.5	4.6	5.2	0.0	0.0	0.0	115.0
MLP	39s	39.4	41.5	4.1	10.0	5.9	6.0	0.0	46.9
MLP	39m	39.4	41.5	0.0	1.0	0.0	0.0	0.0	2.7
MLP	39d	39.4	41.5	0.0	0.0	0.0	0.0	0.0	63.3
MLP	40m	61.5	43.9	0.0	1.7	0.0	0.0	0.0	3.6
MLP	41m	78.5	56.2	0.0	0.0	0.0	0.0	0.0	5.2
MLP	41d	78.5	56.2	13.9	29.1	15.6	71.0	23.3	1301.0
CPT	43	23.1	95.0	0.0	6.5	1.8	3.0	2.4	45.6
MLP	44s	113.3	110.7	0.0	0.0	0.0	0.0	0.0	5.6
MLP	44m	113.3	110.7	0.0	0.0	0.0	0.0	0.0	5.4
MLP	44d	113.3	110.7	0.0	3.9	0.0	5.6	0.0	12.7



# Hill AFB Site 6/93 Ground-Water Data

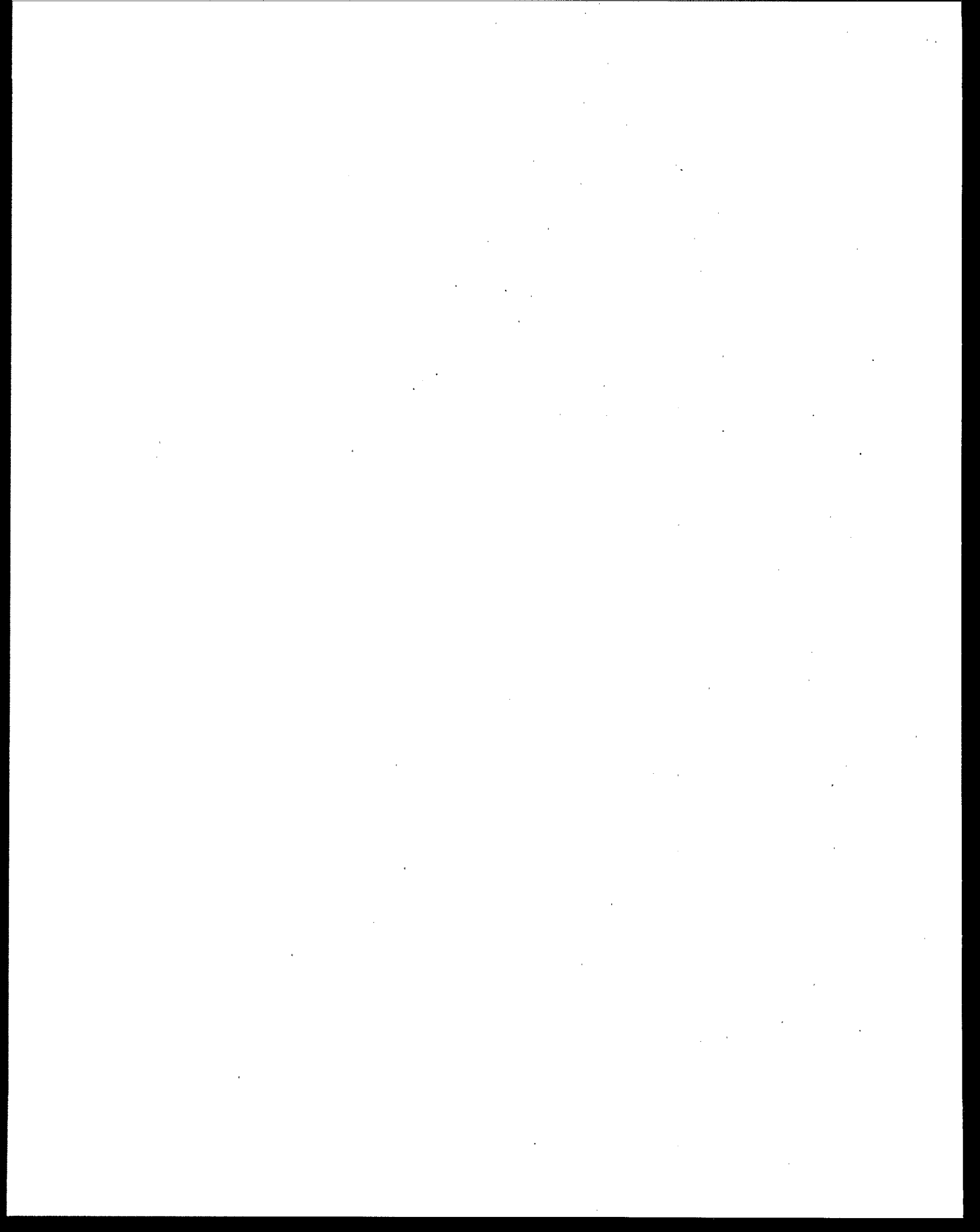
Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
MW	2	63.6	-112.7	0.0	0.4	0.0	0.0	0.8	18.5
MW	3	16.7	32.9	4.7	2.5	3.0	3.1	0.0	56.1
MW	4	-21.2	60.0	0.0	4.0	0.6	0.4	0.0	18.4
MW	5	33.7	126.7	0.0	0.0	0.0	0.0	0.0	29.8
MW	6	20.8	35.6	10.4	10.5	5.2	5.5	0.0	90.3
CPT	2	-1.0	70.7	2.1	5.2	2.9	2.9	0.0	50.9
CPT	3	8.2	52.3	8.7	17.4	8.5	9.8	0.0	94.6
CPT	4	22.7	82.2	0.0	0.0	0.0	0.0	0.0	5.4
CPT	5	23.1	48.5	9.1	3.1	1.2	1.2	3.6	44.0
CPT	6	27.5	59.0	0.0	2.8	1.1	0.8	0.0	9.2
CPT	8	35.44	77.5	0.0	0.0	0.0	0.0	0.0	31.2
CPT	9	52.4	43.9	8.7	10.3	13.0	15.5	0.0	187.0
CPT	10	50.2	74.7	34.7	15.2	7.3	9.0	0.0	205.0
CPT	11	42.3	93.4	7.6	7.1	2.9	3.0	0.0	61.8
CPT	12	63.6	79.1	3.1	9.2	5.4	6.5	0.0	170.0
CPT	13	68.2	39.5	36.7	9.1	11.8	78.4	66.5	2665.0
CPT	14	50.6	99.4	4.9	4.9	2.4	2.3	0.0	42.7
CPT	15	99.0	132.2	1.7	1.1	0.0	0.0	0.0	7.9
CPT	16	84.9	153.4	0.0	1.1	0.0	0.7	2.3	15.1
CPT	17	113.7	110.7	1.5	2.1	1.0	2.0	0.0	24.2
CPT	18	37.9	30.9	0.0	1.2	0.0	0.0	0.0	4.6
CPT	20	85.4	36.3	5.7	6.2	2.8	2.6	0.0	47.7
CPT	21	110.8	147.7	1.3	1.4	0.4	0.0	1.2	19.9
CPT	25	84.5	22.7	4.8	10.4	5.0	5.7	0.0	60.9
CPT	26	18.3	67.7	3.1	2.2	3.7	3.3	0.0	45.8
CPT	27	67.1	54.8	2.9	6.2	1.9	1.4	0.0	45.9
CPT	28	2.4	38.3	4.8	10.3	5.0	5.8	1.6	70.5
CPT	29	73.6	95.7	0.0	2.1	5.9	0.0	0.0	241.0
CPT	30	119.5	159.0	0.4	1.9	0.9	0.0	1.3	24.4
CPT	31	60.6	27.0	3.5	3.0	2.6	2.4	0.0	35.7
CPT	32	87.2	50.8	3.1	4.6	2.4	2.6	0.0	37.6
CPT	33	79.7	77.7	0.0	1.0	0.4	0.0	3.7	41.8
CPT	34	30.6	97.9	2.1	2.0	0.5	0.5	0.3	13.5
MLP	35s	59.4	73.8	0.0	0.6	0.0	0.0	0.0	144.0
MLP	35m	59.4	73.8	0.0	0.0	0.0	0.0	0.0	4.4
MLP	35d	59.4	73.8	21.1	18.3	6.6	6.1	0.0	97.4
MLP	35dr	59.4	73.8	3.3	2.9	0.0	0.4	0.0	14.6
MLP	36m	46.3	84.6	0.0	1.5	0.0	1.3	0.0	32.1
MLP	36d	46.3	84.6	7.2	3.3	0.0	1.5	0.0	36.2
MLP	37s	51.7	61.2	0.0	0.6	0.0	0.0	0.0	7.1
MLP	37m	51.7	61.2	0.0	0.5	0.0	0.0	0.0	3.0
MLP	37d	51.7	61.2	0.0	1.0	0.0	0.0	0.0	25.4
MLP	38s	30.7	56.5	0.3	0.2	0.0	0.0	4.1	21.5
MLP	38m	30.7	56.5	3.5	8.8	4.1	6.5	5.8	81.9
MLP	38d	30.7	56.5	1.8	2.8	2.9	3.7	6.8	79.7
MLP	39s	39.4	41.5	2.3	3.0	1.1	1.2	1.6	21.5
MLP	39m	39.4	41.5	0.0	1.1	0.3	0.0	5.9	22.4
MLP	39d	39.4	41.5	0.9	1.4	0.3	0.0	0.0	5.8
MLP	40s	61.5	43.9	0.0	8.3	0.0	0.0	0.0	80.5
MLP	40m	61.5	43.9	3.0	3.8	0.6	0.6	0.0	35.1
MLP	40d	61.5	43.9	5.1	11.3	0.0	2.6	0.0	91.7
MLP	41s	78.5	56.2	1.1	0.3	0.0	0.0	0.0	12.6
MLP	41m	78.5	56.2	8.9	5.0	4.0	3.8	0.0	57.2
MLP	41d	78.5	56.2	0.0	1.1	0.0	0.0	0.0	9.8
CPT	42	42.7	6.3	0.0	8.4	4.3	4.8	0.0	39.9
CPT	43	23.1	95.0	0.0	0.0	0.0	0.0	0.0	1.6

# Hill AFB Site 9/93 Ground-Water Data

Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
MW	2	63.6	-112.7	3.7	4.0	1.6	1.4	0.0	113.0
MW	3	16.7	32.9	0.0	11.9	3.4	5.2	0.0	134.0
MW	4	-21.2	60.0	3.2	3.1	1.6	1.2	0.0	71.5
MW	5	33.7	126.7	4.0	2.0	0.9	2.1	0.0	73.0
MW	6	20.8	35.6	2.1	9.2	2.9	4.0	0.0	114.0
CPT	2	-1.0	70.7	0.0	0.9	0.0	0.0	0.0	42.0
CPT	3	8.2	52.3	0.0	0.0	0.0	0.0	0.0	17.0
CPT	4	22.7	82.2	0.0	0.0	0.0	0.0	0.0	5.0
CPT	5	23.1	48.5	4.4	9.3	4.0	2.4	0.0	671.0
CPT	6	27.5	59.0	0.0	0.0	0.0	0.0	0.0	238.0
CPT	8	35.4	77.5	0.0	0.0	0.0	0.0	0.0	4.0
CPT	9	52.4	43.9	0.0	0.3	0.2	0.0	0.0	36.0
CPT	10	50.2	74.7	4.8	9.4	4.5	4.0	0.0	137.0
CPT	11	42.3	93.4	0.0	0.9	0.2	0.0	0.0	38.0
CPT	13	68.2	39.5	0.0	0.3	0.0	0.0	0.0	18.0
CPT	14	50.6	99.4	0.0	0.6	0.2	0.0	0.0	11.0
CPT	15	99.0	132.2	1.7	1.6	0.0	0.5	0.0	67.0
CPT	16	84.9	153.4	0.0	0.0	0.0	0.0	0.0	186.0
CPT	17	113.7	110.7	38.9	43.4	25.3	25.5	0.0	744.0
CPT	18	37.9	30.9	1.1	0.0	0.0	0.0	0.0	36.0
CPT	21	110.8	147.7	74.0	92.0	0.0	54.2	0.0	1390.0
CPT	25	84.5	22.7	0.0	0.6	0.3	0.0	0.0	70.0
CPT	26	18.3	67.7	1.8	1.8	0.6	0.0	0.8	85.0
CPT	27	67.1	54.8	0.0	0.7	0.2	0.0	0.0	16.0
CPT	28	2.4	38.3	0.0	0.0	0.0	0.0	0.0	0.0
CPT	29	73.6	95.7	6.0	11.8	5.8	0.0	0.0	207.0
CPT	30	119.5	159.0	0.0	0.0	0.0	0.0	0.0	19.0
CPT	31	60.6	27.0	0.0	1.9	2.3	0.0	20.9	137.0
CPT	32	87.2	50.8	0.0	0.3	0.0	0.0	0.0	16.0
CPT	33	79.7	77.7	13.4	6.5	6.0	0.0	0.0	210.0
MLP	35s	59.4	73.8	0.0	0.0	0.0	0.0	0.0	0.0
MLP	36m	46.3	84.6	0.0	0.0	0.0	0.0	0.0	22.0
MLP	37s	51.7	61.2	0.0	0.0	0.0	0.0	0.0	66.0
MLP	40s	61.5	43.9	0.0	0.0	0.0	0.0	1.3	57.0
CPT	42	42.7	6.3	0.0	1.4	0.0	0.8	0.0	22.0
CPT	43	23.1	95.0	4.0	4.4	4.0	0.0	2.2	126.0

# Hill AFB Site 1/94 Ground-Water Data

Well	No.	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
MW	2	63.6	-112.7	0.0	0.0	0.0	0.0	0.0	7.6
MW	3	16.7	32.9	0.0	0.5	0.4	0.8	0.0	24.9
MW	4	-21.2	60.0	0.0	0.4	0.3	0.3	0.0	19.3
MW	5	33.7	126.7	0.6	0.0	0.0	0.0	0.0	2.9
MW	6	20.8	35.6	0.0	0.6	0.0	0.0	0.0	2.3
CPT	2	-1.0	70.7	1.4	0.1	0.0	0.0	0.0	6.9
CPT	3	8.2	52.3	0.8	0.0	0.0	0.0	0.0	4.5
CPT	5	23.1	48.5	20.7	13.6	5.1	1.1	0.0	184.0
CPT	6	27.5	59.0	0.6	0.0	0.0	0.0	0.0	4.3
CPT	8	35.4	77.5	0.0	0.5	0.3	0.5	0.0	18.7
CPT	9	52.4	43.9	0.9	0.0	0.0	0.0	0.0	3.8
CPT	10	50.2	74.7	0.0	0.6	0.4	0.8	0.0	20.4
CPT	11	42.3	93.4	0.0	0.4	0.2	0.3	0.0	17.9
CPT	12	63.6	79.1	0.0	0.8	0.2	0.6	7.9	37.4
CPT	14	50.6	99.4	0.0	0.3	0.3	0.4	0.0	19.2
CPT	15	99.0	132.2	0.0	1.2	1.3	1.8	0.0	46.0
CPT	16	84.9	153.4	0.0	1.1	1.3	1.7	0.0	51.0
CPT	17	113.7	110.7	0.0	0.6	0.6	0.9	0.0	26.3
CPT	18	37.9	30.9	0.8	0.0	0.0	0.0	0.0	27.0
CPT	20	85.4	36.3	0.0	0.0	0.0	0.0	0.0	5.5
CPT	21	110.8	147.7	0.0	1.3	1.7	2.4	0.0	64.6
CPT	25	84.5	22.7	0.0	0.0	0.0	0.0	0.0	7.1
CPT	26	18.3	67.7	0.5	0.0	0.0	0.0	0.0	3.5
CPT	28	2.4	38.3	0.8	0.0	0.0	0.0	0.0	2.5
CPT	29	73.6	95.7	0.0	0.8	0.0	2.1	0.0	35.6
CPT	30	119.5	159.0	0.0	1.7	2.2	2.7	0.0	78.6
CPT	31	60.6	27.0	0.0	0.0	0.0	0.0	0.0	7.2
CPT	32	87.2	50.8	0.0	0.7	0.6	1.0	0.0	30.2
CPT	33	79.7	77.7	0.0	0.9	1.0	1.5	0.0	40.3
CPT	34	30.6	97.9	0.0	0.4	0.4	0.7	0.0	18.6
MLP	35dr	59.4	73.8	0.0	0.4	0.1	0.6	0.0	18.5
CPT	42	42.7	6.3	0.0	0.0	0.0	0.0	0.0	6.0
CPT	43	23.1	95.0	0.0	1.1	1.2	1.8	0.0	52.0



## Appendix G

# BTEX, Naphthalene, and TPH Ground-Water Dissolved Plume Mass and Mass Center Calculations for the Hill AFB Site

### Hill AFB Site, 4/92 Data

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Benzene (µg/L)	Benzene Mass (g)	Benzene-x (g-ft)	Benzene-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	1.6	0.53	40	13
MW	2	63.6	-112.7	2,352	104.2				2,632	0.0	0.00	0	0
MW	3	16.7	32.9	2,459	98.9				2,752	36.3	2.83	47	93
MW	4	-21.2	60.0	1,680					1,880	0.0	0.00	0	0
MW	5	33.7	126.7	8,843	98.8				9,897	0.0	0.00	0	0
MW	6	20.8	35.6	2,351	98.0	87.8	88.9	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	2.83	47	93
										Center of Mass (ft,ft)		17	33
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Toluene (µg/L)	Toluene Mass (g)	Toluene-x (g-ft)	Toluene-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	0.0	0.00	0	0
MW	2	63.6	-112.7	2,352	104.2				2,632	0.0	0.00	0	0
MW	3	16.7	32.9	2,459	98.9				2,752	21.2	1.65	28	54
MW	4	-21.2	60.0	1,680					1,880	20.2	1.08	(23)	64
MW	5	33.7	126.7	8,843	98.8				9,897	0.0	0.00	0	0
MW	6	20.8	35.6	2,351	98.0	87.8	88.9	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	2.73	5	119
										Center of Mass (ft,ft)		2	44
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Ethylbenzene (µg/L)	Ethylbenzene Mass (g)	Ethylbenzene-x (g-ft)	Ethylbenzene-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	0.0	0.00	0	0
MW	2	63.6	-112.7	2,352	104.2				2,632	0.0	0.00	0	0
MW	3	16.7	32.9	2,459	98.9				2,752	29.2	2.27	38	75
MW	4	-21.2	60.0	1,680					1,880	30.2	1.51	(34)	92
MW	5	33.7	126.7	8,843	98.75				9,897	0.0	0.00	0	0
MW	6	20.8	35.6	2,351	97.98	87.76	88.88	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	3.88	4	171
										Center of Mass (ft,ft)		1	44
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	p-Xylene (µg/L)	p-Xylene Mass (g)	p-Xylene-x (g-ft)	p-Xylene-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	0.0	0.00	0	0
MW	2	63.6	-112.7	2,352	104.21				2,632	0.0	0.00	0	0
MW	3	16.7	32.9	2,459	98.9				2,752	95.3	7.42	124	244
MW	4	-21.2	60.0	1,680					1,880	126.0	6.71	(142)	402
MW	5	33.7	126.7	8,843	98.75				9,897	0.0	0.00	0	0
MW	6	20.8	35.6	2,351	97.98	87.76	88.88	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	14.13	(18)	646
										Center of Mass (ft,ft)		(1)	46
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	0.0	0.00	0	0
MW	2	63.6	-112.7	2,352	104.21				2,632	0.0	0.00	0	0
MW	3	16.7	32.9	2,459	98.9				2,752	29.5	2.31	39	76
MW	4	-21.2	60.0	1,680					1,880	0.0	0.00	0	0
MW	5	33.7	126.7	8,843	98.75				9,897	0.0	0.00	0	0
MW	6	20.8	35.6	2,351	97.98	87.76	88.88	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	2.31	39	76
										Center of Mass (ft,ft)		17	33
Sample Location Designation	No.	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Total (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	1	74.3	24.3	10,419					11,661	7.4	2.43	180	59
MW	2	63.6	-112.7	2,352	104.21				2,632	2.3	0.17	11	(19)
MW	3	16.7	32.9	2,459	98.9				2,752	1408.0	107.59	1,833	3,608
MW	4	-21.2	60.0	1,680					1,880	223.0	11.57	(252)	712
MW	5	33.7	126.7	8,843	98.75				9,897	13.5	3.78	122	479
MW	6	20.8	35.6	2,351	97.98	87.76	88.88	1.1	2,631	0.0	0.00	0	0
						Max Depth (ft)		1.1		Totals =	127.94	1,900	4,838
										Center of Mass (ft,ft)		15	38

# Hill AFB Site, 8/92 Data

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Assigned Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Toluene (µg/L)	Toluene Mass (g)	Toluene-x (g-ft)	Toluene-y (g-ft)
MW	2	63.4	-112.7	2,496	104.2				5,025	0.0	0.00	0	0
MW	3	16.7	32.9	610	98.9				1,228	8.6	0.30	0	10
MW	4	31.7	126.7	1,385					2,788	0.0	0.00	0	0
MW	5	20.8	35.4	263	98.8				533	0.0	0.00	0	0
CH	1	38.2	-111.8	3,201	101.1	91.0			6,442	9.3	1.70	63	23
CH	2	-1.0	70.7	992	98.1	88.0	89.0	1.00	1,996	0.0	0.00	0	0
CH	3	8.2	52.3	341	98.7	88.2	89.2	0.99	587	0.0	0.00	0	0
CH	4	22.7	82.2	281	98.0	87.8	88.8	1.00	566	0.0	0.00	0	0
CH	5	20.1	48.3	189					380	10.0	0.11	2	3
CH	6	27.3	59.0	244	98.3	88.0	89.1	1.01	491	0.0	0.00	0	0
CH	7	38.0	44.2	374	99.2	88.7			753	159.0	3.39	129	130
CH	8	35.4	77.3	250	98.2	87.8	88.8	1.00	503	0.0	0.00	0	0
CH	9	37.4	43.9	283	98.9	88.6	89.6	1.02	570	0.0	0.00	0	0
CH	10	30.2	74.7	135	98.1	87.7	88.7	1.02	311	0.0	0.00	0	0
CH	11	42.3	93.4	130	97.7	87.3	88.3	1.01	301	0.0	0.00	0	0
CH	12	63.4	79.1	120	98.1	87.3	88.3	0.99	242	6.9	0.00	0	0
CH	13	68.3	39.3	228	99.0	88.2	89.2	1.02	525	22.2	0.33	28	13
CH	14	30.4	99.4	228	97.4	87.0	88.0	1.00	1,249	0.0	0.00	0	0
CH	15	99.0	132.2	890	98.1	85.3	86.3	1.01	1,791	0.0	0.00	0	0
CH	16	84.9	153.4	1,025	98.6	85.9	86.9	0.99	2,063	0.0	0.00	0	0
CH	17	113.7	110.7	545	98.6	85.1	87.1	2.01	1,097	0.0	0.00	0	0
CH	18	128.0	183.9	328	98.4	84.1			560	0.0	0.00	0	0
CH	19	102.4	36.3	703	99.2	88.3	89.3	1.00	1,413	0.0	0.00	0	0
CH	20	110.8	147.7	702	97.1	84.8	85.8	1.02	1,412	0.0	0.00	0	0
CH	21	126.4	89.2	1,226	99.6	88.0			2,468	0.0	0.00	0	0
CH	22	84.3	22.7	2,092	99.3	88.8			4,210	0.0	0.00	0	0
CH	23	18.3	67.7	244	98.2	88.0	89.0	1.00	491	0.0	0.00	0	0
CH	24	67.1	54.8	354	98.7	88.2	89.2	0.99	587	0.0	0.00	0	0
CH	25	2.4	38.3	833	98.9	88.8	89.8	0.99	1,721	0.0	0.00	0	0
CH	26	73.4	95.7	979	97.3	86.8	87.8	1.02	1,970	0.0	0.00	0	0
CH	27	119.5	159.0	444	98.7	84.4	85.4	1.00	894	0.0	0.00	0	0
CH	28	60.4	27.0	375	98.9	88.6	89.7	1.00	1,158	0.0	0.00	0	0
CH	29	87.2	50.8	1,140	98.8	88.1	89.0	0.99	2,295	0.0	0.00	0	0
CH	30	79.7	77.7	801	98.1	87.3	88.3	0.99	1,513	0.0	0.00	0	0
CH	31	30.4	97.9	237	97.6				477	0.0	0.00	0	0
CH	32	59.4	73.8	139	98.0	87.3	88.3	0.99	320	0.0	0.00	0	0
CH	33	46.3	84.8	120	97.9	87.5	88.5	0.93	242	0.0	0.00	0	0
CH	34	46.3	84.8		97.8				0	0.0	0.00	0	0
CH	35	51.7	61.2	253	98.4	87.8	88.8	1.00	512	0.0	0.00	0	0
CH	36	42.7	6.3	1,130	99.6	89.4	90.4	1.01	2,284	50.1	2.24	138	20
CH	43	23.1	95.0	558	97.7	87.6	88.6	1.00	1,119	0.0	0.00	0	0
CH	44	113.3	110.7	545	98.7	86.3	87.1	0.71	1,097	71.8	2.23	254	24
CH	45					Max Depth (ft)		2.01				1,010	70
CH	46											Center of Mass (ft,ft)	37
CH	47												36
CH	48												
CH	49												
CH	50												
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CH	93												
CH	94												
CH	95												
CH	96												
CH	97												
CH	98												
CH	99												
CH	100												

# Hill AFB Site, 8/92 Data (continued)

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation SOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Emulibenzene (µg/L)	Emulibenzene Mass (g)	Emulibenzene-X (g-ft)	Emulibenzene-Y (g-ft)
MW	2	63.4	-112.7	2,496	104.2				5,025	0.03	0.00	0.00	0.00
MW	3	16.7	32.9	610	98.9				1,228	28.4	0.99	1.63	32
MW	5	33.7	126.7	1,385					2,788	0.03	0.00	0.00	0.00
MW	6	20.8	35.3	265	98.8				533	0.03	0.00	0.00	0.00
CHI	1	38.2	-11.6	3,201	101.1	91.0			6,442	9.83	1.77	83	21
CHI	2	-1.0	70.7	992	98.1	88.0	89.0	1.00	1,996	0.03	0.00	0.00	0.00
CHI	3	8.2	52.3	341	98.7	88.6	89.6	0.99	897	0.03	0.00	0.00	0.00
CHI	4	22.7	82.2	281	98.0	87.8	88.8	1.00	563	0.03	0.00	0.00	0.00
CHI	5	23.1	48.5	189	98.3	88.0	89.1	1.01	360	16.9	0.20	0.00	10
CHI	7	27.3	59.0	244	98.3	88.0	89.1	1.01	491	0.03	0.00	0.00	0.00
CHI	7	38.0	44.2	373	97.2	88.7			753	321.0	6.84	288	303
CHI	8	35.4	77.3	250	98.3	87.8	88.8	1.00	503	0.03	0.00	0.00	0.00
CHI	9	32.4	43.9	283	98.9	88.2	89.2	1.02	570	73.4	1.19	62	52
CHI	10	50.2	74.7	155	98.1	87.7	88.7	1.02	311	0.03	0.00	0.00	0.00
CHI	11	42.3	93.4	150	97.7	87.2	88.2	1.01	301	0.03	0.00	0.00	0.00
CHI	12	63.4	79.1	120	98.1	87.3	88.3	0.99	242	10.0	0.07	4	3
CHI	13	48.2	39.5	260	99.0	88.4	89.4	1.02	523	0.03	0.00	0.00	0.00
CHI	14	50.6	99.4	620	97.6	87.0	88.0	1.00	1,249	0.03	0.00	0.00	0.00
CHI	15	99.0	132.2	890	98.1	85.3	86.3	1.01	1,751	0.03	0.00	0.00	0.00
CHI	16	84.9	153.4	1,025	98.6	85.9	86.9	0.99	2,043	0.03	0.00	0.00	0.00
CHI	17	113.7	110.7	545	98.3	85.1	87.1	2.01	1,097	0.03	0.00	0.00	0.00
CHI	19	128.0	165.9	338	96.4	84.1	87.1	0.99	460	0.03	0.00	0.00	0.00
CHI	20	85.4	36.3	703	97.1	86.3	89.5	1.00	1,415	24.3	0.98	84	36
CHI	21	110.8	147.7	702	97.1	84.8	85.8	1.02	1,312	0.03	0.00	0.00	0.00
CHI	22	124.1	89.2	1,226	99.6	86.0			2,488	0.03	0.00	0.00	0.00
CHI	25	84.3	22.7	2,092	99.5	88.8			4,210	0.03	0.00	0.00	0.00
CHI	26	18.3	67.7	244	98.2	88.0	89.0	1.00	491	0.03	0.00	0.00	0.00
CHI	27	67.1	54.8	324	98.7	88.6	89.2	0.66	713	30.4	0.61	41	34
CHI	28	2.4	38.3	833	98.7	88.8	89.8	0.99	1,721	0.03	0.00	0.00	0.00
CHI	29	73.6	95.7	979	97.5	86.8	87.8	1.02	1,970	0.03	0.00	0.00	0.00
CHI	30	119.5	159.0	444	96.7	84.4	85.4	1.00	894	0.03	0.00	0.00	0.00
CHI	31	60.6	27.0	575	98.9	88.3	89.3	1.00	1,158	0.03	0.00	0.00	0.00
CHI	32	87.2	30.8	1,140	98.8	88.1	89.0	0.99	2,295	0.03	0.00	0.00	0.00
CHI	33	79.7	77.7	801	98.1	87.3	88.3	0.99	1,613	163.0	7.44	593	575
CHI	34	30.6	97.9	232	97.4	87.3	88.3	0.99	477	0.03	0.00	0.00	0.00
MUP	364	39.4	73.5	136	98.0	87.5	88.5	0.99	320	0.03	0.00	0.00	0.00
MUP	365	46.3	84.6	120	97.9	87.3	88.3	0.93	242	0.03	0.00	0.00	0.00
MUP	366	46.3	84.6		97.8				0	0.03	0.00	0.00	0.00
MUP	369	51.7	61.2	252	98.4	87.8	88.8	1.00	516	0.03	0.00	0.00	0.00
CHI	42	42.7	6.3	1,135	99.4	89.4	90.4	1.01	2,284	0.03	0.00	0.00	0.00
CHI	43	23.1	95.0	556	97.7	87.6	88.6	1.00	1,119	0.03	0.00	0.00	0.00
MUP	448	113.3	110.7	545	98.7	95.3	87.1	0.71	1,097	17.2	0.00	414	404
Max Depth (m)									2.01	Totals =			
										33.87	2.50	2.24	65
									169.81	Center of Mass (ft-ft)			
										743	46		
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation SOC (ft)	Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	P-Xylene (µg/L)	P-Xylene Mass (g)	P-Xylene-X (g-ft)	P-Xylene-Y (g-ft)
MW	2	63.4	-112.7	2,496	104.2				5,025	0.00	0.00	0.00	0.00
MW	3	16.7	32.9	610	98.9				1,228	11.8	0.41	7	13
MW	5	33.7	126.7	1,385					2,788	0.00	0.00	0.00	0.00
MW	6	20.8	35.3	265	98.8				533	0.00	0.00	0.00	0.00
CHI	1	38.2	-11.6	3,201	101.1	91.0			6,442	0.00	0.00	0.00	0.00
CHI	2	-1.0	70.7	992	98.1	88.0	89.0	1.00	1,996	0.00	0.00	0.00	0.00
CHI	3	8.2	52.3	341	98.7	88.6	89.6	0.99	897	0.00	0.00	0.00	0.00
CHI	4	22.7	82.2	281	98.0	87.8	88.8	1.00	563	0.00	0.00	0.00	0.00
CHI	5	23.1	48.5	189	98.3	88.0	89.1	1.01	360	0.00	0.00	0.00	0.00
CHI	7	27.3	59.0	244	98.3	88.0	89.1	1.01	491	0.00	0.00	0.00	0.00
CHI	7	38.0	44.2	373	97.2	88.7			753	839.0	17.89	679	721
CHI	8	35.4	77.3	250	98.3	87.8	88.8	1.00	503	0.00	0.00	0.00	0.00
CHI	9	32.4	43.9	283	98.9	88.2	89.2	1.02	570	77.0	1.57	82	69
CHI	10	50.2	74.7	155	98.1	87.7	88.7	1.02	311	0.00	0.00	0.00	0.00
CHI	11	42.3	93.4	150	97.7	87.2	88.2	1.01	301	0.00	0.00	0.00	0.00
CHI	12	63.4	79.1	120	98.1	87.3	88.3	0.99	242	10.0	0.07	4	3
CHI	13	48.2	39.5	260	99.0	88.4	89.4	1.02	523	0.00	0.00	0.00	0.00
CHI	14	50.6	99.4	620	97.6	87.0	88.0	1.00	1,249	0.00	0.00	0.00	0.00
CHI	15	99.0	132.2	890	98.1	85.3	86.3	1.01	1,751	0.00	0.00	0.00	0.00
CHI	16	84.9	153.4	1,025	98.6	85.9	86.9	0.99	2,043	0.00	0.00	0.00	0.00
CHI	17	113.7	110.7	545	98.3	85.1	87.1	2.01	1,097	0.00	0.00	0.00	0.00
CHI	19	128.0	165.9	338	96.4	84.1	87.1	0.99	460	0.00	0.00	0.00	0.00
CHI	20	85.4	36.3	703	97.1	86.3	89.5	1.00	1,415	24.3	0.98	84	36
CHI	21	110.8	147.7	702	97.1	84.8	85.8	1.02	1,312	0.00	0.00	0.00	0.00
CHI	22	124.1	89.2	1,226	99.6	86.0			2,488	0.00	0.00	0.00	0.00
CHI	25	84.3	22.7	2,092	99.5	88.8			4,210	0.00	0.00	0.00	0.00
CHI	26	18.3	67.7	244	98.2	88.0	89.0	1.00	491	0.00	0.00	0.00	0.00
CHI	27	67.1	54.8	324	98.7	88.6	89.2	0.66	713	30.4	0.61	41	34
CHI	28	2.4	38.3	833	98.7	88.8	89.8	0.99	1,721	0.00	0.00	0.00	0.00
CHI	29	73.6	95.7	979	97.5	86.8	87.8	1.02	1,970	0.00	0.00	0.00	0.00
CHI	30	119.5	159.0	444	96.7	84.4	85.4	1.00	894	0.00	0.00	0.00	0.00
CHI	31	60.6	27.0	575	98.9	88.3	89.3	1.00	1,158	0.00	0.00	0.00	0.00
CHI	32	87.2	30.8	1,140	98.8	88.1	89.0	0.99	2,295	0.00	0.00	0.00	0.00
CHI	33	79.7	77.7	801	98.1	87.3	88.3	0.99	1,613	163.0	7.44	593	575
CHI	34	30.6	97.9	232	97.4	87.3	88.3	0.99	477	0.00	0.00	0.00	0.00
MUP	364	39.4	73.5	136	98.0	87.5	88.5	0.99	320	0.00	0.00	0.00	0.00
MUP	365	46.3	84.6	120	97.9	87.3	88.3	0.93	242	0.00	0.00	0.00	0.00
MUP	366	46.3	84.6		97.8				0	0.00	0.00	0.00	0.00
MUP	369	51.7	61.2	252	98.4	87.8	88.8	1.00	516	0.00	0.00	0.00	0.00
CHI	42	42.7	6.3	1,135	99.4	89.4	90.4	1.01	2,284	0.00	0.00	0.00	0.00
CHI	43	23.1	95.0	556	97.7	87.6	88.6	1.00	1,119	0.00	0.00	0.00	0.00
MUP	448	113.3	110.7	545	98.7	95.3	87.1	0.71	1,097	17.2	0.00	414	404
Max Depth (m)									2.01	Totals =			
										32.43	1.903	1.231	59
										Center of Mass (ft-ft)			

# Hill AFB Site, 8/92 Data (continued)

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	2	63.6	-112.7	2,496	104.2				5,025	0.0	0.00	0	0
MW	3	16.7	32.9	610	98.9				1,228	30.0	1.04	17	34
MW	5	33.7	126.7	1,385					2,788	0.0	0.00	0	0
MW	6	20.8	35.6	265	98.8				533	0.0	0.00	0	0
CT	1	38.2	-11.6	3,201	101.1	91.0			6,442	0.0	0.00	0	0
CT	2	-1.0	70.7	992	98.1	88.0	89.0	1.00	1,996	0.0	0.00	0	0
CT	3	8.2	52.3	341	98.7	88.6	89.6	0.99	687	0.0	0.00	0	0
CT	4	22.7	82.2	281	98.0	87.8	88.8	1.00	566	0.0	0.00	0	0
CT	5	23.1	48.5	189					360	40.4	0.43	10	21
CT	6	27.5	59.0	244	98.3	88.0	89.1	1.01	491	23.9	0.33	9	19
CT	7	38.0	44.2	374	99.2	88.7			753	349.0	7.44	283	325
CT	8	35.4	77.5	250	98.2	87.8	88.8	1.00	503	15.5	0.22	8	17
CT	9	52.4	43.9	283	98.9	88.6	89.6	1.02	570	208.0	3.36	176	147
CT	10	50.2	74.7	155	98.1	87.7	88.7	1.02	311	0.0	0.00	0	0
CT	11	42.3	93.4	150	97.7	87.2	88.2	1.01	301	0.0	0.00	0	0
CT	12	63.6	79.1	120	98.1	87.5	88.5	0.99	249	0.3	0.00	0	0
CT	13	63.6	39.5	260	99.0	88.6	89.6	1.02	523	2.2	0.03	2	1
CT	14	50.4	99.4	620	97.6	87.0	88.0	1.00	1,249	2.7	0.09	5	9
CT	15	99.0	132.2	890	98.1	85.5	86.5	1.01	1,791	3.7	0.19	19	25
CT	16	84.9	153.4	1,025	98.6	85.9	86.9	0.99	2,063	0.0	0.00	0	0
CT	17	113.7	110.7	545	98.6	85.1	87.1	2.01	1,097	0.0	0.00	0	0
CT	19	126.0	165.9	328	96.4	84.1			660	0.0	0.00	0	0
CT	20	85.4	36.3	703	99.2	88.5	89.5	1.00	1,415	55.1	2.21	188	80
CT	21	110.8	147.7	702	97.1	84.8	85.8	1.02	1,412	0.0	0.00	0	0
CT	22	126.4	82.2	1,226	99.6	86.0			2,468	0.0	0.00	0	0
CT	25	84.5	22.7	2,092	99.5	88.8			4,210	0.0	0.00	0	0
CT	26	18.3	67.7	244	98.2	88.0	89.0	1.00	491	0.0	0.00	0	0
CT	27	62.1	54.8	354	98.7	88.6	89.6	0.99	713	25.1	0.25	8	7
CT	28	2.4	38.3	855	98.7	88.8	89.8	0.99	1,721	0.0	0.00	0	0
CT	29	73.6	95.7	979	97.5	86.8	87.8	1.02	1,970	0.0	0.00	0	0
CT	30	119.5	159.0	444	96.7	84.4	85.4	1.00	894	0.0	0.00	0	0
CT	31	60.6	27.0	575	98.9	88.6	89.7	1.00	1,158	0.0	0.00	0	0
CT	32	87.2	50.8	1,140	98.8	88.1	89.0	0.99	2,295	7.8	0.51	44	26
CT	33	79.7	77.7	801	98.1	87.3	88.3	0.99	1,613	177.0	8.08	644	628
CT	34	30.6	97.9	237	97.6				477	0.0	0.00	0	0
MUP	35a	59.4	73.8	159	98.0	87.5	88.5	0.99	320	0.0	0.00	0	0
MUP	36a	46.3	84.6	120	97.9	87.5	88.5	0.93	242	0.0	0.00	0	0
MUP	37a	46.3	84.6		97.8				0	0.0	0.00	0	0
MUP	37b	51.7	61.2	256	98.4	87.8	88.8	1.00	516	0.0	0.00	0	0
CT	42	42.2	6.3	1,135	99.6	89.4	90.4	1.01	2,284	0.6	0.04	2	0
CT	43	23.1	95.0	556	97.7	87.6	88.6	1.00	1,119	0.0	0.00	0	0
MUP	44a	113.3	110.7	545	98.7	86.3	87.1	0.71	1,097	67.6	2.10	238	232
Max Depth (ft)										2.01	26.20	1,653	1,577
Center of Mass (ft,ft)												63	60
Sample Location Designation	Number	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	TPH (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	2	63.6	-112.7	2,496	104.2				5,025	12,611	1,794	114,105	-202,159
MW	3	16.7	32.9	610	98.9				1,228	2,253	79	1,310	2,579
MW	5	33.7	126.7	1,385					2,788	3	1	17	63
MW	6	20.8	35.6	265	98.8				533	4	0	1	2
CT	1	38.2	-11.6	3,201	101.1	91.0			6,442	60	11	417	-127
CT	2	-1.0	70.7	992	98.1	88.0	89.0	1.00	1,996	0	0	0	0
CT	3	8.2	52.3	341	98.7	88.6	89.6	0.99	687	41	1	7	42
CT	4	22.7	82.2	281	98.0	87.8	88.8	1.00	566	172	3	62	227
CT	5	23.1	48.5	189					360	544	6	135	284
CT	6	27.5	59.0	244	98.3	88.0	89.1	1.01	491	992	14	379	813
CT	7	38.0	44.2	374	99.2	88.7			753	40,135	856	32,503	37,861
CT	8	35.4	77.5	250	98.2	87.8	88.8	1.00	503	653	9	330	728
CT	9	52.4	43.9	283	98.9	88.6	89.6	1.02	570	6,196	100	5,244	4,388
CT	10	50.2	74.7	155	98.1	87.7	88.7	1.02	311	124	1	55	81
CT	11	42.3	93.4	150	97.7	87.2	88.2	1.01	301	107	1	39	85
CT	12	63.6	79.1	120	98.1	87.5	88.5	0.99	249	736	5	321	399
CT	13	63.6	39.5	260	99.0	88.6	89.6	1.02	523	1,234	18	1,245	721
CT	14	50.4	99.4	620	97.6	87.0	88.0	1.00	1,249	141	5	252	494
CT	15	99.0	132.2	890	98.1	85.5	86.5	1.01	1,791	294	15	1,475	1,971
CT	16	84.9	153.4	1,025	98.6	85.9	86.9	0.99	2,063	8	0	40	73
CT	17	113.7	110.7	545	98.6	85.1	87.1	2.01	1,097	8	0	28	28
CT	19	126.0	165.9	328	96.4	84.1			660	0	0	0	0
CT	20	85.4	36.3	703	99.2	88.5	89.5	1.00	1,415	2,517	101	8,602	3,665
CT	21	110.8	147.7	702	97.1	84.8	85.8	1.02	1,412	0	0	0	0
CT	22	126.4	82.2	1,226	99.6	86.0			2,468	31	0	23	16
CT	25	84.5	22.7	2,092	99.5	88.8			4,210	0	0	0	0
CT	26	18.3	67.7	244	98.2	88.0	89.0	1.00	491	0	0	0	0
CT	27	62.1	54.8	354	98.7	88.6	89.6	0.99	713	266	5	360	294
CT	28	2.4	38.3	855	98.7	88.8	89.8	0.99	1,721	25	1	3	47
CT	29	73.6	95.7	979	97.5	86.8	87.8	1.02	1,970	16	1	66	85
CT	30	119.5	159.0	444	96.7	84.4	85.4	1.00	894	0	0	0	0
CT	31	60.6	27.0	575	98.9	88.6	89.7	1.00	1,158	29	1	57	26
CT	32	87.2	50.8	1,140	98.8	88.1	89.0	0.99	2,295	196	13	1,110	647
CT	33	79.7	77.7	801	98.1	87.3	88.3	0.99	1,613	10,362	473	37,633	36,766
MUP	35a	59.4	73.8	159	98.0	87.5	88.5	0.99	320	0	0	0	0
MUP	36a	46.3	84.6	120	97.9	87.5	88.5	0.93	242	27	0	9	16
MUP	37a	46.3	84.6		97.8				0	4	0	0	0
MUP	37b	51.7	61.2	256	98.4	87.8	88.8	1.00	516	12	0	6	10
CT	42	42.2	6.3	1,135	99.6	89.4	90.4	1.01	2,284	962	62	2,654	392
CT	43	23.1	95.0	556	97.7	87.6	88.6	1.00	1,119	180	6	132	542
MUP	44a	113.3	110.7	545	98.7	86.3	87.1	0.71	1,097	12,003	373	42,237	41,268
Max Depth (ft)										2.01	26.20	1,653	1,577
Center of Mass (ft,ft)												63	60



# Hill AFB Site, 12/92 Data

Location	X Coordinate	Y Coordinate	Associated	Elevation	Elevation	Top of	Water Col	Volume	Benzene	Benzene	Benzene-x	Benzene-y
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	36.6	3.42	217
MW	3	16.7	32.9	682	98.9				902	0.0	0.00	0
MW	5	33.7	126.7	1,697					2,242	29.0	1.48	479
MW	6	20.8	35.6	406	98.8				537	0.0	0.00	0
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	17.3	0.67	15
CPT	7	38.0	44.2	888	99.2	88.7			1,174	0.0	0.00	0
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	0.0	0.00	0
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	17.5	0.16	7
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	3.9	0.20	13
CPT	13	68.2	39.5	2,431	99.0	88.4	89.4	0.84	3,212	0.0	0.00	0
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	35.4	0.81	41
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	0.0	0.00	0
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	0.0	0.00	0
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	8.1	0.97	72
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,023	0.0	0.00	0
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	13.8	1.04	63
CPT	34	30.6	97.9	310	97.8				410	0.0	0.00	0
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	8.5	1.33	57
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	9.4	0.22	5
						Max Depth (m)	1.32			Totals =	10.28	539
										Center of Mass (ft,ft)		117
												11
Location	X Coordinate	Y Coordinate	Associated	Elevation	Elevation	Top of	Water Col	Volume	Toluene	Toluene	Toluene-x	Toluene-y
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	0.0	0.00	0
MW	3	16.7	32.9	682	98.9				902	9.2	0.23	4
MW	5	33.7	126.7	1,697					2,242	34.3	2.18	73
MW	6	20.8	35.6	406	98.8				537	0.0	0.00	0
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	20.8	0.81	18
CPT	7	38.0	44.2	888	99.2	88.7			1,174	13.2	0.44	17
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	0.0	0.00	0
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	5.4	0.08	2
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	5.8	0.30	19
CPT	13	68.2	39.5	2,431	99.0	88.4	89.4	0.84	3,212	0.0	0.00	0
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	53.4	1.22	62
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	0.0	0.00	0
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	9.2	0.53	1
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	13.1	1.58	116
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,023	0.0	0.00	0
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	15.1	1.14	69
CPT	34	30.6	97.9	310	97.8				410	6.7	0.08	2
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	6.1	0.93	41
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	89.5	2.09	48
						Max Depth (m)	1.32			Totals =	11.62	473
										Center of Mass (ft,ft)		80
												41
Location	X Coordinate	Y Coordinate	Associated	Elevation	Elevation	Top of	Water Col	Volume	Ethylbenzene	Ethylbenzene	Ethylbenzene-x	Ethylbenzene-y
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	24.4	2.28	145
MW	3	16.7	32.9	682	98.9				902	0.0	0.00	0
MW	5	33.7	126.7	1,697					2,242	21.4	1.36	46
MW	6	20.8	35.6	406	98.8				537	0.0	0.00	0
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	9.8	0.38	9
CPT	7	38.0	44.2	888	99.2	88.7			1,174	0.0	0.00	0
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	0.0	0.00	0
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	15.1	0.13	6
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	9.8	0.51	33
CPT	13	68.2	39.5	2,431	99.0	88.4	89.4	0.84	3,212	0.0	0.00	0
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	34.0	0.78	39
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	8.8	0.92	102
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	2.6	0.16	6
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	6.7	0.81	59
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,023	0.0	0.00	0
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	13.2	0.99	60
CPT	34	30.6	97.9	310	97.8				410	0.0	0.00	0
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	3.0	0.47	20
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	8.9	0.18	4
						Max Depth (m)	1.32			Totals =	8.95	522
										Center of Mass (ft,ft)		38
												58

# Hill AFB Site, 12/92 Data (continued)

Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	p-Xylene (µg/L)	p-Xylene Mass (g)	p-Xylene-x (g-ft)	p-Xylene-y (g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	29.8	2.78	177	-314
MW	3	16.7	32.9	682	98.9				902	0.0	0.00	0	0
MW	5	33.7	126.7	1,697					2,242	20.8	1.32	44	167
MW	6	20.8	35.6	406	98.8				537	0.0	0.00	0	0
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	0.0	0.00	0	0
CPT	7	38.0	44.2	888	99.2	88.7			1,174	0.0	0.00	0	0
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	0.0	0.00	0	0
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	15.3	0.14	6	13
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	6.2	0.33	21	26
CPT	13	68.2	39.5	2,431	99.0	88.6	89.4	0.84	3,212	0.0	0.00	0	0
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	32.6	0.75	38	74
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	0.0	0.00	0	0
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	2.6	0.16	0	6
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	8.3	1.00	73	96
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,022	0.0	0.00	0	0
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	22.3	1.68	102	45
CPT	34	30.6	97.9	310	97.6				410	0.0	0.00	0	0
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	3.5	0.55	23	3
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	7.7	0.18	4	17
Max Depth (m)									1.32	Totals =			
Center of Mass (ft-ft)											8.87	489	134
											55	15	15
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	0.0	0.00	0	0
MW	3	16.7	32.9	682	98.9				902	0.0	0.00	0	0
MW	5	33.7	126.7	1,697					2,242	0.0	0.00	0	0
MW	6	20.8	35.6	406	98.8				537	0.0	0.00	0	0
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	0.0	0.00	0	0
CPT	7	38.0	44.2	888	99.2	88.7			1,174	0.0	0.00	0	0
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	0.0	0.00	0	0
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	1.6	0.01	1	1
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	34.2	1.79	114	142
CPT	13	68.2	39.5	2,431	99.0	88.6	89.4	0.84	3,212	0.0	0.00	0	0
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	0.0	0.00	0	0
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	0.0	0.00	0	0
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	0.0	0.00	0	0
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	0.0	0.00	0	0
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,022	0.0	0.00	0	0
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	6.0	0.45	27	12
CPT	34	30.6	97.9	310	97.6				410	0.0	0.00	0	0
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	0.0	0.00	0	0
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	0.0	0.00	0	0
Max Depth (m)									1.32	Totals =			
Center of Mass (ft-ft)											2.26	142	156
											63	69	69
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Total (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	2	63.6	-112.7	2,498	104.2				3,299	241.0	22.51	1,432	-2,537
MW	3	16.7	32.9	682	98.9				902	20.2	0.52	9	17
MW	5	33.7	126.7	1,697					2,242	160.0	10.15	342	1,286
MW	6	20.8	35.6	406	98.8				537	44.2	0.67	14	24
CPT	4	22.7	82.2	1,038	98.0	87.8	88.9	1.12	1,371	94.6	3.67	83	302
CPT	7	38.0	44.2	888	99.2	88.7			1,174	16.9	0.54	21	25
CPT	8	35.4	77.5	561	98.2	87.8	88.9	1.04	740	41.9	0.88	31	68
CPT	11	42.3	93.4	237	97.7	87.2	88.2	1.03	314	128.0	1.14	48	106
CPT	12	63.6	79.1	1,403	98.1	87.5	88.4	0.89	1,854	285.0	14.96	952	1,183
CPT	13	68.2	39.5	2,431	99.0	88.6	89.4	0.84	3,212	16.3	1.48	101	58
CPT	14	50.6	99.4	612	97.6	87.0	88.0	0.98	809	261.0	5.98	302	594
CPT	21	110.8	147.7	2,787	97.1	84.8	85.7	0.87	3,681	104.0	10.84	1,201	1,600
CPT	28	2.4	38.3	1,608	98.7	88.8	90.1	1.32	2,124	17.5	1.05	3	40
CPT	29	73.6	95.7	3,216	97.5	86.8	87.7	0.88	4,248	60.1	7.23	532	692
CPT	30	119.5	159.0	774	96.7	84.4	85.3	0.89	1,022	2.4	0.07	8	11
CPT	31	60.6	27.0	2,012	98.9	88.6	89.5	0.88	2,659	632.0	47.57	2,893	1,284
CPT	34	30.6	97.9	310	97.6				410	54.2	0.63	19	62
CPT	42	42.7	6.3	4,172	99.6	89.4	90.5	1.04	5,512	30.8	4.81	205	30
CPT	43	23.1	95.0	625	97.7	87.6	88.6	1.02	826	142.0	3.32	77	316
Max Depth (m)									1.32	Totals =			
Center of Mass (ft-ft)											138.03	8,263	5,162
											60	37	37

# Hill AFB Site, 2/93 Data

Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Benzene (µg/L)	Benzene Mass (g)	Benzene-x (g-ft)	Benzene-y (g-ft)
MW	2	63.6	-112.7	2,498	104.2				13,498	0.0	0.00	0	0
MW	3	16.7	32.9	917	98.9				4,957	15.0	2.11	35	69
MW	4	-21.2	60.0	728	98.1				3,936	0.0	0.00	0	0
MW	5	33.7	126.7	1,353	98.9				7,311	0.0	0.00	0	0
MW	6	20.8	35.6	171	98.8				927	0.0	0.00	0	0
CPT	3	8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	10.8	0.68	6	36
CPT	4	22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0
CPT	5	23.1	48.5	155					836	0.0	0.00	0	0
CPT	6	27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0
CPT	8	35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	0.0	0.00	0	0
CPT	9	52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	0.0	0.00	0	0
CPT	10	50.2	74.7	151	98.1	87.7	91.6	3.93	816	0.0	0.00	0	0
CPT	11	42.3	93.4	153	97.7	87.2	91.3	4.09	829	5.9	0.14	6	13
CPT	12	63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	0.0	0.00	0	0
CPT	13	68.2	39.5	190	99.0	88.6	92.3	3.70	1,028	0.0	0.00	0	0
CPT	14	50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0.0	0.00	0	0
CPT	15	99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	49.9	5.14	507	680
CPT	16	84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0.0	0.00	0	0
CPT	17	113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	0.0	0.00	0	0
CPT	18	37.9	30.9	1,743	99.0				9,418	3.9	1.04	39	32
CPT	19	128.0	165.9	555	96.4	84.1			2,999	0.0	0.00	0	0
CPT	20	85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	0.0	0.00	0	0
CPT	21	110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	0.0	0.00	0	0
CPT	25	84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	0.0	0.00	0	0
CPT	26	18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0.0	0.00	0	0
CPT	27	67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	2.5	0.09	6	5
CPT	28	2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	0.0	0.00	0	0
CPT	29	73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	0.0	0.00	0	0
CPT	31	60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0.0	0.00	0	0
CPT	32	87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	3.1	0.72	63	37
CPT	34	30.6	97.9	300	97.6				1,621	0.0	0.00	0	0
MLP	35s	59.4	73.8	157	98.0	87.5	90.9	3.35	848	0.0	0.00	0	0
MLP	36s	46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	1.1	0.03	1	3
MLP	37s	51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	3.8	0.16	8	10
MLP	38s	30.7	56.5	206	98.4				1,114	1.5	0.05	1	3
MLP	39s	39.4	41.5	225	98.8				1,218	1.4	0.05	2	2
MLP	40m	61.5	43.9	123	98.7				666	0.0	0.00	0	0
MLP	41m	78.5	56.2	361	98.7				1,952	7.0	0.38	30	22
CPT	43	23.1	95.0	637	97.7	87.6	91.8	5.40	3,443	0.0	0.00	0	0
MLP	44s	113.3	110.7	1,007	98.6	86.3			5,444	0.0	0.00	0	0
Max Depth (m)									5.40	Totals =			
										Center of Mass (ft-ft)			
											10.59	707	910
												67	86
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Toluene (µg/L)	Toluene Mass (g)	Toluene-x (g-ft)	Toluene-y (g-ft)
MW	2	63.6	-112.7	2,498	104.2				13,498	0.0	0.00	0	0
MW	3	16.7	32.9	917	98.9				4,957	37.7	5.29	88	174
MW	4	-21.2	60.0	728	98.1				3,936	2.4	0.27	-6	16
MW	5	33.7	126.7	1,353	98.9				7,311	0.0	0.00	0	0
MW	6	20.8	35.6	171	98.8				927	2.5	0.07	1	2
CPT	3	8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	28.1	1.77	15	93
CPT	4	22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0
CPT	5	23.1	48.5	155					836	0.0	0.00	0	0
CPT	6	27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0
CPT	8	35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	0.0	0.00	0	0
CPT	9	52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	2.6	0.08	4	4
CPT	10	50.2	74.7	151	98.1	87.7	91.6	3.93	816	0.0	0.00	0	0
CPT	11	42.3	93.4	153	97.7	87.2	91.3	4.09	829	6.1	0.14	6	13
CPT	12	63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	0.0	0.00	0	0
CPT	13	68.2	39.5	190	99.0	88.6	92.3	3.70	1,028	25.4	0.74	50	29
CPT	14	50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0.0	0.00	0	0
CPT	15	99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	6.2	0.64	63	84
CPT	16	84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0.0	0.00	0	0
CPT	17	113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	4.7	0.72	82	80
CPT	18	37.9	30.9	1,743	99.0				9,418	19.8	5.28	200	163
CPT	19	128.0	165.9	555	96.4	84.1			2,999	0.0	0.00	0	0
CPT	20	85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	6.5	0.70	60	25
CPT	21	110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	0.0	0.00	0	0
CPT	25	84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	0.0	0.00	0	0
CPT	26	18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0.0	0.00	0	0
CPT	27	67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	3.3	0.11	8	6
CPT	28	2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	0.0	0.00	0	0
CPT	29	73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	0.0	0.00	0	0
CPT	31	60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0.0	0.00	0	0
CPT	32	87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	6.8	1.58	138	80
CPT	34	30.6	97.9	300	97.6				1,621	1.9	0.09	3	9
MLP	35s	59.4	73.8	157	98.0	87.5	90.9	3.35	848	3.9	0.09	5	7
MLP	36s	46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	1.6	0.05	2	4
MLP	37s	51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	6.8	0.28	15	17
MLP	38s	30.7	56.5	206	98.4				1,114	7.9	0.25	8	14
MLP	39s	39.4	41.5	225	98.8				1,218	3.7	0.13	5	5
MLP	40m	61.5	43.9	123	98.7				666	1.7	0.03	2	1
MLP	41m	78.5	56.2	361	98.7				1,952	14.6	0.80	63	45
CPT	43	23.1	95.0	637	97.7	87.6	91.8	5.40	3,443	6.5	0.63	15	60
MLP	44s	113.3	110.7	1,007	98.6	86.3			5,444	1.3	0.20	23	22
Max Depth (m)									5.40	Totals =			
										Center of Mass (ft-ft)			
											12.96	851	956
												43	48

# Hill AFB Site, 2/93 Data (continued)

Location		X Coordinate	Y Coordinate	Associated	Elevation		Top of	Water Col	Water Col	Volume	Ethylbenzene	Ethylbenzene	Ethylbenzene-x	Ethylbenzene-y	
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)	(g-ft)	
MW	2	63.6	-112.7	2,498	104.2					13,498	0.0	0.00	0	0	
MW	3	16.7	32.9	917	98.9					4,957	3.9	0.55	9	18	
MW	4	-21.2	60.0	728	98.1					3,936	0.0	0.00	0	0	
MW	5	33.7	126.7	1,353	98.9					7,311	0.0	0.00	0	0	
MW	6	20.8	35.6	171	98.8					927	1.4	0.04	1	1	
CPI	3	8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	41.0	2.59	21	135		
CPI	4	22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0		
CPI	5	23.1	48.5	155						836	0.0	0.00	0	0	
CPI	6	27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0		
CPI	8	35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	0.0	0.00	0	0		
CPI	9	52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	0.0	0.00	0	0		
CPI	10	50.2	74.7	151	98.1	87.7	91.6	3.93	816	0.0	0.00	0	0		
CPI	11	42.3	93.4	153	97.7	87.2	91.3	4.09	829	1.6	0.04	2	4		
CPI	12	63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	0.0	0.00	0	0		
CPI	13	68.2	39.5	190	99.0	88.6	92.3	3.70	1,028	5.4	0.16	11	6		
CPI	14	50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0.0	0.00	0	0		
CPI	15	99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	2.1	0.21	21	28		
CPI	16	84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0.0	0.00	0	0		
CPI	17	113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	2.8	0.43	49	48		
CPI	18	37.9	30.9	1,743	99.0				9,418	32.1	8.56	325	264		
CPI	19	128.0	165.9	555	96.4	84.1			2,999	0.0	0.00	0	0		
CPI	20	85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	3.3	0.36	30	13		
CPI	21	110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	0.0	0.00	0	0		
CPI	25	84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	0.0	0.00	0	0		
CPI	26	18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0.0	0.00	0	0		
CPI	27	67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	2.2	0.08	5	4		
CPI	28	2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	0.0	0.00	0	0		
CPI	29	73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	0.0	0.00	0	0		
CPI	31	60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0.0	0.00	0	0		
CPI	32	87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	3.6	0.84	73	43		
CPI	34	30.6	97.9	300	97.6				1,621	0.0	0.00	0	0		
MLP	35s	59.4	73.8	157	98.0	87.5	90.9	3.35	848	6.7	0.16	10	12		
MLP	36s	46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	1.1	0.03	1	3		
MLP	37s	51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	2.5	0.10	5	6		
MLP	38s	30.7	56.5	206	98.4				1,114	8.2	0.26	8	15		
MLP	39s	39.4	41.5	225	98.8				1,218	2.0	0.07	3	3		
MLP	40m	61.5	43.9	123	98.7				666	0.0	0.00	0	0		
MLP	41m	78.5	56.2	361	98.7				1,952	7.8	0.43	34	24		
CPI	43	23.1	95.0	637	97.7	87.6			3,443	1.8	0.18	4	17		
MLP	44s	113.3	110.7	1,007	98.6	86.3	91.8	5.40	5,444	0.0	0.00	0	0		
Max Depth (m)										5.40	Totals = 15.07				
										Center of Mass (ft,ft)				41	43

Location		X Coordinate	Y Coordinate	Associated	Elevation		Top of	Water Col	Water Col	Volume	p-Xylene	p-Xylene	p-Xylene-x	p-Xylene-y	
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)	(g-ft)	
MW	2	63.6	-112.7	2,498	104.2					13,498	0.0	0.00	0	0	
MW	3	16.7	32.9	917	98.9					4,957	5.5	0.77	13	25	
MW	4	-21.2	60.0	728	98.1					3,936	0.0	0.00	0	0	
MW	5	33.7	126.7	1,353	98.9					7,311	0.0	0.00	0	0	
MW	6	20.8	35.6	171	98.8					927	2.4	0.06	1	2	
CPI	3	8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	39.8	2.51	21	131		
CPI	4	22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0		
CPI	5	23.1	48.5	155						836	0.0	0.00	0	0	
CPI	6	27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0		
CPI	8	35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	0.0	0.00	0	0		
CPI	9	52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	1.7	0.06	3	2		
CPI	10	50.2	74.7	151	98.1	87.7	91.6	3.93	816	0.0	0.00	0	0		
CPI	11	42.3	93.4	153	97.7	87.2	91.3	4.09	829	1.8	0.04	2	4		
CPI	12	63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	0.0	0.00	0	0		
CPI	13	68.2	39.5	190	99.0	88.6	92.3	3.70	1,028	9.2	0.27	18	11		
CPI	14	50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0.0	0.00	0	0		
CPI	15	99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	2.9	0.29	29	39		
CPI	16	84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0.0	0.00	0	0		
CPI	17	113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	2.8	0.43	49	48		
CPI	18	37.9	30.9	1,743	99.0				9,418	19.2	5.12	194	158		
CPI	19	128.0	165.9	555	96.4	84.1			2,999	0.0	0.00	0	0		
CPI	20	85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	3.7	0.40	34	15		
CPI	21	110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	0.0	0.00	0	0		
CPI	25	84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	0.0	0.00	0	0		
CPI	26	18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0.0	0.00	0	0		
CPI	27	67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	3.2	0.11	7	4		
CPI	28	2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	0.0	0.00	0	0		
CPI	29	73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	0.0	0.00	0	0		
CPI	31	60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0.0	0.00	0	0		
CPI	32	87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	3.6	0.84	73	43		
CPI	34	30.6	97.9	300	97.6				1,621	0.0	0.00	0	0		
MLP	35s	59.4	73.8	157	98.0	87.5	90.9	3.35	848	4.1	0.10	6	7		
MLP	36s	46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	1.1	0.03	1	3		
MLP	37s	51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	3.5	0.15	8	9		
MLP	38s	30.7	56.5	206	98.4				1,114	6.5	0.20	6	11		
MLP	39s	39.4	41.5	225	98.8				1,218	2.0	0.07	3	3		
MLP	40m	61.5	43.9	123	98.7				666	0.0	0.00	0	0		
MLP	41m	78.5	56.2	361	98.7				1,952	35.5	1.96	154	110		
CPI	43	23.1	95.0	637	97.7	87.6			3,443	3.0	0.29	7	28		
MLP	44s	113.3	110.7	1,007	98.6	86.3	91.8	5.40	5,444	1.9	0.29	33	32		
Max Depth (m)										5.40	Totals = 14.00				
										Center of Mass (ft,ft)				47	49

# Hill AFB Site, 2/93 (continued)

Location	Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	2		63.6	-112.7	2,498	104.2				13,498	0.0	0.00	0	0
MW	3		16.7	32.9	917	98.9				4,957	0.0	0.00	0	0
MW	4		-21.2	60.0	728	98.1				3,936	0.0	0.00	0	0
MW	5		33.7	126.7	1,353	98.9				7,311	0.0	0.00	0	0
MW	6		20.8	35.6	171	98.8				927	0.0	0.00	0	0
CPT	3		8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	8.5	0.54	4	28
CPT	4		22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0
CPT	5		23.1	48.5	155					836	0.0	0.00	0	0
CPT	6		27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0
CPT	8		35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	0.0	0.00	0	0
CPT	9		52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	0.0	0.00	0	0
CPT	10		50.2	74.7	151	98.1	87.7	91.6	3.93	816	0.0	0.00	0	0
CPT	11		42.3	93.4	153	97.7	87.2	91.3	4.09	829	0.0	0.00	0	0
CPT	12		63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	0.0	0.00	0	0
CPT	13		68.2	39.5	190	99.0	88.4	92.3	3.70	1,028	12.3	0.36	24	14
CPT	14		50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0.0	0.00	0	0
CPT	15		99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	0.6	0.06	6	7
CPT	16		84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0.0	0.00	0	0
CPT	17		113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	0.0	0.00	0	0
CPT	18		37.9	30.9	1,743	99.0				9,418	96.4	25.70	975	794
CPT	19		128.0	165.9	555	96.4	84.1			2,999	0.0	0.00	0	0
CPT	20		85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	0.0	0.00	0	0
CPT	21		110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	0.0	0.00	0	0
CPT	25		84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	0.0	0.00	0	0
CPT	26		18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0.0	0.00	0	0
CPT	27		67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	0.0	0.00	0	0
CPT	28		2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	0.0	0.00	0	0
CPT	29		73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	0.0	0.00	0	0
CPT	31		60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0.0	0.00	0	0
CPT	32		87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	0.0	0.00	0	0
CPT	34		30.6	97.9	300	97.6				1,621	0.0	0.00	0	0
MLP	35s		59.4	73.8	157	98.0	87.5	90.9	3.35	848	55.5	1.33	72	98
MLP	36s		46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	1.1	0.03	1	3
MLP	37s		51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	0.5	0.02	1	1
MLP	38s		30.7	56.5	206	98.4				1,114	19.8	0.63	19	35
MLP	39s		39.4	41.5	225	98.8				1,218	0.0	0.00	0	0
MLP	40m		61.5	43.9	123	98.7				666	0.0	0.00	0	0
MLP	41m		78.5	56.2	361	98.7				1,952	11.7	0.64	51	36
CPT	43		23.1	95.0	637	97.7	87.6	91.8	5.40	3,443	2.4	0.23	5	22
MLP	44s		113.3	110.7	1,007	98.6	86.3			5,444	0.0	0.00	0	0
Max Depth (m)										5.40	Totals =			
											Center of Mass (ft,ft)			
											39			
Location	Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Total (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	2		63.6	-112.7	2,498	104.2				13,498	0.7	0.28	18	-32
MW	3		16.7	32.9	917	98.9				4,957	285.0	40.00	668	1,315
MW	4		-21.2	60.0	728	98.1				3,936	9.3	1.04	-22	62
MW	5		33.7	126.7	1,353	98.9				7,311	0.0	0.00	0	0
MW	6		20.8	35.6	171	98.8				927	22.6	0.59	12	21
CPT	3		8.2	52.3	413	98.7	88.6	92.7	4.06	2,231	235.0	14.84	122	776
CPT	4		22.7	82.2	400	98.0	87.8	91.9	4.12	2,160	0.0	0.00	0	0
CPT	5		23.1	48.5	155					836	1.5	0.03	1	2
CPT	6		27.5	59.0	125	98.3	88.0	91.9	3.90	678	0.0	0.00	0	0
CPT	8		35.4	77.5	259	98.2	87.8	91.9	4.04	1,400	24.0	0.95	34	74
CPT	9		52.4	43.9	212	98.9	88.6	92.4	3.84	1,147	21	3	155	129
CPT	10		50.2	74.7	151	98.1	87.7	91.6	3.93	816	0	0	0	0
CPT	11		42.3	93.4	153	97.7	87.2	91.3	4.09	829	21	0	21	46
CPT	12		63.6	79.1	392	98.1	87.5	91.3	3.85	2,120	37	2	139	173
CPT	13		68.2	39.5	190	99.0	88.4	92.3	3.70	1,028	801	23	1,590	920
CPT	14		50.6	99.4	350	97.6	87.0	91.1	4.07	1,893	0	0	0	0
CPT	15		99.0	132.2	673	98.1	85.5	89.3	3.78	3,639	245	25	2,493	3,331
CPT	16		84.9	153.4	1,031	98.6	85.9	89.9	3.95	5,571	0	0	0	0
CPT	17		113.7	110.7	1,007	98.6	85.1	89.6	4.55	5,444	45	7	779	759
CPT	18		37.9	30.9	1,743	99.0				9,418	2,910	776	29,438	23,968
CPT	19		128.0	165.9	555	96.4	84.1			2,999	0	0	0	0
CPT	20		85.4	36.3	705	99.2	88.5	91.9	3.36	3,811	31	3	287	122
CPT	21		110.8	147.7	884	97.1	84.8	88.5	3.67	4,777	9	1	139	186
CPT	25		84.5	22.7	3,386	99.5	88.8	92.3	3.50	18,298	2	5	398	107
CPT	26		18.3	67.7	434	98.2	88.0	91.9	3.90	2,346	0	0	0	0
CPT	27		67.1	54.8	227	98.7	88.6	91.2	2.61	1,224	122	4	284	232
CPT	28		2.4	38.3	685	98.7	88.8	92.7	3.97	3,703	1,368	143	343	5,495
CPT	29		73.6	95.7	1,663	97.5	86.8	90.7	3.88	8,990	3	1	49	63
CPT	31		60.6	27.0	1,798	98.9	88.6	92.3	3.68	9,717	0	0	0	0
CPT	32		87.2	50.8	1,522	98.8	88.1	91.6	3.56	8,228	34	8	695	405
CPT	34		30.6	97.9	300	97.6				1,621	3	0	4	13
MLP	35s		59.4	73.8	157	98.0	87.5	90.9	3.35	848	1,518	36	2,164	2,689
MLP	36s		46.3	84.6	191	97.9	87.5	90.9	3.37	1,032	9	0	12	22
MLP	37s		51.7	61.2	274	98.4	87.8	91.8	4.04	1,482	94	4	204	242
MLP	38s		30.7	56.5	206	98.4				1,114	738	23	714	1,314
MLP	39s		39.4	41.5	225	98.8				1,218	38	1	51	54
MLP	40m		61.5	43.9	123	98.7				666	4	0	4	3
MLP	41m		78.5	56.2	361	98.7				1,952	653	36	2,832	2,030
CPT	43		23.1	95.0	637	97.7	87.6	91.8	5.40	3,443	46	4	103	422
MLP	44s		113.3	110.7	1,007	98.6	86.3			5,444	8	1	138	135
Max Depth (m)										5.40	Totals =			
											Center of Mass (ft,ft)			
											1.167			
											43,868			
											38			



# Hill AFB Site, 6/93 Data

Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Benzene (µg/L)	Benzene Mass (g)	Benzene-x (g-ft)	Benzene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	0.0	0.00	0	0
MW	3	16.7	32.9	509	98.9				3,149	4.7	0.42	7	14
MW	4	-21.2	40.0	476	98.1				2,944	0.0	0.00	0	0
MW	5	33.7	126.7	1,385	98.9				8,570	0.0	0.00	0	0
MW	6	20.8	35.6	144	98.8				1,014	10.4	0.30	6	11
CPI	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	2.1	0.16	0	12
CPI	3	8.2	52.3	317	98.7	88.6	92.7	4.09	1,663	8.7	0.48	4	25
CPI	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	0.0	0.00	0	0
CPI	5	28.1	48.5	188					1,163	9.1	0.30	7	15
CPI	6	27.5	59.0	135	98.3	88.0	92.1	4.05	838	0.0	0.00	0	0
CPI	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	0.0	0.00	0	0
CPI	9	32.4	43.9	208	98.9	88.6	92.7	4.13	1,290	8.7	0.32	17	14
CPI	10	50.2	74.7	153	98.1	87.7	91.7	4.04	946	34.7	0.93	47	69
CPI	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	7.6	0.20	7	19
CPI	12	43.6	79.1	199	98.1	87.5	91.4	3.91	1,232	3.1	0.11	7	9
CPI	13	68.2	39.5	208	99.0	88.6	92.7	4.12	1,284	36.7	1.33	91	53
CPI	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,580	4.9	0.50	25	49
CPI	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	1.7	0.27	27	36
CPI	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	0.0	0.00	0	0
CPI	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	1.5	0.52	59	57
CPI	18	37.9	30.9	441	99.0		92.8		2,729	0.0	0.00	0	0
CPI	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	5.7	0.48	58	25
CPI	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	1.3	0.13	15	20
CPI	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	4.8	2.41	204	55
CPI	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	3.1	0.18	3	12
CPI	27	67.1	54.8	123	98.7	88.6	92.0	3.47	762	2.2	0.04	4	3
CPI	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	4.8	0.58	1	22
CPI	29	73.6	95.7	933	97.5	86.8	90.7	3.91	5,774	0.0	0.00	0	0
CPI	30	119.5	159.0	773	96.7	84.4	88.0	3.59	4,781	0.4	0.05	6	8
CPI	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	3.5	0.32	19	9
CPI	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	3.1	0.75	65	38
CPI	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	0.0	0.00	0	0
CPI	34	30.6	97.9	257	97.6		91.2		1,593	2.1	0.09	3	9
MWP	35i	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	5.4	0.22	13	14
MWP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	2.4	0.10	5	9
MWP	37i	31.7	61.2	322	98.4	87.8	92.0	4.24	1,994	0.0	0.00	0	0
MWP	38i	30.7	56.5	182	98.4				1,124	1.2	0.06	2	3
MWP	39i	39.4	41.5	217	98.8				1,346	1.8	0.07	3	3
MWP	40i	61.3	43.9	123	98.7				763	2.7	0.04	4	3
MWP	41i	78.5	56.2	250	98.7				1,545	3.3	0.15	7	8
CPI	42	42.7	6.3	3,535	97.7	87.4	93.8	6.19	21,872	8.4	5.20	222	33
CPI	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	0.0	0.00	0	0
Totals =										11,731	720	623	53
Center of Mass (ft,ft)											61		
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Toluene (µg/L)	Toluene Mass (g)	Toluene-x (g-ft)	Toluene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	0.4	0.19	12	-22
MW	3	16.7	32.9	509	98.9				3,149	2.5	0.22	4	7
MW	4	-21.2	40.0	476	98.1				2,944	4.0	0.33	4	20
MW	5	33.7	126.7	1,385	98.9				8,570	0.0	0.00	0	0
MW	6	20.8	35.6	144	98.8				1,014	10.5	0.30	6	11
CPI	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	5.2	0.41	0	29
CPI	3	8.2	52.3	317	98.7	88.6	92.7	4.09	1,663	17.4	0.97	8	51
CPI	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	0.0	0.00	0	0
CPI	5	28.1	48.5	188					1,163	3.1	0.10	2	8
CPI	6	27.5	59.0	135	98.3	88.0	92.1	4.05	838	2.8	0.07	2	4
CPI	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	0.0	0.00	0	0
CPI	9	32.4	43.9	208	98.9	88.6	92.7	4.13	1,290	10.3	0.58	20	13
CPI	10	50.2	74.7	153	98.1	87.7	91.7	4.04	946	15.2	0.41	20	30
CPI	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	7.1	0.19	8	18
CPI	12	43.6	79.1	199	98.1	87.5	91.4	3.91	1,232	9.2	0.32	20	23
CPI	13	68.2	39.5	208	99.0	88.6	92.7	4.12	1,284	9.1	0.33	23	13
CPI	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,580	4.9	0.50	25	49
CPI	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	1.7	0.18	17	23
CPI	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	1.1	0.20	17	30
CPI	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	2.1	0.74	84	82
CPI	18	37.9	30.9	441	99.0		92.8		2,729	1.2	0.09	4	3
CPI	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	6.2	0.74	64	27
CPI	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	1.4	0.14	16	21
CPI	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	10.4	5.22	441	118
CPI	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	2.2	0.13	2	9
CPI	27	67.1	54.8	123	98.7	88.6	92.0	3.47	762	6.2	0.13	9	7
CPI	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	10.3	1.24	3	48
CPI	29	73.6	95.7	933	97.5	86.8	90.7	3.91	5,774	2.1	0.34	25	33
CPI	30	119.5	159.0	773	96.7	84.4	88.0	3.59	4,781	1.9	0.26	31	41
CPI	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	3.0	0.27	17	7
CPI	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	4.6	1.11	96	56
CPI	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	1.0	0.14	11	11
CPI	34	30.6	97.9	257	97.6		91.2		1,593	2.0	0.09	3	9
MWP	35i	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	5.4	0.19	12	14
MWP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	2.4	0.07	3	6
MWP	37i	31.7	61.2	322	98.4	87.8	92.0	4.24	1,994	0.7	0.04	2	2
MWP	38i	30.7	56.5	182	98.4				1,124	3.9	0.13	4	7
MWP	39i	39.4	41.5	217	98.8				1,346	1.8	0.07	3	3
MWP	40i	61.3	43.9	123	98.7				763	2.7	0.17	10	7
MWP	41i	78.5	56.2	250	98.7				1,545	3.3	0.09	7	5
CPI	42	42.7	6.3	3,535	97.7	87.4	93.8	6.19	21,872	8.4	5.20	222	33
CPI	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	0.0	0.00	0	0
Totals =										21,703	1,246	860	40
Center of Mass (ft,ft)											57		

# Hill AFB Site, 6/93 Data (continued)

Location Designation		X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Ethylbenzene (ug/L)	Ethylbenzene Mass (g)	Ethylbenzene-x (g-ft)	Ethylbenzene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	0.0	0.00	0	0
MW	3	16.7	32.9	509	98.9				3,149	3.0	0.27	4	9
MW	4	-21.2	60.0	476	98.1				2,944	0.8	0.05	-1	3
MW	5	33.7	126.7	1,385	98.9				8,570	0.0	0.00	0	0
MW	6	20.8	35.6	164	98.8				1,014	5.2	0.15	3	5
CPT	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	2.9	0.23	0	14
CPT	3	8.2	52.3	317	98.7	88.6	92.7	4.09	1,963	8.8	0.47	4	28
CPT	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	0.0	0.00	0	0
CPT	5	23.1	48.5	188					1,163	1.2	0.04	1	2
CPT	6	27.5	59.0	135	98.3	88.0	92.1	4.05	838	1.1	0.03	1	2
CPT	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	0.0	0.00	0	0
CPT	9	52.4	43.9	208	98.9	88.4	92.7	4.13	1,290	13.0	0.47	25	21
CPT	10	50.2	74.7	153	98.1	87.7	91.7	4.04	946	7.3	0.20	10	15
CPT	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	2.9	0.08	3	7
CPT	12	63.6	79.1	192	98.1	87.5	91.4	3.91	1,232	5.4	0.19	12	18
CPT	13	68.2	39.5	208	97.0	88.6	92.7	4.12	1,284	11.8	0.43	29	17
CPT	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,380	2.4	0.24	12	23
CPT	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	0.0	0.00	0	0
CPT	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	0.0	0.00	0	0
CPT	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	1.0	0.34	39	38
CPT	18	37.9	30.9	441	99.0		92.8		2,729	0.0	0.00	0	0
CPT	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	2.8	0.34	29	12
CPT	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	0.4	0.04	4	5
CPT	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	5.0	2.51	212	57
CPT	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	3.7	0.21	4	14
CPT	27	67.1	54.8	123	98.7	88.4	92.0	3.47	722	1.9	0.04	3	2
CPT	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	5.0	0.61	1	23
CPT	29	73.4	95.7	933	97.5	86.8	90.7	3.91	5,774	5.9	0.96	71	92
CPT	30	119.5	159.0	773	92.7	84.4	88.0	3.59	4,781	0.9	0.12	15	19
CPT	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	2.4	0.24	14	4
CPT	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	2.4	0.58	50	23
CPT	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	0.4	0.02	3	3
CPT	34	30.6	97.9	257	97.6		91.2		1,593	0.5	0.02	1	1
MLP	35s	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	1.7	0.06	4	4
MLP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	0.0	0.00	0	0
MLP	37s	51.7	61.2	322	98.4	87.8	92.0	4.24	1,994	0.0	0.00	0	0
MLP	38s	30.7	56.5	182	98.4				1,124	2.3	0.07	2	2
MLP	39s	39.4	41.5	217	98.8				1,345	0.0	0.02	1	1
MLP	40s	61.5	43.9	123	98.7				763	0.2	0.00	0	0
MLP	41s	78.5	56.2	250	98.7				1,545	1.3	0.06	3	3
CPT	42	42.7	6.3	3,535	97.7	87.6	93.8	6.19	21,872	4.3	2.66	114	17
CPT	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	0.0	0.00	0	0
Max Depth (m)									6.19	Totals = 11.79			
										Center of Mass (ft-ft)			
										57			

Location Designation		X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	p-Xylene (ug/L)	p-Xylene Mass (g)	p-Xylene-x (g-ft)	p-Xylene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	0.0	0.00	0	0
MW	3	16.7	32.9	509	98.9				3,149	3.1	0.28	5	9
MW	4	-21.2	60.0	476	98.1				2,944	0.4	0.03	-1	2
MW	5	33.7	126.7	1,385	98.9				8,570	0.0	0.00	0	0
MW	6	20.8	35.6	164	98.8				1,014	5.3	0.16	3	5
CPT	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	2.9	0.23	0	14
CPT	3	8.2	52.3	317	98.7	88.6	92.7	4.09	1,963	9.8	0.54	4	28
CPT	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	0.0	0.00	0	0
CPT	5	23.1	48.5	188					1,163	1.2	0.04	1	2
CPT	6	27.5	59.0	135	98.3	88.0	92.1	4.05	838	0.8	0.02	1	1
CPT	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	0.0	0.00	0	0
CPT	9	52.4	43.9	208	98.9	88.4	92.7	4.13	1,290	15.5	0.57	30	25
CPT	10	50.2	74.7	153	98.1	87.7	91.7	4.04	946	9.0	0.24	12	18
CPT	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	3.0	0.08	3	7
CPT	12	63.6	79.1	192	98.1	87.5	91.4	3.91	1,232	6.5	0.23	14	18
CPT	13	68.2	39.5	208	97.0	88.6	92.7	4.12	1,284	78.4	2.85	194	112
CPT	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,580	2.3	0.23	12	23
CPT	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	0.0	0.00	0	0
CPT	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	0.0	0.00	0	0
CPT	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	2.0	0.69	78	74
CPT	18	37.9	30.9	441	99.0		92.8		2,729	0.0	0.00	0	0
CPT	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	2.8	0.31	27	11
CPT	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	0.0	0.00	0	0
CPT	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	5.7	2.86	242	65
CPT	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	3.3	0.19	3	13
CPT	27	67.1	54.8	123	98.7	88.4	92.0	3.47	722	1.4	0.03	2	2
CPT	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	5.8	0.70	2	27
CPT	29	73.4	95.7	933	97.5	86.8	90.7	3.91	5,774	0.0	0.00	0	0
CPT	30	119.5	159.0	773	92.7	84.4	88.0	3.59	4,781	0.0	0.00	0	0
CPT	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	2.4	0.22	13	4
CPT	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	2.3	0.43	52	38
CPT	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	0.0	0.00	0	0
CPT	34	30.6	97.9	257	97.6		91.2		1,593	0.5	0.02	1	2
MLP	35s	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	1.6	0.06	3	3
MLP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	1.4	0.04	2	3
MLP	37s	51.7	61.2	322	98.4	87.8	92.0	4.24	1,994	0.0	0.00	0	0
MLP	38s	30.7	56.5	182	98.4				1,124	3.4	0.11	3	6
MLP	39s	39.4	41.5	217	98.8				1,345	0.4	0.02	1	1
MLP	40s	61.5	43.9	123	98.7				763	1.1	0.02	1	1
MLP	41s	78.5	56.2	250	98.7				1,545	1.3	0.06	4	3
CPT	42	42.7	6.3	3,535	97.7	87.6	93.8	6.19	21,872	4.8	2.97	127	19
CPT	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	0.0	0.00	0	0
Max Depth (m)									6.19	Totals = 14.55			
										Center of Mass (ft-ft)			
										58			

# Hill AFB Site, 6/93 Data (continued)

Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	0.8	0.34	21	-38
MW	3	14.7	32.9	509	98.9				3,149	0.0	0.00	0	0
MW	4	-21.3	60.0	476	98.1				2,944	0.0	0.00	0	0
MW	5	33.7	124.7	1,385	98.9				8,570	0.0	0.00	0	0
MW	6	20.8	35.4	144	98.8				1,014	0.0	0.00	0	0
CPI	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	0.0	0.00	0	0
CPI	3	8.2	52.3	317	98.7	88.4	92.7	4.09	1,963	0.0	0.00	0	0
CPI	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	0.0	0.00	0	0
CPI	5	23.1	48.5	188					1,163	3.6	0.12	3	4
CPI	6	27.5	39.0	135	98.3	88.0	92.1	4.05	838	0.0	0.00	0	0
CPI	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	0.0	0.00	0	0
CPI	9	52.4	43.9	208	98.9	88.6	92.7	4.13	1,290	0.0	0.00	0	0
CPI	10	50.2	74.7	153	98.1	87.7	91.7	4.04	948	0.0	0.00	0	0
CPI	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	0.0	0.00	0	0
CPI	12	43.6	79.1	199	98.1	87.5	91.4	3.91	1,232	0.0	0.00	0	0
CPI	13	48.2	39.5	208	99.0	88.6	92.7	4.12	1,284	66.5	2.42	165	93
CPI	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,580	0.0	0.00	0	0
CPI	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	0.0	0.00	0	0
CPI	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	2.3	0.41	35	64
CPI	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	0.0	0.00	0	0
CPI	18	37.9	30.9	441	99.0				2,729	0.0	0.00	0	0
CPI	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	0.0	0.00	0	0
CPI	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	1.2	0.12	14	18
CPI	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	0.0	0.00	0	0
CPI	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	0.0	0.00	0	0
CPI	27	67.1	54.8	123	98.7	88.6	92.0	3.47	762	0.0	0.00	0	0
CPI	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	1.4	0.19	0	0
CPI	29	73.6	95.7	933	97.5	85.8	90.7	3.91	5,774	189.0	30.90	2,273	2,952
CPI	30	119.5	159.0	773	96.7	84.4	88.0	3.59	4,781	1.3	0.18	21	26
CPI	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	0.0	0.00	0	0
CPI	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	0.0	0.00	0	0
CPI	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	3.7	0.53	42	41
CPI	34	30.6	97.9	257	97.6				1,593	0.3	0.01	0	1
MLP	35i	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	0.0	0.00	0	0
MLP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	0.0	0.00	0	0
MLP	37i	51.7	61.2	322	98.4	87.8	92.0	4.24	1,994	0.0	0.00	0	0
MLP	38i	30.7	56.5	182	98.4				1,124	5.6	0.18	5	10
MLP	39i	39.4	41.5	217	98.8				1,345	2.5	0.10	4	4
MLP	40i	61.5	43.9	123	98.7				763	0.0	0.00	0	0
MLP	41i	78.5	56.2	250	98.7				1,545	0.0	0.00	0	0
CPI	42	42.7	6.3	3,535	97.7	87.6	93.8	6.19	21,872	0.0	0.00	0	0
CPI	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	0.0	0.00	0	0
Totals =										35.50	2.584	3,194	90
Center of Mass (ft,ft)												73	90
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Total (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				15,371	19	8	512	-907
MW	3	14.7	32.9	509	98.9				3,149	56	5	84	164
MW	4	-21.2	60.0	476	98.1				2,944	18	2	-33	92
MW	5	33.7	124.7	1,385	98.9				8,570	30	7	244	912
MW	6	20.8	35.4	144	98.8				1,014	90	3	54	92
CPI	2	-1.0	70.7	448	98.1	88.0	92.1	4.08	2,771	51	4	-4	282
CPI	3	8.2	52.3	317	98.7	88.4	92.7	4.09	1,963	95	3	43	275
CPI	4	22.7	82.2	398	98.0	87.8	91.8	4.07	2,463	5	0	9	31
CPI	5	23.1	48.5	188					1,163	44	1	33	70
CPI	6	27.5	39.0	135	98.3	88.0	92.1	4.05	838	9	0	4	13
CPI	8	35.4	77.5	249	98.2	87.8	91.8	4.00	1,538	31	1	48	105
CPI	9	52.4	43.9	208	98.9	88.6	92.7	4.13	1,290	187	7	358	299
CPI	10	50.2	74.7	153	98.1	87.7	91.7	4.04	948	205	5	275	410
CPI	11	42.3	93.4	153	97.7	87.2	91.2	4.01	949	62	2	70	153
CPI	12	43.6	79.1	199	98.1	87.5	91.4	3.91	1,232	170	6	377	469
CPI	13	48.2	39.5	208	99.0	88.6	92.7	4.12	1,284	2,665	97	6,603	3,823
CPI	14	50.6	99.4	578	97.6	87.0	91.0	3.94	3,580	43	4	219	430
CPI	15	99.0	132.2	914	98.1	85.5	89.5	3.94	5,653	8	1	125	167
CPI	16	84.9	153.4	1,028	98.6	85.9	89.7	3.77	6,363	19	3	231	417
CPI	17	113.7	110.7	1,969	98.6	85.1	89.8	4.73	12,185	24	8	749	924
CPI	18	37.9	30.9	441	99.0				2,729	5	0	13	11
CPI	20	85.4	36.3	685	99.2	88.5	92.6	4.05	4,239	48	6	489	208
CPI	21	110.8	147.7	588	97.1	84.8	88.4	3.57	3,640	20	2	227	303
CPI	25	84.5	22.7	2,866	99.5	88.8	92.9	4.05	17,735	61	31	2,593	693
CPI	26	18.3	67.7	329	98.2	88.0	92.0	3.97	2,037	46	3	48	179
CPI	27	67.1	54.8	123	98.7	88.6	92.0	3.47	762	46	1	66	54
CPI	28	2.4	38.3	691	98.7	88.8	92.7	3.98	4,276	71	9	20	327
CPI	29	73.6	95.7	933	97.5	85.8	90.7	3.91	5,774	430	70	5,170	6,726
CPI	30	119.5	159.0	773	96.7	84.4	88.0	3.59	4,781	24	3	325	525
CPI	31	60.6	27.0	523	98.9	88.6	92.8	4.12	3,237	36	3	198	88
CPI	32	87.2	50.8	1,373	98.8	88.1	92.0	3.98	8,497	38	9	789	459
CPI	33	79.7	77.7	822	98.1	87.3	91.2	3.91	5,085	42	6	472	468
CPI	34	30.6	97.9	257	97.6				1,593	14	1	19	60
MLP	35i	59.4	73.8	204	98.0	87.5	92.1	4.56	1,262	65	2	138	172
MLP	36m	46.3	84.6	163	97.9	87.5	91.8	4.27	1,007	34	1	45	82
MLP	37i	51.7	61.2	322	98.4	87.8	92.0	4.24	1,994	12	1	35	41
MLP	38i	30.7	56.5	182	98.4				1,124	61	2	60	110
MLP	39i	39.4	41.5	217	98.8				1,345	17	1	25	26
MLP	40i	61.5	43.9	123	98.7				763	69	1	92	65
MLP	41i	78.5	56.2	250	98.7				1,545	27	1	91	65
CPI	42	42.7	6.3	3,535	97.7	87.6	93.8	6.19	21,872	40	25	1,054	156
CPI	43	23.1	95.0	637	98.6	86.3	91.6	5.21	3,943	2	0	4	17
Totals =										348	348	22,244	19,064
Center of Mass (ft,ft)												64	55



# Hill AFB Site, 9/93 Data

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Benzene (µg/L)	Benzene Mass (g)	Benzene-x (g-ft)	Benzene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	3.7	0.67	43	-76
MW	3	16.7	32.9	509	98.9				1,315	0.0	0.00	0	0
MW	4	21.2	60.0	476	98.1				1,229	3.2	0.11	-2	15
MW	5	33.7	126.7	1,385	98.9				3,577	4.0	0.41	14	51
MW	6	20.8	35.6	164	98.8				423	2.1	0.03	1	4
CPT	2	-1.0	70.7	448	98.1	88.0			1,157	0.0	0.00	0	0
CPT	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	0.0	0.00	0	0
CPT	4	22.7	82.2	398	98.0				1,028	0.0	0.00	0	0
CPT	5	23.1	48.5	243					628	4.4	0.08	2	4
CPT	6	27.5	59.0	280	98.3	88.0	89.3	1.45	723	0.0	0.00	0	0
CPT	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	0.0	0.00	0	0
CPT	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	0.0	0.00	0	0
CPT	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	4.8	0.14	7	10
CPT	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	0.0	0.00	0	0
CPT	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	0.0	0.00	0	0
CPT	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	0.0	0.00	0	0
CPT	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	1.3	0.11	11	13
CPT	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	0.0	0.00	0	0
CPT	17	113.7	110.7	1,969	98.6	85.1	87.6	2.58	5,086	38.9	5.40	637	620
CPT	18	37.9	30.9	465	99.0		90.2		1,201	1.1	0.04	1	1
CPT	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	92.0	3.96	439	584
CPT	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	0.6	0.13	11	3
CPT	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	1.8	0.04	1	3
CPT	27	67.1	54.8	175	98.7				452	0.0	0.00	0	0
CPT	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.00	0	0
CPT	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	6.0	0.41	30	39
CPT	30	119.5	159.0	773	96.7	84.4	85.9	1.54	1,995	0.0	0.00	0	0
CPT	31	60.6	27.0	523	98.9	88.2	90.3	1.68	1,351	0.0	0.00	0	0
CPT	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	0.3	0.03	3	2
CPT	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	6.5	0.42	33	33
MLP	35s	59.4	73.8	380	98.0	87.5			981	0.0	0.00	0	0
MLP	36m	46.3	84.6	163	97.8				420	0.0	0.00	0	0
MLP	37s	51.7	61.2	322	98.4				832	0.0	0.00	0	0
MLP	40s	61.5	43.9	223	98.7				576	0.0	0.00	0	0
CPT	42	42.7	6.3	3,535	99.6		91.1		9,129	1.4	0.36	15	2
CPT	43	23.1	95.0	719	97.7	87.6			1,857	4.4	0.23	5	22
Max Depth (ft)									2.58	Totals =			
										Center of Mass (ft,ft)			
										98			
										104			
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Toluene (µg/L)	Toluene Mass (g)	Toluene-x (g-ft)	Toluene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	4.0	0.73	46	-82
MW	3	16.7	32.9	509	98.9				1,315	11.9	0.44	7	15
MW	4	21.2	60.0	476	98.1				1,229	3.1	0.11	-2	6
MW	5	33.7	126.7	1,385	98.9				3,577	2.0	0.20	7	26
MW	6	20.8	35.6	164	98.8				423	9.2	0.11	2	4
CPT	2	-1.0	70.7	448	98.1	88.0			1,157	0.2	0.03	0	0
CPT	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	0.0	0.00	0	0
CPT	4	22.7	82.2	398					1,028	0.0	0.00	0	0
CPT	5	23.1	48.5	243					628	9.3	0.17	4	8
CPT	6	27.5	59.0	280	98.3	88.0	89.5	1.45	723	0.0	0.00	0	0
CPT	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	0.0	0.00	0	0
CPT	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	0.3	0.01	0	0
CPT	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	9.4	0.27	14	21
CPT	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	0.9	0.01	0	1
CPT	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	0.3	0.02	1	1
CPT	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	0.3	0.02	2	2
CPT	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	1.3	0.11	11	13
CPT	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	0.0	0.00	0	0
CPT	17	113.7	110.7	1,969	98.6	85.1	87.6	2.58	5,086	43.4	6.25	710	691
CPT	18	37.9	30.9	465	99.0		90.2		1,201	0.0	0.00	0	0
CPT	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	92.0	3.96	439	584
CPT	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	0.6	0.13	11	3
CPT	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	1.8	0.04	1	3
CPT	27	67.1	54.8	175	98.7				452	0.0	0.00	0	0
CPT	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.00	0	0
CPT	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	11.8	0.81	59	77
CPT	30	119.5	159.0	773	96.7	84.4	85.9	1.54	1,995	0.0	0.00	0	0
CPT	31	60.6	27.0	523	98.9	88.2	90.3	1.68	1,351	1.9	0.07	4	2
CPT	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	0.3	0.03	3	2
CPT	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	6.5	0.42	33	33
MLP	35s	59.4	73.8	380	98.0	87.5			981	0.0	0.00	0	0
MLP	36m	46.3	84.6	163					420	0.0	0.00	0	0
MLP	37s	51.7	61.2	322					832	0.0	0.00	0	0
MLP	40s	61.5	43.9	223					576	0.0	0.00	0	0
CPT	42	42.7	6.3	3,535	99.6		91.1		9,129	1.4	0.36	15	2
CPT	43	23.1	95.0	719	97.7	87.6			1,857	4.4	0.23	5	22
Max Depth (ft)									2.58	Totals =			
										Center of Mass (ft,ft)			
										94			

# Hill AFB Site, 9/93 Data (continued)

Location		X Coordinate	Y Coordinate	Associated	Elevation	Elevation	Top of	Water Col	Volume	Ethylbenzene	Ethylbenzene	Ethylbenzene	Ethylbenzene
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)	(g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	1.6	0.29	18	-33
MW	3	16.7	32.9	509	98.9				1,315	3.4	0.13	2	4
MW	4	-21.2	60.0	476	98.1				1,229	1.6	0.05	-1	3
MW	5	33.7	126.7	1,385	98.9				3,577	0.9	0.09	3	12
MW	6	20.8	35.6	164	98.8				423	2.9	0.03	1	1
CPI	2	-1.0	70.7	448	98.1	88.0			1,157	0.0	0.00	0	0
CPI	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	0.0	0.00	0	0
CPI	4	22.7	82.2	398					1,028	0.0	0.00	0	0
CPI	5	23.1	48.5	243					628	4.0	0.07	2	3
CPI	6	27.5	59.0	280	98.3	88.0	89.5	1.45	723	0.0	0.00	0	0
CPI	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	0.0	0.00	0	0
CPI	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	0.2	0.01	0	0
CPI	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	4.5	0.13	7	10
CPI	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	0.2	0.00	0	0
CPI	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	0.0	0.00	0	0
CPI	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	0.2	0.01	0	1
CPI	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	0.0	0.00	0	0
CPI	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	0.0	0.00	0	0
CPI	17	113.7	110.7	1,969	98.6	85.1	87.6	2.58	5,086	25.3	3.64	414	403
CPI	18	37.9	30.9	465	99.0		90.2		1,201	0.0	0.00	0	0
CPI	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	0.0	0.00	0	0
CPI	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	0.3	0.06	5	1
CPI	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	0.6	0.01	0	1
CPI	27	67.1	54.8	175					452	0.2	0.00	0	0
CPI	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.00	0	0
CPI	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	5.8	0.40	29	38
CPI	30	119.5	159.0	773	96.7	84.4	85.9	1.54	1,995	0.0	0.00	0	0
CPI	31	60.6	27.0	523	98.9	88.6	90.3	1.68	1,351	2.3	0.09	5	2
CPI	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	0.0	0.00	0	0
CPI	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	6.0	0.39	31	30
MLP	35s	59.4	73.8	380	98.0	87.5			981	0.0	0.00	0	0
MLP	36m	46.3	84.6	163					420	0.0	0.00	0	0
MLP	37s	51.7	61.2	322					832	0.0	0.00	0	0
MLP	40s	61.5	43.9	223					576	0.0	0.00	0	0
CPI	42	42.7	6.3	3,535	99.6		91.1		9,129	0.0	0.00	0	0
CPI	43	23.1	95.0	719	97.7				1,857	4.0	0.21	5	20
Max Depth (ft)									2.58	Totals =		5.62	498
										Center of Mass (ft,ft)		93	89
Location		X Coordinate	Y Coordinate	Associated	Elevation	Elevation	Top of	Water Col	Volume	p-Xylene	p-Xylene	p-Xylene-x	p-Xylene-y
Designation	Site	(ft)	(ft)	Area (ft²)	TOC (ft)	BOC (ft)	Elev (ft)	Depth (ft)	(ft³)	(µg/L)	Mass (g)	(g-ft)	(g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	1.4	0.25	16	-29
MW	3	16.7	32.9	509	98.9				1,315	5.2	0.19	3	6
MW	4	-21.2	60.0	476	98.1				1,229	1.2	0.04	-1	3
MW	5	33.7	126.7	1,385	98.9				3,577	2.1	0.21	7	27
MW	6	20.8	35.6	164	98.8				423	4.0	0.05	1	2
CPI	2	-1.0	70.7	448	98.1	88.0			1,157	0.0	0.00	0	0
CPI	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	0.0	0.00	0	0
CPI	4	22.7	82.2	398					1,028	0.0	0.00	0	0
CPI	5	23.1	48.5	243					628	2.4	0.04	1	2
CPI	6	27.5	59.0	280	98.3	88.0	89.5	1.45	723	0.0	0.00	0	0
CPI	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	0.0	0.00	0	0
CPI	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	0.0	0.00	0	0
CPI	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	4.0	0.12	6	9
CPI	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	0.0	0.00	0	0
CPI	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	0.0	0.00	0	0
CPI	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	0.0	0.00	0	0
CPI	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	0.5	0.03	3	4
CPI	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	0.0	0.00	0	0
CPI	17	113.7	110.7	1,969	98.6	85.1	87.6	2.58	5,086	25.5	3.67	417	406
CPI	18	37.9	30.9	465	99.0		90.2		1,201	0.0	0.00	0	0
CPI	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	54.2	2.33	258	344
CPI	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	0.0	0.00	0	0
CPI	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	0.0	0.00	0	0
CPI	27	67.1	54.8	175					452	0.0	0.00	0	0
CPI	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.00	0	0
CPI	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	0.0	0.00	0	0
CPI	30	119.5	159.0	773	96.7	84.4	85.9	1.54	1,995	0.0	0.00	0	0
CPI	31	60.6	27.0	523	98.9	88.6	90.3	1.68	1,351	0.0	0.00	0	0
CPI	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	0.0	0.00	0	0
CPI	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	0.0	0.00	0	0
MLP	35s	59.4	73.8	380	98.0	87.5			981	0.0	0.00	0	0
MLP	36m	46.3	84.6	163					420	0.0	0.00	0	0
MLP	37s	51.7	61.2	322					832	0.0	0.00	0	0
MLP	40s	61.5	43.9	223					576	0.0	0.00	0	0
CPI	42	42.7	6.3	3,535	99.6		91.1		9,129	0.8	0.19	8	1
CPI	43	23.1	95.0	719	97.7				1,857	0.0	0.00	0	0
Max Depth (ft)									2.58	Totals =		7.14	776
										Center of Mass (ft,ft)		101	109

# Hill AFB Site, 9/93 Data (continued)

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Naphthalene (µg/L)	Naphthalene Mass (g)	Naphthalene-x (g-ft)	Naphthalene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	0.0	0.0	0	0
MW	3	16.7	32.9	509	98.9				1,315	0.0	0.0	0	0
MW	4	-21.2	60.0	476	98.1				1,229	0.0	0.0	0	0
MW	5	33.7	126.7	1,385	98.9				3,577	0.0	0.0	0	0
MW	6	20.8	35.6	164	98.8				423	0.0	0.0	0	0
CPT	2	-1.0	70.7	448	98.1	88.0			1,157	0.0	0.0	0	0
CPT	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	0.0	0.0	0	0
CPT	4	22.7	82.2	398					1,028	0.0	0.0	0	0
CPT	5	23.1	48.5	243					628	0.0	0.0	0	0
CPT	6	27.3	59.0	280	98.3	88.0	89.5	1.45	723	0.0	0.0	0	0
CPT	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	0.0	0.0	0	0
CPT	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	0.0	0.0	0	0
CPT	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	0.0	0.0	0	0
CPT	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	0.0	0.0	0	0
CPT	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	0.0	0.0	0	0
CPT	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	0.0	0.0	0	0
CPT	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	0.0	0.0	0	0
CPT	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	0.0	0.0	0	0
CPT	17	113.7	110.7	1,949	98.6	85.1	87.6	2.58	5,086	0.0	0.0	0	0
CPT	18	37.9	30.9	465	99.0		90.2		1,201	0.0	0.0	0	0
CPT	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	0.0	0.0	0	0
CPT	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	0.0	0.0	0	0
CPT	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	0.0	0.0	0	0
CPT	27	67.1	54.8	175					452	0.0	0.0	0	0
CPT	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.0	0	0
CPT	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	0.0	0.0	0	0
CPT	30	119.5	159.0	773	97.7	84.4	85.9	1.54	1,995	0.0	0.0	0	0
CPT	31	60.6	27.0	523	98.9	88.6	90.3	1.68	1,351	20.9	0.80	48	22
CPT	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	0.0	0.0	0	0
CPT	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	0.0	0.0	0	0
MLP	35s	59.4	73.8	380	98.0	87.5			981	0.0	0.0	0	0
MLP	36m	46.3	84.6	163					420	0.0	0.0	0	0
MLP	37s	51.7	61.2	322					832	0.0	0.0	0	0
MLP	40s	61.5	43.9	223					576	1.3	0.02	1	1
CPT	42	42.7	6.3	3,535	99.6		91.1		9,129	0.0	0.0	0	0
CPT	43	23.1	95.0	719	97.7	87.6			1,857	2.2	0.12	3	11
Max Depth (ft)									2.58	Totals =			
										Center of Mass (ft,ft)			
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Total (µg/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				6,416	113.0	20.5	1,305	-2,313
MW	3	16.7	32.9	509	98.9				1,315	134.0	5.0	83	164
MW	4	-21.2	60.0	476	98.1				1,229	71.5	2.5	-53	149
MW	5	33.7	126.7	1,385	98.9				3,577	73.0	7.4	249	936
MW	6	20.8	35.6	164	98.8				423	114.0	1.4	28	49
CPT	2	-1.0	70.7	448	98.1	88.0			1,157	42.0	1.4	-1	97
CPT	3	8.2	52.3	317	98.7	88.6	90.1	1.44	819	17.0	0.4	3	21
CPT	4	22.7	82.2	398					1,028	5.0	0.1	3	12
CPT	5	23.1	48.5	243					628	67.0	1.1	275	578
CPT	6	27.3	59.0	280	98.3	88.0	89.5	1.45	723	236.0	4.9	134	287
CPT	8	35.4	77.5	320	98.2	87.8	89.2	1.42	826	4.0	0.1	3	7
CPT	9	52.4	43.9	350	98.9	88.6	90.2	1.62	904	36.0	0.9	48	40
CPT	10	50.2	74.7	400	98.1	87.7	89.2	1.53	1,033	137.0	4.0	201	299
CPT	11	42.3	93.4	153	97.7	87.2	88.6	1.41	396	38.0	0.4	18	40
CPT	13	68.2	39.5	708	98.1	87.5	89.0	1.51	1,829	18.0	0.9	64	37
CPT	14	50.6	99.4	578	97.6	87.0	88.4	1.41	1,494	11.0	0.5	24	48
CPT	15	99.0	132.2	914	98.1	85.5	87.0	1.43	2,360	67.0	4.5	443	592
CPT	16	84.9	153.4	1,028	98.6	85.9	87.3	1.36	2,656	186.0	14.0	1,187	2,146
CPT	17	113.7	110.7	1,949	98.6	85.1	87.6	2.58	5,086	744.0	107.1	12,175	11,854
CPT	18	37.9	30.9	465	99.0		90.2		1,201	35.0	1.2	46	38
CPT	21	110.8	147.7	588	97.1	84.8	86.2	1.39	1,519	1390.0	59.8	6,628	8,828
CPT	25	84.5	22.7	2,866	99.5	88.8	90.5	1.65	7,403	70.0	14.7	1,239	332
CPT	26	18.3	67.7	329	98.2	88.0	89.3	1.22	850	85.0	2.0	37	139
CPT	27	67.1	54.8	175					452	18.0	0.2	14	11
CPT	28	2.4	38.3	691	98.7	88.8	90.1	1.34	1,785	0.0	0.0	0	0
CPT	29	73.6	95.7	933	97.5	86.8	88.4	1.58	2,410	207.0	14.1	1,039	1,352
CPT	30	119.5	159.0	773	97.7	84.4	85.9	1.54	1,995	19.0	1.1	128	171
CPT	31	60.6	27.0	523	98.9	88.6	90.3	1.68	1,351	137.0	5.2	318	142
CPT	32	87.2	50.8	1,553	98.8	88.1	89.6	1.58	4,011	16.0	1.8	158	92
CPT	33	79.7	77.7	884	98.1	87.3	88.8	1.51	2,283	210.0	13.4	1,081	1,055
MLP	35s	59.4	73.8	380	98.0	87.5			981	0	0.0	0	0
MLP	36m	46.3	84.6	163					420	22	0.3	12	22
MLP	37s	51.7	61.2	322					832	66	1.6	80	93
MLP	40s	61.5	43.9	223					576	57	0.9	57	41
CPT	42	42.7	6.3	3,535	99.6		91.1		9,129	22	5.7	243	36
CPT	43	23.1	95.0	719	97.7	87.6			1,857	126	6.6	153	629
Max Depth (ft)									2.58	Totals =			
										Center of Mass (ft,ft)			

# Hill AFB Site, 1/94 Data

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Benzene (µg/L)	Benzene Mass (g)	Benzene-X (g-ft)	Benzene-Y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				4,081	0.0	0.00	0	0
MW	3	12.7	32.9	672	98.9				1,104	0.0	0.00	0	0
MW	4	-21.2	60.0	482	98.1				791	0.0	0.00	0	0
MW	5	33.7	124.7	1,385	98.9				2,275	0.0	0.00	0	0
MW	6	20.8	35.6	175	98.8				287	0.0	0.00	0	0
CPI	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	1.4	0.05	0	3
CPI	3	8.2	52.3	324	98.7	88.6	89.3	0.73	532	0.8	0.01	0	1
CPI	5	23.1	48.5	243					399	20.7	0.23	5	1
CPI	6	27.5	59.0	280	98.3	88.0	88.6	0.59	459	0.6	0.01	0	0
CPI	8	35.4	77.3	320	98.2	87.8	88.5	0.67	528	0.6	0.00	0	0
CPI	9	52.4	43.9	464	98.9	88.3	89.2	0.82	782	0.9	0.02	1	1
CPI	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	0.0	0.00	0	0
CPI	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	0.4	0.00	0	0
CPI	12	63.6	79.1	241	98.1	87.5	88.2	0.75	396	0.0	0.00	0	0
CPI	14	80.3	99.4	549	97.6	87.0	87.8	0.74	901	0.0	0.00	0	0
CPI	15	99.0	132.2	914	98.1	85.5	86.3	0.73	1,801	0.0	0.00	0	0
CPI	16	84.9	153.4	1,036	98.6	85.9	86.8	0.83	1,702	0.0	0.00	0	0
CPI	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	0.0	0.00	0	0
CPI	18	37.9	30.9	465	99.0		89.3		785	0.8	0.02	0	0
CPI	20	85.4	36.3	730	99.2	88.5	89.0	0.50	1,199	0.0	0.00	0	0
CPI	21	110.8	147.7	588	97.1	84.8	85.8	0.98	266	0.0	0.00	0	0
CPI	25	84.5	22.7	2,866	99.5	88.8	89.3	0.45	4,708	0.0	0.00	0	0
CPI	26	18.3	67.7	346	98.2	88.0	88.6	0.51	569	0.5	0.01	0	1
CPI	28	2.4	38.3	681	98.7	88.8	89.4	0.59	1,118	0.8	0.00	0	0
CPI	29	73.6	95.7	913	97.5	86.8	87.6	0.79	1,499	0.0	0.00	0	0
CPI	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	0.0	0.00	0	0
CPI	31	60.6	27.0	672	98.9	88.6	89.2	0.54	1,104	0.0	0.00	0	0
CPI	32	87.2	50.8	1,546	98.8	88.1	88.6	0.55	2,540	0.0	0.00	0	0
CPI	33	79.7	77.7	884	98.1	87.3	88.1	0.73	1,452	0.0	0.00	0	0
CPI	34	30.6	97.9	258	97.6		88.0		424	0.9	0.04	3	3
MLP	35	59.4	73.8	380	98.0	87.5			624	0.0	0.00	0	0
CPI	42	42.7	6.3	3,424	99.6		88.3		5,624	0.0	0.00	0	0
CPI	43	23.1	95.0	719	97.7	87.6		0.74	1,181	0.0	0.00	0	0
Max Depth (ft)										1.64	Totals =		
											Center of Mass (ft,ft)		
											24		
											67		
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Toluene (µg/L)	Toluene Mass (g)	Toluene-X (g-ft)	Toluene-Y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				4,081	0.0	0.00	0	0
MW	3	12.7	32.9	672	98.9				1,104	0.0	0.00	0	0
MW	4	-21.2	60.0	482	98.1				791	0.4	0.01	0	0
MW	5	33.7	124.7	1,385	98.9				2,275	0.0	0.00	0	0
MW	6	20.8	35.6	175	98.8				287	0.4	0.00	0	0
CPI	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	0.1	0.00	0	0
CPI	3	8.2	52.3	324	98.7	88.6	89.3	0.73	532	0.0	0.00	0	0
CPI	5	23.1	48.5	243					399	13.4	0.15	4	1
CPI	6	27.5	59.0	280	98.3	88.0	88.6	0.59	459	0.0	0.00	0	0
CPI	8	35.4	77.3	320	98.2	87.8	88.5	0.67	528	0.3	0.01	0	0
CPI	9	52.4	43.9	464	98.9	88.3	89.2	0.82	782	0.0	0.00	0	0
CPI	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	0.4	0.01	1	1
CPI	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	0.4	0.00	0	0
CPI	12	63.6	79.1	241	98.1	87.5	88.2	0.75	396	0.8	0.01	0	0
CPI	14	80.3	99.4	549	97.6	87.0	87.8	0.74	901	0.5	0.01	0	1
CPI	15	99.0	132.2	914	98.1	85.5	86.3	0.73	1,801	1.2	0.05	5	1
CPI	16	84.9	153.4	1,036	98.6	85.9	86.8	0.83	1,702	1.1	0.05	4	1
CPI	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	0.6	0.03	0	0
CPI	18	37.9	30.9	465	99.0		89.3		785	0.8	0.00	0	0
CPI	20	85.4	36.3	730	99.2	88.5	89.0	0.50	1,199	0.0	0.00	0	0
CPI	21	110.8	147.7	588	97.1	84.8	85.8	0.98	266	1.3	0.04	2	3
CPI	25	84.5	22.7	2,866	99.5	88.8	89.3	0.45	4,708	0.0	0.00	0	0
CPI	26	18.3	67.7	346	98.2	88.0	88.6	0.51	569	0.0	0.00	0	0
CPI	28	2.4	38.3	681	98.7	88.8	89.4	0.59	1,118	0.0	0.00	0	0
CPI	29	73.6	95.7	913	97.5	86.8	87.6	0.79	1,499	0.0	0.00	0	0
CPI	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	1.7	0.06	7	10
CPI	31	60.6	27.0	672	98.9	88.6	89.2	0.54	1,104	0.0	0.00	0	0
CPI	32	87.2	50.8	1,546	98.8	88.1	88.6	0.55	2,540	0.0	0.00	0	0
CPI	33	79.7	77.7	884	98.1	87.3	88.1	0.73	1,452	0.0	0.00	0	0
CPI	34	30.6	97.9	258	97.6		88.0		424	0.9	0.04	3	3
MLP	35	59.4	73.8	380	98.0	87.5			624	0.7	0.01	1	1
CPI	42	42.7	6.3	3,424	99.6		88.3		5,624	0.0	0.00	0	0
CPI	43	23.1	95.0	719	97.7	87.6		0.74	1,181	1.1	0.04	4	6
Max Depth (ft)										1.64	Totals =		
											Center of Mass (ft,ft)		
											48		
											67		

# Hill AFB Site, 1/94 Data (continued)

Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	Ethylbenzene (µg/L)	Ethylbenzene Mass (g)	Ethylbenzene-x (g-ft)	Ethylbenzene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				4,081	0.0	0.00	0	0
MW	3	16.7	32.9	672	98.9				1,104	0.4	0.01	0	0
MW	4	-21.2	60.0	482	98.1				791	0.3	0.01	0	0
MW	5	33.7	126.7	1,385	98.9				2,275	0.0	0.00	0	0
MW	6	20.8	35.6	175	98.8				287	0.0	0.00	0	0
CPT	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	0.0	0.00	0	0
CPT	3	8.2	52.3	324	98.7	88.6	89.3	0.73	532	0.0	0.00	0	0
CPT	5	23.1	48.5	243					399	5.1	0.06	1	3
CPT	6	27.5	59.0	280	98.3	88.0	88.6	0.59	459	0.0	0.00	0	0
CPT	8	35.4	77.5	320	98.2	87.8	88.5	0.67	526	0.3	0.01	0	0
CPT	9	52.4	43.9	464	98.9	88.6	89.2	0.62	762	0.0	0.00	0	0
CPT	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	0.4	0.01	1	1
CPT	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	0.2	0.00	0	0
CPT	12	63.6	79.1	241	98.1	87.5	88.2	0.75	396	0.2	0.00	0	0
CPT	14	50.6	99.4	549	97.6	87.0	87.8	0.74	901	0.3	0.01	0	1
CPT	15	99.0	132.2	914	98.1	85.5	86.3	0.73	1,501	1.3	0.06	5	7
CPT	16	84.9	153.4	1,036	98.6	85.9	86.8	0.83	1,702	1.3	0.06	5	10
CPT	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	0.6	0.05	6	6
CPT	18	37.9	30.9	465	99.0		89.3		765	0.0	0.00	0	0
CPT	20	85.4	36.3	730	99.2	88.5	89.0	0.50	1,199	0.0	0.00	0	0
CPT	21	110.8	147.7	588	97.1	84.8	85.8	0.98	966	1.7	0.05	5	7
CPT	25	84.5	22.7	2,866	99.5	88.8	89.3	0.45	4,708	0.0	0.00	0	0
CPT	26	18.3	67.7	346	98.2	88.0	88.6	0.51	569	0.0	0.00	0	0
CPT	28	2.4	38.3	681	98.7	88.8	89.4	0.59	1,118	0.0	0.00	0	0
CPT	29	73.6	95.7	913	97.5	86.8	87.6	0.79	1,499	0.0	0.00	0	0
CPT	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	2.2	0.08	9	13
CPT	31	60.6	27.0	672	98.9	88.6	89.2	0.54	1,104	0.0	0.00	0	0
CPT	32	87.2	50.8	1,546	98.8	88.1	88.6	0.55	2,540	0.4	0.04	4	2
CPT	33	79.7	77.7	884	98.1	87.3	88.1	0.73	1,452	1.0	0.04	3	3
CPT	34	30.6	97.9	258	97.6		88.0		424	0.4	0.00	0	0
MLP	35	59.4	73.8	380	98.0	87.5			624	0.4	0.00	0	0
CPT	42	42.7	6.3	3,424	99.6				5,624	0.0	0.00	0	0
CPT	43	23.1	95.0	719	97.7	87.6	88.3	0.74	1,181	1.2	0.04	1	2
Max Depth (ft)										Totals =			
										Center of Mass (ft,ft)			
										80			
										58			
										109			
Location Designation	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft²)	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft³)	p-Xylene (µg/L)	p-Xylene Mass (g)	p-Xylene-x (g-ft)	p-Xylene-y (g-ft)
MW	2	63.6	-112.7	2,484	104.2				4,081	0.0	0.00	0	0
MW	3	16.7	32.9	672	98.9				1,104	0.8	0.03	0	1
MW	4	-21.2	60.0	482	98.1				791	0.3	0.01	0	0
MW	5	33.7	126.7	1,385	98.9				2,275	0.0	0.00	0	0
MW	6	20.8	35.6	175	98.8				287	0.0	0.00	0	0
CPT	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	0.0	0.00	0	0
CPT	3	8.2	52.3	324	98.7	88.6	89.3	0.73	532	0.0	0.00	0	0
CPT	5	23.1	48.5	243					399	1.1	0.01	0	1
CPT	6	27.5	59.0	280	98.3	88.0	88.6	0.59	459	0.0	0.00	0	0
CPT	8	35.4	77.5	320	98.2	87.8	88.5	0.67	526	0.3	0.01	0	1
CPT	9	52.4	43.9	464	98.9	88.6	89.2	0.62	762	0.0	0.00	0	0
CPT	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	0.8	0.02	1	1
CPT	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	0.3	0.00	0	0
CPT	12	63.6	79.1	241	98.1	87.5	88.2	0.75	396	0.4	0.01	0	1
CPT	14	50.6	99.4	549	97.6	87.0	87.8	0.74	901	0.4	0.01	1	1
CPT	15	99.0	132.2	914	98.1	85.5	86.3	0.73	1,501	1.8	0.08	8	10
CPT	16	84.9	153.4	1,036	98.6	85.9	86.8	0.83	1,702	1.7	0.08	7	13
CPT	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	0.9	0.09	10	10
CPT	18	37.9	30.9	465	99.0		89.3		765	0.0	0.00	0	0
CPT	20	85.4	36.3	730	99.2	88.5	89.0	0.50	1,199	0.0	0.00	0	0
CPT	21	110.8	147.7	588	97.1	84.8	85.8	0.98	966	2.4	0.07	7	10
CPT	25	84.5	22.7	2,866	99.5	88.8	89.3	0.45	4,708	0.0	0.00	0	0
CPT	26	18.3	67.7	346	98.2	88.0	88.6	0.51	569	0.0	0.00	0	0
CPT	28	2.4	38.3	681	98.7	88.8	89.4	0.59	1,118	0.0	0.00	0	0
CPT	29	73.6	95.7	913	97.5	86.8	87.6	0.79	1,499	2.1	0.09	7	9
CPT	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	2.7	0.10	12	15
CPT	31	60.6	27.0	672	98.9	88.6	89.2	0.54	1,104	0.0	0.00	0	0
CPT	32	87.2	50.8	1,546	98.8	88.1	88.6	0.55	2,540	1.0	0.07	4	4
CPT	33	79.7	77.7	884	98.1	87.3	88.1	0.73	1,452	1.5	0.06	5	3
CPT	34	30.6	97.9	258	97.6		88.0		424	0.7	0.01	0	1
MLP	35	59.4	73.8	380	98.0	87.5			624	0.4	0.01	0	1
CPT	42	42.7	6.3	3,424	99.6				5,624	0.0	0.00	0	0
CPT	43	23.1	95.0	719	97.7	87.6	88.3	0.74	1,181	1.8	0.02	1	2
Max Depth (ft)										Totals =			
										Center of Mass (ft,ft)			
										83			
										87			

# Hill AFB Site, 1/94 Data (continued)

Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Naphthalene (ug/L)	Naphthalene Mass (g)	Naphthalene (g-ft)	Naphthalene (g-ft)
MW	1	43.4	-112.3	2,484	104.2				4,081	0.00	0.00	0.00	0.00
MW	2	12.7	32.9	672	98.9				1,104	0.00	0.00	0.00	0.00
MW	3	-21.2	60.0	482	98.1				791	0.00	0.00	0.00	0.00
MW	4	33.7	126.7	1,385	98.9				2,275	0.00	0.00	0.00	0.00
MW	5	20.8	35.6	1,755	98.8				2,287	0.00	0.00	0.00	0.00
CPI	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	0.00	0.00	0.00	0.00
CPI	3	8.4	52.3	324	98.7	88.3	89.3	0.73	532	0.00	0.00	0.00	0.00
CPI	4	23.1	48.5	243					399	0.00	0.00	0.00	0.00
CPI	5	27.5	59.0	280	98.3	88.0	88.6	0.59	459	0.00	0.00	0.00	0.00
CPI	6	35.4	77.3	320	98.2	87.8	88.5	0.67	526	0.00	0.00	0.00	0.00
CPI	7	32.4	43.9	444	98.3	88.4	89.2	0.62	762	0.00	0.00	0.00	0.00
CPI	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	0.00	0.00	0.00	0.00
CPI	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	0.00	0.00	0.00	0.00
CPI	12	43.4	79.1	241	98.1	87.3	88.2	0.75	396	0.00	0.00	0.00	0.00
CPI	14	50.4	99.4	549	97.3	87.0	87.8	0.73	901	0.00	0.00	0.00	0.00
CPI	15	89.0	132.2	914	96.1	85.3	86.3	0.73	1,501	0.00	0.00	0.00	0.00
CPI	16	84.9	153.4	1,036	98.4	85.9	86.8	0.83	1,702	0.00	0.00	0.00	0.00
CPI	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	0.00	0.00	0.00	0.00
CPI	18	37.9	30.3	415	99.0				325	0.00	0.00	0.00	0.00
CPI	20	85.4	32.3	730	99.2	88.5	89.0	0.50	1,199	0.00	0.00	0.00	0.00
CPI	21	110.8	147.2	588	97.1	84.8	85.8	0.98	966	0.00	0.00	0.00	0.00
CPI	23	84.5	22.7	2,866	99.5	88.8	89.3	0.43	4,708	0.00	0.00	0.00	0.00
CPI	25	18.3	27.7	344	98.2	88.0	88.6	0.51	569	0.00	0.00	0.00	0.00
CPI	26	12.7	38.3	481	98.2	88.0	88.6	0.59	1,118	0.00	0.00	0.00	0.00
CPI	28	74.2	95.7	913	97.3	86.8	87.6	0.79	1,499	0.00	0.00	0.00	0.00
CPI	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	0.00	0.00	0.00	0.00
CPI	31	60.4	27.0	672	98.9	88.6	89.2	0.54	1,104	0.00	0.00	0.00	0.00
CPI	32	87.2	50.8	1,546	98.3	88.1	88.6	0.53	2,540	0.00	0.00	0.00	0.00
CPI	33	79.7	77.7	864	98.1	87.3	88.1	0.73	1,452	0.00	0.00	0.00	0.00
CPI	34	30.4	97.9	258	97.4		88.0		424	0.00	0.00	0.00	0.00
MWP	35	59.4	73.8	380	98.0	87.5			624	2.4	0.04	3.0	3.0
CPI	42	42.7	6.3	3,424	97.6				5,624	0.00	0.00	0.00	0.00
CPI	43	23.1	95.0	719	97.7	87.6	88.3	0.74	1,181	0.00	0.00	0.00	0.00
Max Depth (ft)										1.24	Total =		
											Center of Mass (ft-ft)		
											6.2	8.0	7.7
Location	Site	X Coordinate (ft)	Y Coordinate (ft)	Associated Area (ft <sup>2</sup> )	Elevation TOC (ft)	Elevation BOC (ft)	Top of Water Col Elev (ft)	Water Col Depth (ft)	Volume (ft <sup>3</sup> )	Total (ug/L)	Total Mass (g)	Total-x (g-ft)	Total-y (g-ft)
MW	1	43.4	-112.3	2,484	104.2				4,081	7.6	0.88	58	-99
MW	2	12.7	32.9	672	98.9				1,104	24.9	0.78	13	26
MW	3	-21.2	60.0	482	98.1				791	19.3	0.43	-9	24
MW	4	33.7	126.7	1,385	98.9				2,275	2.9	0.19	8	24
MW	5	20.8	35.6	1,755	98.8				2,287	2.3	0.02	0	1
CPI	2	-1.0	70.7	692	98.1	88.0	88.8	0.82	1,137	8.9	0.22	0	16
CPI	3	8.4	52.3	324	98.7	88.3	89.3	0.73	532	4.3	0.07	1	2
CPI	4	23.1	48.5	243					399	184.0	2.08	48	101
CPI	5	27.5	59.0	280	98.3	88.0	88.6	0.59	459	4.3	0.06	2	3
CPI	6	35.4	77.3	320	98.2	87.8	88.5	0.67	526	18.7	0.28	10	22
CPI	7	32.4	43.9	444	98.3	88.4	89.2	0.62	762	3.8	0.08	4	7
CPI	10	50.2	74.7	551	98.1	87.7	88.4	0.67	906	20.4	0.52	26	39
CPI	11	42.3	93.4	161	97.7	87.2	88.1	0.84	265	17.9	0.13	6	13
CPI	12	43.4	79.1	241	98.1	87.3	88.2	0.75	396	37.4	0.42	27	33
CPI	14	50.4	99.4	549	97.3	87.0	87.8	0.73	901	19.2	0.49	25	39
CPI	15	89.0	132.2	914	96.1	85.3	86.3	0.73	1,501	45.0	1.35	138	258
CPI	16	84.9	153.4	1,036	98.4	85.9	86.8	0.83	1,702	51.0	2.46	209	377
CPI	17	113.7	110.7	2,042	98.6	85.1	86.7	1.64	3,355	28.3	2.30	284	272
CPI	18	37.9	30.3	415	99.0				325	27.0	0.38	23	13
CPI	20	85.4	32.3	730	99.2	88.5	89.0	0.50	1,199	5.5	0.19	15	7
CPI	21	110.8	147.2	588	97.1	84.8	85.8	0.98	966	64.6	1.77	126	261
CPI	23	84.5	22.7	2,866	99.5	88.8	89.3	0.43	4,708	7.1	0.95	80	21
CPI	25	18.3	27.7	344	98.2	88.0	88.6	0.51	569	3.5	0.08	1	7
CPI	26	12.7	38.3	481	98.2	88.0	88.6	0.59	1,118	2.5	0.08	0	3
CPI	28	74.2	95.7	913	97.3	86.8	87.6	0.79	1,499	35.8	1.51	111	148
CPI	30	119.5	159.0	773	96.7	84.4	85.2	0.87	1,269	78.6	2.82	337	449
CPI	31	60.4	27.0	672	98.9	88.6	89.2	0.54	1,104	7.2	0.23	14	6
CPI	32	87.2	50.8	1,546	98.3	88.1	88.6	0.53	2,540	30.2	2.17	189	110
CPI	33	79.7	77.7	864	98.1	87.3	88.1	0.73	1,452	40.3	1.64	132	129
CPI	34	30.4	97.9	258	97.4		88.0		424	18.3	0.22	7	22
MWP	35	59.4	73.8	380	98.0	87.5			624	18.5	0.33	19	24
CPI	42	42.7	6.3	3,424	97.6				5,624	6.0	0.76	41	6
CPI	43	23.1	95.0	719	97.7	87.6	88.3	0.74	1,181	32.0	1.74	40	123
Max Depth (ft)										1.24	Total =		
											Center of Mass (ft-ft)		
											29.90	2,105	2,520
											73	88	



## Appendix H

### Dissolved Oxygen Concentrations Measured in Ground-Water Monitoring Wells and Sampling Points During the Study at the Hill AFB Site

		DO	DO	DO	DO	DO	DO	DO
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Well Number		7/31/92	10/9/92	11/6/92	3/19/93	6/26/93	9/21/93	1/7/94
MW	1	2.5						
MW	2		2.2		6.8	7.9	5.5	3.5
MW	3	1.9	0.1	0.2	0.7	4.1	1.3	0.5
MW	4	3.2	2.5		3.7	4.3	5.0	3.2
MW	5			7.7	4.8	3.7	3.0	1.9
MW	6	2.0	1.3	2.5		1.8	1.5	4.9
cpt	2		1.4	3.8	4.5	5.4	4.5	4.8
cpt	3		1.0	9.4	3.0	0.9	3.3	
cpt	4			10.9	5.3	3.8	2.6	1.7
cpt	5		0.2	0.4	0.1	0.6	2.5	2.4
cpt	6		0.2	0.2	4.6	0.1	0.6	2.4
cpt	8			0.6	0.1	0.1	0.9	0.8
cpt	9		0.3	0.5	0.1	0.1	1.4	5.6
cpt	10				1.8	1.3	0.4	0.8
cpt	11			4.1	0.3	2.1	1.6	3.3
cpt	12			0.3	0.1	0.1	0.7	0.3
cpt	13		0.1	0.2	0.1	0.1	1.2	2.5
cpt	14			0.3	3.6	0.2	0.7	3.4
cpt	15		0.4	1.0	0.2	0.2	0.8	0.5
cpt	16				0.7	0.4	0.6	0.5
cpt	17		1.3	1.9	7.4	5.9	2.5	1.2
cpt	18		0.1	0.6	0.1	0.8	1.4	2.7
cpt	20		0.3	0.3	0.1	0.2	2.5	2.3
cpt	21		0.3		0.1	0.1	0.4	0.8
cpt	25		1.3	1.8	0.9	1.9	3.4	4.0
cpt	26		2.2	3.9	5.5		2.8	3.9
cpt	27		0.1	0.3	0.1	0.1	0.8	0.6

		DO	DO	DO	DO	DO	DO	DO
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Well Number		7/31/92	10/9/92	11/6/92	3/19/93	6/26/93	9/21/93	1/7/94
cpt	28		1.2	9.9	3.5	5.8	3.6	5.2
cpt	29		0.3	0.4	0.1	0.1	0.5	0.3
cpt	30		0.5		3.4	0.3	1.2	1.2
cpt	31		1.2	0.3	0.1	0.2	1.4	2.3
cpt	32			0.3	0.1	0.2	0.4	0.6
cpt	33		0.1	0.4	1.3	0.2	0.4	0.3
cpt	34			13.5	5.2	4.1	2.7	2.7
cpt	42		0.1	1.0	0.8	1.6	1.0	
cpt	43				3.4	3.3	2.9	2.2
MLP	35-8.6'			15.6		3.0		
	35-9.7'					1.2		
	35-10.7'			4.7			5.2	
MLP	36-8.5'					2.9		
	36-9.6'			5.6		3.8	2.2	
	36-10.4'			0.3		0.2		
MLP	37-8.56'					1.5		
	37-9.65'		3.4	5.8		2.8	1.3	
	37-10.15'		3.8	0.5		0.1	3.4	
	37-10.65'		2.5	0.8			1.5	
MLP	38-8.5'					2.9	2.3	
	38-9.6'					1.2	7.6	
	38-10.1'					0.1	3.0	
MLP	39-8.58'					1.6	5.8	
	39-9.7'		4.2	7.6		2.9	1.2	
	39-10.2'		4.2	3.1		0.1	0.5	
MLP	40-8.65'					0.2	2.9	
	40-9.75'		1.1	1.5		0.2	1.9	
	40-10.25'		0.3	0.5		0.2	2.3	
MLP	41-9.0'		0.1			0.2	3.2	
	41-10.15'		0.8	0.5		0.1	2.5	1.1
	41-10.65'		1.6	5.7		0.1	1.3	0.4
MLP	44-12.4'			5.4				
	44-12.9'		0.4	2.7				



## Appendix I

### Summarized BTEX, Naphthalene, and TPH Ground-Water Concentration Data Used for Plume Centerline and Mass Calculations for the Layton Site

#### 7/92 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	0	0	0	0	0	0
CPT	2	54.6	-122.4	0	0	0	0	0	0
CPT	3	-47.5	-52.8	0	0	0	0	0	0
CPT	4	-4.5	-42.8	22	79	363	1,714	3	7,840
CPT	5	-36.3	-74.6	0	0	0	0	0	4
CPT	6	108.7	55.4	0	0	0	0	0	3
CPT	7	-41.9	-2.2						5,993
CPT	8	59.4	13.7	651	635	419	1,716	105	7,661
CPT	9	-51.3	24.9	0	139	0	0	0	796
CPT	10	63.4	58.1	0	0	0	0	0	313
CPT	12	64.7	35.9	756	268	1,474	5,167	13	28,269
CPT	13	108.7	11.5	3,969	6,864	1,630	8,554	13	43,478
CPT	14	19.0	-8.9	3,490	3,139	1,054	4,747	225	23,351
CPT	15	14.3	15.4	650	137	1,408	4,789	10	24,504
CPT	16	26.2	-35.4	5,947	3,729	1,345	6,120	209	30,322
CPT	17	9.1	33.8	29	83	72	50	5	3,537
CPT	18	-4.3	-61.9	0	0	0	0	0	17
CPT	20	28.5	-58.4	5,656	4,277	2,009	9,274	548	41,899
CPT	21	37.8	-82.8	0	0	0	0	0	135
MLP	4 - 9.5	30.5	27.4	0	0	0	11	5	3,785
MLP	4 - 9.0	31.2	28.1	0	89	52	214	165	15,472
MLP	6 - 9.0	-59.9	-3.2	0	0	0	0	0	52
MW	1	103.0	35.7	137	49	21	0	0	397
MW	3	0.0	0.0	861	82	283	210	49	3,354
MW	4	-17.2	-137.5	0	0	0	0	0	4

### 12/92 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	0	1	0	0	0	2
CPT	3	-47.5	-52.8	45	57	31	64	0	392
CPT	4	-4.5	-42.8	2,693	1,907	1,030	3,375	10	15,923
CPT	5	-36.3	-74.6	0	4	0	0	0	33
CPT	8	59.4	13.7	6,032	4,555	2,870	9,898	567	78,090
CPT	9	-51.3	24.9	12	21	6	22	9	148
CPT	12	64.7	35.9	1,473	153	557	2,383	67	15,341
CPT	13	108.7	11.5	2,428	3,347	373	5,955	45	34,394
CPT	14	19.0	-8.9	7,381	6,163	1,130	8,923	36	41,841
CPT	15	14.3	15.4	413	9	441	859	42	8,532
CPT	16	26.2	-35.4	7,127	3,285	2,123	7,591	139	36,698
CPT	18	-4.3	-61.9	4	4	5	0	0	136
CPT	19	52.0	-40.6	2,808	899	737	6,037	288	32,583
CPT	20	28.5	-58.4	5,500	4,916	1,044	9,399	655	52,403
CPT	21	37.8	-82.8	0	3	0	0	0	13
MLP	5 - 9.5	-7.3	-14.3	3,664	564	420	5,503	300	21,799
MLP	6 - 8.5	-59.9	-4.2	83	59	38	120	8	618
MW	1	103.0	35.7	532	136	449	523	0	3,313
MW	3	0.0	0.0	524	69	24	73	78	2,111

### 3/93 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	0	3	0	0	0	16
CPT	3	-47.5	-52.8	60	347	77	331	11	5,995
CPT	4	-4.5	-42.8	1,165	371	432	1,479	37	7,116
CPT	5	-36.3	-74.6	0	0	0	0	0	56
CPT	7	-41.9	-2.2	33	109	59	393	42	3,150
CPT	8	59.4	13.7	4,491	2,675	1,727	7,560	545	32,537
CPT	9	-51.3	24.9	14	50	18	150	13	902
CPT	10	63.4	58.1	84	51	38	140	9	922
CPT	11	-16.0	16.5	257	862	1,778	9,836	795	37,614
CPT	12	64.7	35.9	1,215	210	77	1,634	52	10,515
CPT	13	108.7	11.5	6,644	8,805	2,599	15,763	497	156,219
CPT	14	19.0	-8.9	7,646	5,661	7,334	2,914	49	37,438
CPT	15	14.3	15.4	1,176	185	1,158	3,315	81	19,256
CPT	16	26.2	-35.4	4,664	2,773	1,517	6,317	55	30,300
CPT	17	9.1	33.8	34	23	39	51	0	783
CPT	18	-4.3	-61.9	6	16	0	0	0	81
CPT	19	52.0	-40.6	2,051	936	777	3,977	280	23,230
CPT	20	28.5	-58.4	6,996	4,473	1,946	11,441	1,544	99,832
CPT	21	37.8	-82.8	0	0	0	0	0	0
MLP	4 - 9.5	30.5	27.4	166	61	406	1,365	230	15,212
MW	1	103.0	35.7	1,831	577	83	1,448	34	8,017
MW	3	0.0	0.0	377	146	0	781	31	5,732
MW	4	-17.2	-137.5	21	23	9	46	29	347

# 6/93 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	2	0	3	3	0	92
CPT	3	-47.5	-52.8	12	22	9	19	9	1,570
CPT	4	-4.5	-42.8	0	4	0	57	0	372
CPT	5	-36.3	-74.6	15	19	9	73	9	395
CPT	7	-41.9	-2.2	0	6	7	3	2	1,109
CPT	8	59.4	13.7	5,273	2,974	1,136	8,315	502	36,004
CPT	9	-51.3	24.9	0	3	0	2	0	211
CPT	10	63.4	58.1	30	6	69	20	0	227
CPT	11	-16.0	16.5	39	66	0	2,060	369	8,886
CPT	12	64.7	35.9	933	136	206	1,202	260	8,689
CPT	13	108.7	11.5	5,545	7,297	1,591	10,325	883	63,463
CPT	14	19.0	-8.9	2,506	293	0	52	0	4,417
CPT	15	14.3	15.4	593	190	515	1,815	87	14,001
CPT	17	9.1	33.8	87	79	52	38	70	3,240
CPT	18	-4.3	-61.9	4	10	0	3	0	112
CPT	19	52.0	-40.6	2,218	679	1,007	4,672	403	23,757
CPT	20	28.5	-58.4	5,201	979	640	4,343	330	33,917
CPT	21	37.8	-82.8	7	11	1	14	0	279
MLP	4 - 9.5	30.5	27.4	142	92	80	752	177	8,138
MLP	5 - 9.0	-7.3	-14.3	2,723	374	595	3,249	209	14,938
MLP	5 - 8.5	-7.2	-15.4	2,049	313	13	3,002	177	13,068
MLP	6 - 9.0	-59.9	-3.2	7	15	5	92	0	1,618
MLP	6 - 8.5	-59.9	-4.2	11	31	28	78	0	1,607
MW	1	103.0	35.7	1,733	670	218	916	33	6,667
MW	3	0.0	0.0	21	34	0	11	32	689
MW	4	-17.2	-137.5	0	2	1	0	2	54

# 9/93 Ground-Water Data

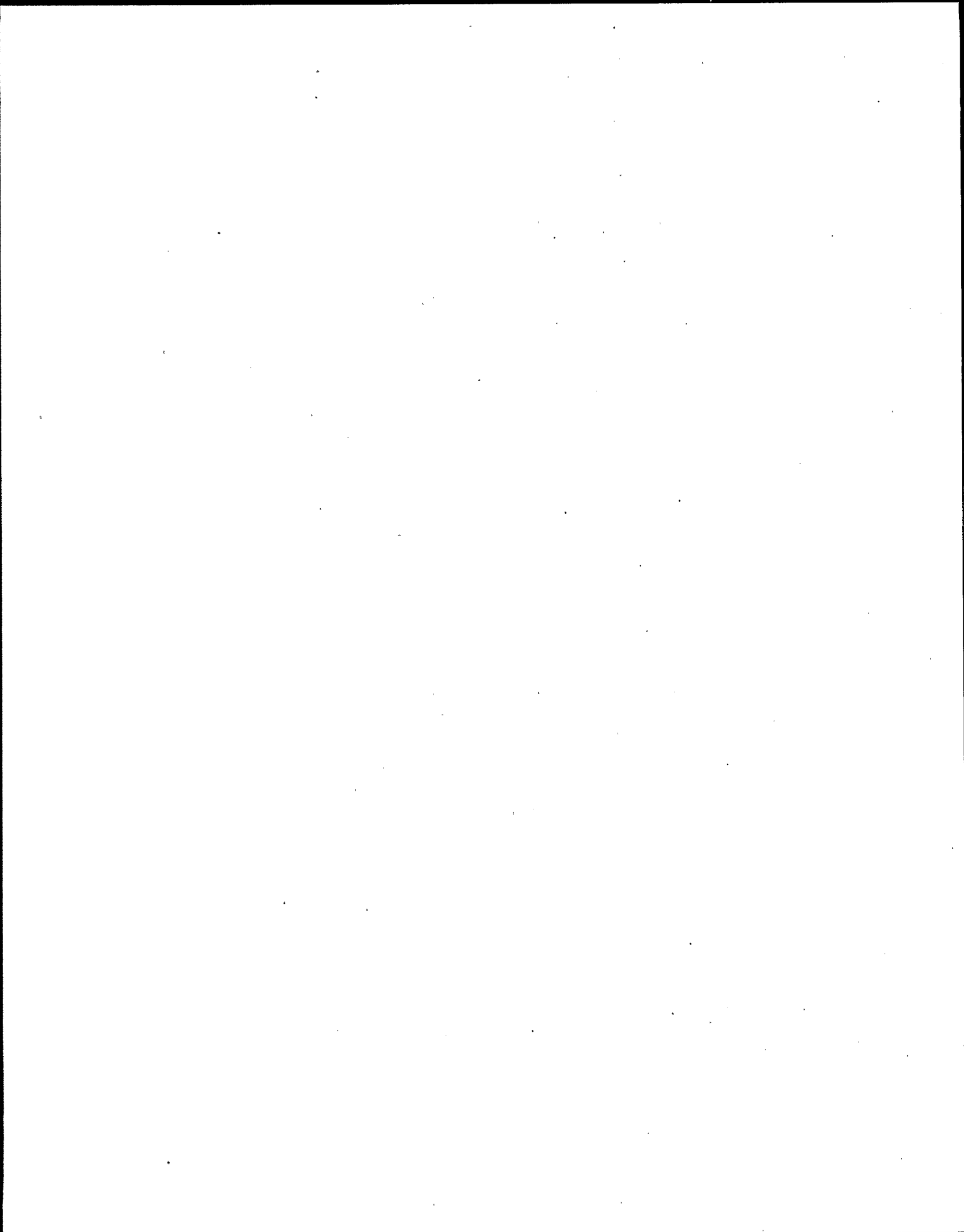
Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	3	-47.5	-52.8	3	9	5	5	0	96
CPT	4	-4.5	-42.8	655	225	0	575	39	3,657
CPT	5	-36.3	-74.6	0	0	0	0	0	7
CPT	8	59.4	13.7	1,860	1,023	30	2,680	27	13,724
CPT	9	-51.3	24.9	0	0	0	0	0	25
CPT	10	63.4	58.1	34	18	1	68	0	373
CPT	11	-16.0	16.5	3	31	0	85	39	1,258
CPT	12	64.7	35.9	717	261	202	416	145	5,252
CPT	13	108.7	11.5	2,429	2,444	0	4,684	93	26,389
CPT	14	19.0	-8.9	4,782	1,838	0	3,248	98	18,339
CPT	15	14.3	15.4	41	51	3	4	2	577
CPT	17	9.1	33.8	3	0	2	0	0	39
CPT	18	-4.3	-61.9	0	2	0	0	0	20
CPT	19	52.0	-40.6	2,007	762	358	728	22	9,697
CPT	20	28.5	-58.4	3,221	831	267	925	41	13,586
CPT	21	37.8	-82.8	1	1	0	0	0	7
MLP	4 - 9.5	30.5	27.4	22	27	30	160	36	2,618
MW	1	103.0	35.7	192	48	0	68	0	553
MW	3	0.0	0.0	87	14	0	0	0	245
MW	4	-17.2	-137.5	0	0	0	3	0	17

### 1/94 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	1	3	0	0	0	8
CPT	3	-47.5	-52.8	1	0	0	0	0	3
CPT	4	-4.5	-42.8	105	17	0	66	418	1,992
CPT	5	-36.3	-74.6	25	4	0	19	0	91
CPT	8	59.4	13.7	2,301	330	0	3,977	558	18,409
CPT	9	-51.3	24.9	2	5	7	7	0	122
CPT	10	63.4	58.1	3	0	0	0	0	13
CPT	11	-16.0	16.5	23	15	0	383	11	2,306
CPT	12	64.7	35.9	141	153	0	106	609	3,877
CPT	13	108.7	11.5	4,344	1,122	0	5,093	856	30,691
CPT	14	19.0	-8.9	4,724	275	0	310	17	10,032
CPT	15	14.3	15.4	6	23	0	0	0	85
CPT	17	9.1	33.8	6	25	0	3	0	84
CPT	18	-4.3	-61.9	0	4	3	3	0	126
CPT	19	52.0	-40.6	3,696	307	0	1,538	19	15,727
CPT	20	28.5	-58.4	218	1,471	0	5,600	1,081	36,006
CPT	21	37.8	-82.8	22	0	0	0	0	33
MW	1	103.0	35.7	150	1	0	1	0	222
MW	3	0.0	0.0	24	103	95	95	0	1,416
MW	4	-17.2	-137.5	5	3	0	4	0	61

### 2/95 Ground-Water Data

Well Type	Well Number	X-Coord (ft)	Y-Coord (ft)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	Naphthalene (µg/L)	Total (µg/L)
CPT	1	-8.4	-80.6	0	0	0	0	0	19
CPT	3	-47.5	-52.8	0	4	1	0	4	90
CPT	4	-4.5	-42.8	965	12	48	21	153	4,865
CPT	5	-36.3	-74.6	1	1	1	5	7	65
CPT	7	-41.9	-2.2	0	8	0	1	2	118
CPT	8	59.4	13.7	2,442	922	915	5,332	571	53,981
CPT	9	-51.3	24.9	0	1	0	0	0	1,751
CPT	10	63.4	58.1	0	1	0	1	0	37
CPT	11	-16.0	16.5	0	125	7	1	605	40,185
CPT	12	64.7	35.9	70	37	1	38	101	4,091
CPT	13	108.7	11.5	4,344	3,207	232	3,742	265	50,681
CPT	14	19.0	-8.9	71	4	2	7	0	5,025
CPT	15	14.3	15.4	406	148	541	1,553	524	34,265
CPT	17	9.1	33.8	2	98	3	3	69	64,067
CPT	18	-4.3	-61.9	2	2	7	8	9	464
CPT	19	52.0	-40.6	4,170	655	1,221	5,085	421	68,268
CPT	20	28.5	-58.4	4,893	2,647	1,915	6,332	794	86,090
CPT	21	37.8	-82.8	1	1	0	2	0	29
MW	1	103.0	35.7	1,226	592	95	876	42	11,617
MW	3	0.0	0.0	3	19	1	2	9	1,721
MW	4	-17.2	-137.5	1	1	2	6	0	53



## Appendix J

### BTEX, Naphthalene, and TPH Ground-Water Dissolved Plume Mass and Mass Center Calculations for the Layton Site

#### 7/92 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft^2)	TOC (ft)	BOC (ft)	Depth (ft)	(ft^3)	Mass	Mass	Mass	Mass	Mass	Mass
									(g)	(g)	(g)	(g)	(g)	(g)
CPT	1	-8.4	-80.6	1,464	97.4	6.71	3.02	4,220	0	0	0	0	0	0
CPT	2	54.6	-122.4	3,777				10,889	0	0	0	0	0	0
CPT	3	-47.5	-52.8	1,723	97.2	6.91	2.79	4,966	0	0	0	0	0	0
CPT	4	-4.5	-42.8	1,194	97.9	7.32	2.88	3,442	2	8	35	167	0	764
CPT	5	-36.3	-74.6	2,168	97.1	6.65	2.90	6,251	0	0	0	0	0	1
CPT	6	108.7	55.4	1,270	98.9	plugged		3,663	0	0	0	0	0	0
CPT	7	-41.9	-2.2		96.9	6.75		0	0	0	0	0	0	0
CPT	8	59.4	13.7	1,969	99.6	8.86	2.36	5,676	105	102	67	276	17	1,231
CPT	9	-51.3	24.9	3,814	97.1	7.33	2.10	10,996	0	43	0	0	0	248
CPT	10	63.4	58.1	1,386	98.2	7.58	3.17	3,997	0	0	0	0	0	35
CPT	11	-16.0	16.5		97.4	6.65	3.20	0	0	0	0	0	0	0
CPT	12	64.7	35.9	899	99.0	8.24	3.31	2,592	55	20	108	379	1	2,074
CPT	13	108.7	11.5	3,266	99.7	9.30	2.71	9,417	1,058	1,830	435	2,281	3	11,592
CPT	14	19.0	-8.9	850	98.5	7.68	2.41	2,451	242	218	73	329	16	1,621
CPT	15	14.3	15.4	1,470	98.1	7.12	3.29	4,239	78	16	169	575	1	2,941
CPT	16	26.2	-35.4	1,495	98.6			4,311	726	455	164	747	26	3,701
CPT	17	9.1	33.8		97.7	6.80	3.13	0	0	0	0	0	0	0
CPT	18	-4.3	-61.9	672	97.7	7.00	4.13	1,936	0	0	0	0	0	1
CPT	19	52.0	-40.6		99.5	8.94	3.09	0	0	0	0	0	0	0
CPT	20	28.5	-58.4	1,655	98.4	7.85	1.89	4,771	764	578	271	1,253	74	5,659
CPT	21	37.8	-82.8	2,874	98.8	8.20	2.83	8,285	0	0	0	0	0	32
MLP	4 - 9.5	30.5	27.4		98.5	7.24	6.95	0	0	0	0	0	0	0
MLP	4 - 9.0	31.2	28.1	3,584	98.5	7.00	6.95	10,332	0	26	15	63	48	4,526
MLP	4 - 7.5	30.0	28.0		98.4	6.90	0.61	0	0	0	0	0	0	0
MLP	5 - 9.5	-7.3	-14.3		97.7	7.21	0.20	0	0	0	0	0	0	0
MLP	5 - 9.0	-7.3	-14.3		97.8	7.15	0.40	0	0	0	0	0	0	0
MLP	5 - 7.5	-7.2	-15.4		97.8	7.13		0	0	0	0	0	0	0
MLP	6 - 9.0	-59.9	-3.2	1,502	96.7	6.18	1.23	4,331	0	0	0	0	0	6
MLP	6 - 8.5	-59.9	-4.2		96.8	2.34		0	0	0	0	0	0	0
MLP	6 - 7.5	-59.8	-5.3		96.8	6.80		0	0	0	0	0	0	0
MW	1	103.0	35.7	899	99.7	8.49	8.00	2,591	10	4	2	0	0	29
MW	3	0.0	0.0	1,414	97.5	6.70	9.29	4,075	99	9	33	24	6	387
MW	4	-17.2	-137.5	1,795	96.2	5.89	9.61	5,176	0	0	0	0	0	1
						Max Depth =	9.61	Totals =	3,140	3,309	1,372	6,093	192	34,849

# 7/92 Ground-Water Data (continued)

Location	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		x	y	x	y	x	y	x	y	x	y	x	y
Designation		(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)
CPT	1	0	0	0	0	0	0	0	0	0	0	0	0
CPT	2	0	0	0	0	0	0	0	0	0	0	0	0
CPT	3	0	0	0	0	0	0	0	0	0	0	0	0
CPT	4	-10	-92	-34	-329	-158	-1,513	-746	-7,143	-1	-12	-3,414	-32,673
CPT	5	0	0	0	0	0	0	0	0	0	0	-26	-53
CPT	6	0	0	0	0	0	0	0	0	0	0	34	17
CPT	7	0	0	0	0	0	0	0	0	0	0	0	0
CPT	8	6,218	1,437	6,065	1,402	4,002	925	16,390	3,789	1,003	232	73,173	16,916
CPT	9	0	0	-2,218	1,079	0	0	0	0	0	0	-12,701	6,180
CPT	10	0	0	0	0	0	0	0	0	0	0	2,246	2,058
CPT	11	0	0	0	0	0	0	0	0	0	0	0	0
CPT	12	3,590	1,991	1,273	706	6,999	3,882	24,535	13,607	60	33	134,233	74,443
CPT	13	115,027	12,127	198,929	20,973	47,240	4,980	247,907	26,136	365	38	1,260,055	132,845
CPT	14	4,611	-2,148	4,147	-1,932	1,392	-649	6,271	-2,922	297	-138	30,850	-14,372
CPT	15	1,117	1,198	235	253	2,420	2,596	8,231	8,829	18	19	42,117	45,175
CPT	16	19,010	-25,668	11,920	-16,095	4,299	-5,805	19,563	-26,414	668	-902	96,928	-130,871
CPT	17	0	0	0	0	0	0	0	0	0	0	0	0
CPT	18	0	0	0	0	0	0	0	0	0	0	-4	-58
CPT	19	0	0	0	0	0	0	0	0	0	0	0	0
CPT	20	21,789	-44,619	16,478	-33,743	7,738	-15,846	35,730	-73,167	2,109	-4,319	161,426	-330,561
CPT	21	0	0	0	0	0	0	0	0	0	0	1,196	-2,621
MLP	4 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 9.0	0	0	813	733	470	423	1,954	1,760	1,506	1,357	141,243	127,214
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	-382	-20
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	1,035	359	369	128	161	56	0	0	0	0	2,999	1,039
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	0	0	0	0	0	0	0	0	0	0	-10	-81
Totals=		172,388	-55,414	237,977	-26,826	74,564	-10,950	359,836	-55,525	6,025	-3,693	1,929,963	-105,421
CoM (ft.ft)=		55	-18	72	-8	54	-8	59	-9	31	-19	55	-3



# 12/92 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col.	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft <sup>2</sup> )	TOC (ft)	BOC (ft)	Depth (ft)	(ft <sup>3</sup> )	Mass	Mass	Mass	Mass	Mass	Mass
CPT	1	-8.4	-80.6	3,344	97.4	6.71	2.28	10,522	0	0	0	0	0	1
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	1,671	97.2	6.91	3.28	5,258	7	9	5	10	0	58
CPT	4	-4.5	-42.8	945	97.9	7.32	3.11	2,974	227	161	87	284	1	1,341
CPT	5	-36.3	-74.6	3,586	97.1	6.65	3.39	11,287	0	1	0	0	0	11
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2		96.9	6.75		0	0	0	0	0	0	0
CPT	8	59.4	13.7	1,719	99.6	8.86	2.35	5,410	924	698	440	1,516	87	11,960
CPT	9	-51.3	24.9	3,482	97.1	7.33	2.38	10,957	4	6	2	7	3	46
CPT	10	63.4	58.1		98.2	7.58		0	0	0	0	0	0	0
CPT	11	-16.0	16.5		97.4	6.65		0	0	0	0	0	0	0
CPT	12	64.7	35.9	2,699	99.0	8.24	3.33	8,493	354	37	134	573	16	3,689
CPT	13	108.7	11.5	2,538	99.7	9.30	2.80	7,987	549	757	84	1,347	10	7,778
CPT	14	19.0	-8.9	956	98.5	7.68	2.45	3,009	629	525	96	760	3	3,564
CPT	15	14.3	15.4	2,884	98.1	7.12	3.26	9,075	106	2	113	221	11	2,192
CPT	16	26.2	-35.4	849	98.6			2,671	539	248	161	574	11	2,775
CPT	17	9.1	33.8		97.7	6.80	3.10	0	0	0	0	0	0	0
CPT	18	-4.3	-61.9	672	97.7	7.00	4.39	2,113	0	0	0	0	0	8
CPT	19	52.0	-40.6	3,227	99.5	8.94	3.35	10,155	807	258	212	1,736	83	9,367
CPT	20	28.5	-58.4	772	98.4	7.85	2.11	2,428	378	338	72	646	45	3,603
CPT	21	37.8	-82.8	6,253	98.8	8.20	3.03	19,679	0	1	0	0	0	7
MLP	4-9.5	30.5	27.4		98.5	7.24		0	0	0	0	0	0	0
MLP	4-9.0	31.2	28.1		98.5	7.00		0	0	0	0	0	0	0
MLP	4-7.5	30.0	28.0		98.4	6.90		0	0	0	0	0	0	0
MLP	5-9.5	-7.3	-14.3	761	97.7	7.21	0.55	2,394	248	38	28	373	20	1,478
MLP	5-9.0	-7.3	-14.3		97.8	7.15	0.67	0	0	0	0	0	0	0
MLP	5-7.5	-7.2	-15.4		97.8	7.13		0	0	0	0	0	0	0
MLP	6-9.0	-59.9	-3.2		96.7	6.18	1.21	0	0	0	0	0	0	0
MLP	6-8.5	-59.9	-4.2	1,713	96.8	2.34		5,390	13	9	6	18	1	94
MLP	6-7.5	-59.8	-5.3		96.8	6.80		0	0	0	0	0	0	0
MW	1	103.0	35.7	2,158	99.7	8.49	8.01	6,792	102	26	86	100	0	637
MW	3	0.0	0.0	846	97.5	6.70	9.39	2,662	39	5	2	6	6	159
MW	4	-17.2	-137.5		96.2	5.89	10.49	0	0	0	0	0	0	0
Max Depth =							10.49	Totals =	4,926	3,121	1,528	8,170	296	48,767

# 12/92 Ground-Water Data (continued)

Location Designation	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)
CPT	1	0	0	-2	-19	0	0	0	0	0	0	-5	-48
CPT	2	0	0	0	0	0	0	0	0	0	0	0	0
CPT	3	-316	-351	-405	-450	-220	-245	-455	-506	0	0	-2,770	-3,081
CPT	4	-1,013	-9,697	-717	-6,867	-388	-3,709	-1,270	-12,153	-4	-35	-5,290	-57,338
CPT	5	0	0	-48	-98	0	0	0	0	0	0	-383	-787
CPT	6	0	0	0	0	0	0	0	0	0	0	0	0
CPT	7	0	0	0	0	0	0	0	0	0	0	0	0
CPT	8	54,905	12,693	41,461	9,585	26,124	6,039	90,095	20,829	5,161	1,193	710,802	164,327
CPT	9	-184	90	-331	161	-102	50	-350	170	-137	67	-2,353	1,145
CPT	10	0	0	0	0	0	0	0	0	0	0	0	0
CPT	11	0	0	0	0	0	0	0	0	0	0	0	0
CPT	12	22,920	12,711	2,381	1,320	8,667	4,807	37,080	20,564	1,044	579	238,710	132,385
CPT	13	59,681	6,292	82,271	8,674	9,169	967	146,377	15,432	1,106	117	845,420	89,131
CPT	14	11,968	-5,575	9,993	-4,655	1,832	-854	14,468	-6,740	58	-27	67,842	-31,604
CPT	15	1,519	1,630	33	35	1,623	1,740	3,160	3,390	155	166	31,391	33,670
CPT	16	14,114	-19,057	6,505	-8,784	4,204	-5,677	15,033	-20,297	275	-372	72,675	-98,125
CPT	17	0	0	0	0	0	0	0	0	0	0	0	0
CPT	18	-1	-13	-1	-14	-1	-18	0	0	0	0	-35	-503
CPT	19	42,000	-32,785	13,447	-10,496	11,023	-8,605	90,297	-70,486	4,308	-3,363	487,351	-380,430
CPT	20	10,786	-22,086	9,640	-19,741	2,047	-4,192	18,432	-37,743	1,284	-2,630	102,763	-210,433
CPT	21	0	0	55	-120	0	0	0	0	0	0	274	-600
MLP	4 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	-1,802	-3,542	-277	-545	-207	-406	-2,706	-5,320	-148	-290	-10,720	-21,075
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 8.5	-755	-53	-539	-38	-346	-25	-1,096	-78	-77	-5	-5,644	-400
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	10,535	3,651	2,699	935	8,893	3,082	10,347	3,586	0	0	65,608	22,736
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	0	0	0	0	0	0	0	0	0	0	0	0
Totals =		224,357	-56,094	166,165	-31,117	72,318	-7,046	419,412	-89,353	13,027	-4,600	2,594,934	-361,030
CoM (ft.ft) =		46	-11	53	-10	47	-5	51	-11	44	-16	53	-7

### 3/93 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft <sup>2</sup> )	TOC (ft)	BOC (ft)	Depth (ft)	(ft <sup>3</sup> )	Mass	Mass	Mass	Mass	Mass	Mass
CPT	1	-8.4	-80.6	1,464	97.4	6.71	5.20	5,625	0	0	0	0	0	3
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	1,753	97.2	6.91	5.03	6,738	12	66	15	63	2	1,144
CPT	4	-4.6	-42.8	1,185	97.9	7.32	4.82	4,553	150	48	56	191	5	917
CPT	5	-36.3	-74.6	2,168	97.1	6.65	5.71	8,333	0	0	0	0	0	13
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2	1,738	96.9	6.75	1.82	6,678	6	21	11	74	8	596
CPT	8	59.4	13.7	1,565	99.6	8.86	2.92	6,016	765	456	294	1,288	93	5,542
CPT	9	-51.3	24.9	2,724	97.1	7.33	3.42	10,448	4	15	5	44	4	267
CPT	10	63.4	58.1	1,578	98.2	7.58	4.09	6,064	14	9	7	24	2	158
CPT	11	-16.0	16.5	1,108	97.4	6.65		4,259	31	104	214	1,186	96	4,535
CPT	12	64.7	35.9	795	99.0	8.24	4.55	3,056	105	18	7	141	4	910
CPT	13	108.7	11.5	2,538	99.7	9.30	3.91	9,754	1,835	2,431	718	4,353	137	43,139
CPT	14	19.0	-8.9	956	98.5	7.68	3.95	3,674	795	589	763	303	5	3,894
CPT	15	14.3	15.4	536	98.1	7.12		2,061	69	11	68	193	5	1,123
CPT	16	26.2	-35.4	849	98.6			3,262	431	256	140	583	5	2,798
CPT	17	9.1	33.8	2,009	97.7	6.80	4.47	7,719	7	5	8	11	0	171
CPT	18	-4.3	-61.9	672	97.7	7.00	6.14	2,581	0	1	0	0	0	6
CPT	19	52.0	-40.6	3,296	99.5	8.94	4.82	12,668	736	336	279	1,426	100	8,331
CPT	20	28.5	-58.4	815	98.4	7.85	3.60	3,132	620	397	173	1,014	137	8,852
CPT	21	37.8	-82.8	5,387	98.8	8.20	4.78	20,702	0	0	0	0	0	0
MLP	4 - 9.5	30.5	27.4	922	98.5	7.24		3,698	17	6	42	143	24	1,593
MLP	4 - 9.0	31.2	28.1		98.5	7.00		0	0	0	0	0	0	0
MLP	4 - 7.5	30.0	28.0		98.4	6.90	0.29	0	0	0	0	0	0	0
MLP	5 - 9.5	-7.3	-14.3		97.7	7.21	1.39	0	0	0	0	0	0	0
MLP	5 - 9.0	-7.3	-14.3		97.8	7.15	1.78	0	0	0	0	0	0	0
MLP	5 - 7.5	-7.2	-15.4		97.8	7.13	1.04	0	0	0	0	0	0	0
MLP	6 - 9.0	-59.9	-3.2		96.7	6.18		0	0	0	0	0	0	0
MLP	6 - 8.5	-59.9	-4.2		96.8	2.34		0	0	0	0	0	0	0
MLP	6 - 7.5	-59.8	-5.3		96.8	6.80	1.07	0	0	0	0	0	0	0
MW	1	103.0	35.7	2,097	99.7	8.49	9.07	8,061	418	132	19	330	8	1,830
MW	3	0.0	0.0	791	97.5	6.70	10.95	3,041	32	13	0	67	3	493
MW	4	-17.2	-137.5	4,086	96.2	5.89	12.81	15,702	9	10	4	20	13	154
Maximum Depth =							12.81	Totals =	6,058	4,923	2,822	11,457	650	86,469

### 3/93 Ground-Water Data (continued)

		Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
Location	Site	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Designation		(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)
CPT	1	0	0	-3	-32	0	0	0	0	0	0	-22	-209
CPT	2	0	0	0	0	0	0	0	0	0	0	0	0
CPT	3	-546	-607	-3,142	-3,495	-700	-779	-2,997	-3,334	-96	-107	-54,286	-60,381
CPT	4	-671	-6,422	-214	-2,045	-249	-2,381	-852	-8,153	-21	-205	-4,098	-39,228
CPT	5	0	0	0	0	0	0	0	0	0	0	-481	-988
CPT	6	0	0	0	0	0	0	0	0	0	0	0	0
CPT	7	-264	-14	-864	-46	-471	-25	-3,116	-166	-335	-18	-24,979	-1,331
CPT	8	45,461	10,510	27,078	6,260	17,482	4,042	76,527	17,692	5,517	1,275	329,358	76,143
CPT	9	-214	104	-752	366	-278	135	-2,279	1,109	-201	98	-13,702	6,667
CPT	10	916	840	557	511	414	379	1,524	1,397	99	91	10,035	9,198
CPT	11	-496	512	-1,662	1,718	-3,429	3,543	-18,968	19,601	-1,533	1,584	-72,536	74,957
CPT	12	6,803	3,773	1,176	652	433	240	9,149	5,074	289	181	58,877	32,653
CPT	13	199,431	21,026	264,297	27,844	78,013	8,225	473,154	49,884	14,918	1,573	4,689,183	494,370
CPT	14	15,139	-7,053	11,209	-5,222	14,521	-6,765	5,770	-2,688	96	-45	74,128	-34,533
CPT	15	982	1,054	155	166	967	1,038	2,769	2,971	68	73	16,087	17,255
CPT	16	11,279	-15,229	6,708	-9,054	3,689	-4,953	15,277	-20,628	134	-181	73,276	-98,936
CPT	17	68	253	46	173	76	285	101	375	0	0	1,550	5,785
CPT	18	-2	-26	-5	-71	0	0	0	0	0	0	-26	-368
CPT	19	38,270	-29,874	17,465	-13,633	14,498	-11,317	74,207	-57,926	5,225	-4,078	433,449	-338,353
CPT	20	17,694	-36,233	11,313	-23,166	4,922	-10,079	28,937	-59,255	3,905	-7,997	252,495	-517,046
CPT	21	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 9.5	528	475	194	175	1,293	1,165	4,354	3,922	732	659	48,524	43,705
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	43,034	14,913	13,561	4,700	1,944	674	34,032	11,794	794	275	188,424	65,296
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	-158	-1,259	-174	-1,388	-71	-568	-350	-2,800	-218	-1,742	-2,654	-21,211
Totals =		377,256	-43,256	346,941	-15,568	133,035	-17,142	697,237	-41,131	29,374	-8,583	6,002,603	-286,554
CoM (ft, ft) =		62	-7	70	-3	47	-6	61	-4	45	-13	69	-3

# 6/93 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col.	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft^2)	TOC (ft)	BOC (ft)	Depth (ft)	(ft^3)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
CPT	1	-8.4	-80.6	1.464	97.4	6.71	4.20	4.391	0	0	0	0	0	11
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	1.671	97.2	6.91	3.91	5.012	2	3	1	3	1	223
CPT	4	-4.5	-42.8	1.102	97.9	7.32	3.95	3.305	0	0	0	5	0	35
CPT	5	-38.3	-74.6	2.168	97.1	6.65	4.44	6.505	3	4	2	13	2	73
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2	953	96.9	6.75	2.28	2.860	0	1	1	0	0	90
CPT	8	59.4	13.7	1.556	99.6	8.86	3.12	4.668	697	393	150	1,099	66	4,758
CPT	9	-51.3	24.9	2.601	97.1	7.33	2.88	7.803	0	1	0	0	0	47
CPT	10	63.4	58.1	1.618	98.2	7.58	3.78	4.854	4	1	10	3	0	31
CPT	11	-16.0	16.5	1.101	97.4	6.65	3.70	3.303	4	6	0	193	35	831
CPT	12	64.7	35.9	839	99.0	8.24	4.00	2.517	66	10	15	86	19	619
CPT	13	108.7	11.5	2.538	99.7	9.30	3.37	7.614	1,195	1,573	343	2,226	190	13,681
CPT	14	19.0	-8.9	1.221	98.5	7.68	3.27	3.662	260	30	0	5	0	458
CPT	15	14.3	15.4	536	98.1	7.12	4.15	1,609	27	9	23	83	4	638
CPT	16	26.2	-35.4		98.6			0	0	0	0	0	0	0
CPT	17	9.1	33.8	2,009	97.7	6.80	3.95	6,026	15	13	9	6	12	553
CPT	18	-4.3	-61.9	672	97.7	7.00	5.25	2,015	0	1	0	0	0	6
CPT	19	52.0	-40.6	3,574	99.5	8.94	4.08	10,721	673	206	306	1,418	122	7,211
CPT	20	28.5	-58.4	974	98.4	7.85	2.81	2,923	430	81	53	359	27	2,807
CPT	21	37.8	-82.8	5,387	98.8	8.20	3.87	16,161	3	5	0	6	0	128
MLP	4 - 9.5	30.5	27.4	962	98.5	7.24	0.90	2,887	12	8	7	61	14	665
MLP	4 - 9.0	31.2	28.1	752	98.5	7.00	0.35	2,255	0	0	0	0	0	0
MLP	4 - 7.5	30.0	28.0		98.4	6.90	0.05	0	0	0	0	0	0	0
MLP	5 - 9.5	-7.3	-14.3		97.7	7.21	0.85	0	0	0	0	0	0	0
MLP	5 - 9.0	-7.3	-14.3		97.8	7.15	1.32	0	0	0	0	0	0	0
MLP	5 - 7.5	-7.2	-15.4		97.8	7.13	0.29	0	0	0	0	0	0	0
MLP	6 - 9.0	-59.9	-3.2	863	96.7	6.18	1.61	2,590	0	1	0	7	0	119
MLP	6 - 8.5	-59.9	-4.2		96.8	2.34		0	0	0	0	0	0	0
MLP	6 - 7.5	-59.8	-5.3		96.8	6.80	0.24	0	0	0	0	0	0	0
MW	1	103.0	35.7	2,013	99.7	8.49	8.56	6,040	296	115	37	157	6	1,140
MW	3	0.0	0.0	413	97.5	6.70	9.31	1,239	1	1	0	0	1	24
MW	4	-17.2	-137.5	4,086	96.2	5.89	10.00	12,258	0	1	0	0	1	19
Max Depth							10.00	Totals =	3,689	2,461	957	5,732	500	34,166

# 6/93 Ground-Water Data (continued)

Location	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		x (g-ll)	y (g-ll)	x (g-ll)	y (g-ll)	x (g-ll)	y (g-ll)	x (g-ll)	y (g-ll)	x (g-ll)	y (g-ll)	x (g-ll)	y (g-ll)
CPI	1	-2	-21	0	0	-3	-30	-3	-29	0	0	-96	-920
CPI	2	0	0	0	0	0	0	0	0	0	0	0	0
CPI	3	-78	-87	-146	-163	-61	-67	-130	-145	-57	-64	-10,576	-11,763
CPI	4	0	0	-2	-17	0	0	-24	-229	0	0	-156	-1,489
CPI	5	-102	-209	-129	-265	-58	-120	-485	-996	-62	-128	-2,643	-5,428
CPI	6	0	0	0	0	0	0	0	0	0	0	0	0
CPI	7	0	0	-21	-1	-25	-1	-11	-1	-8	0	-3,767	-201
CPI	8	41,417	9,575	23,359	5,400	8,923	2,063	65,311	15,099	3,943	912	282,795	65,378
CPI	9	0	0	-36	18	0	0	-25	12	0	0	-2,389	1,163
CPI	10	257	236	52	48	604	553	173	159	0	0	1,978	1,813
CPI	11	-58	60	-99	102	0	0	-3,081	3,184	-552	570	-13,289	13,733
CPI	12	4,303	2,384	627	348	950	527	5,544	3,075	1,199	685	40,075	22,225
CPI	13	129,932	13,698	170,985	18,027	37,281	3,930	241,938	25,507	20,691	2,181	1,487,082	154,780
CPI	14	4,946	-2,304	578	-269	0	0	103	-48	0	0	8,718	-4,061
CPI	15	387	415	124	133	336	360	1,184	1,270	57	61	9,131	9,794
CPI	16	0	0	0	0	0	0	0	0	0	0	0	0
CPI	17	134	500	122	455	80	298	59	220	108	401	5,008	18,688
CPI	18	-1	-14	-2	-35	0	0	-1	-12	0	0	-27	-395
CPI	19	35,025	-27,341	10,722	-8,370	15,902	-12,413	73,776	-57,590	6,364	-4,968	375,151	-292,846
CPI	20	12,278	-25,143	2,311	-4,733	1,511	-3,094	10,253	-20,995	779	-1,595	80,071	-163,965
CPI	21	121	-265	183	-402	12	-26	245	-538	0	0	4,823	-10,568
MLP	4 - 9.5	354	318	230	207	199	179	1,873	1,687	441	397	20,265	18,252
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	-30	-2	-65	-3	-23	-1	-406	-22	0	0	-7,109	-379
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	30,522	10,577	11,800	4,089	3,839	1,331	16,133	5,521	572	198	117,422	40,691
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	0	0	-10	-79	-5	-41	0	0	-11	-91	-322	-2,574
Totals =		259,405	-17,620	220,585	14,491	69,462	-6,551	412,426	-24,803	33,462	-1,440	2,392,143	-146,074
CoM (ll, ll) =		708	-5	90	6	73	-7	72	-4	67	-3	70	-4

# 9/93 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col.	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft^2)	TOC (ft)	BOC (ft)	Depth (ft)	(ft^3)	Mass	Mass	Mass	Mass	Mass	Mass
CPT	1	-8.4	-80.6		97.4	6.71		0	0	0	0	0	0	0
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	2,259	97.2	6.91	2.81	6,304	1	2	1	1	0	17
CPT	4	-4.5	-42.8	1,375	97.9	7.32	2.57	3,836	71	24	0	62	4	997
CPT	5	-36.3	-74.6	2,352	97.1	6.85	2.57	6,562	0	0	0	0	0	1
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2		96.9	6.75		0	0	0	0	0	0	0
CPT	8	59.4	13.7	1,556	99.6	8.86	2.10	4,341	229	126	4	329	3	1,687
CPT	9	-51.3	24.9	3,466	97.1	7.33	1.85	9,671	0	0	0	0	0	7
CPT	10	63.4	58.1	1,578	98.2	7.58	3.03	4,402	4	2	0	2	0	46
CPT	11	-16.0	16.5	1,458	97.4	6.65	2.65	4,068	0	4	0	10	4	145
CPT	12	64.7	35.9	795	99.0	8.24	3.11	2,219	45	16	13	26	9	330
CPT	13	108.7	11.5	2,538	99.7	9.30	2.43	7,081	487	490	0	939	19	5,290
CPT	14	19.0	-8.9	1,206	98.5	7.68	2.05	3,365	456	175	0	302	2	1,747
CPT	15	14.3	15.4	536	98.1	7.12	2.95	1,496	2	2	0	0	0	24
CPT	16	26.2	-35.4		98.6			0	0	0	0	0	0	0
CPT	17	2.1	33.8	2,009	97.7	6.80	2.95	5,604	0	0	0	0	0	6
CPT	18	-4.3	-61.9	1,273	97.7	7.00	3.83	3,551	0	0	0	0	0	2
CPT	19	52.0	-40.6	3,539	99.5	8.94	2.95	9,874	561	213	100	204	6	2,711
CPT	20	28.5	-58.4	991	98.4	7.85	1.65	2,765	252	65	21	72	3	1,064
CPT	21	37.8	-82.8	5,743	98.8	8.20	2.45	16,022	0	0	0	0	0	3
MLP	4 - 9.5	30.5	27.4	962	98.5	7.24	0.10	2,685	2	2	2	12	3	199
MLP	4 - 9.0	31.2	28.1		98.5	7.00	0.00	0	0	0	0	0	0	0
MLP	4 - 7.5	30.0	28.0		98.4	6.90	0.00	0	0	0	0	0	0	0
MLP	5 - 9.5	-7.3	-14.3		97.7	7.21	0.00	0	0	0	0	0	0	0
MLP	5 - 9.0	-7.3	-14.3		97.8	7.15	0.10	0	0	0	0	0	0	0
MLP	5 - 7.5	-7.2	-15.4		97.8	7.13	0.15	0	0	0	0	0	0	0
MLP	6 - 9.0	-59.9	-3.2		96.7	6.18	0.66	0	0	0	0	0	0	0
MLP	6 - 8.5	-59.9	-4.2		96.8	2.34		0	0	0	0	0	0	0
MLP	6 - 7.5	-59.8	-5.3		96.8	6.80		0	0	0	0	0	0	0
MW	1	103.0	35.7	2,097	99.7	8.49	7.70	5,852	32	8	0	11	0	92
MW	3	0.0	0.0	906	97.5	6.70	8.93	2,527	6	1	0	0	0	18
MW	4	-17.2	-137.5	4,345	96.2	5.89	9.90	12,129	0	0	0	1	0	6
Max Depth =							9.30	Totals =	2,148	1,131	141	1,986	61	13,792

# 9/93 Ground-Water Data (continued)

Location Designation	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)	x (g-ft)	y (g-ft)
CPT	1	0	0	0	0	0	0	0	0	0	0	0	0
CPT	2	0	0	0	0	0	0	0	0	0	0	0	0
CPT	3	-28	-31	-78	-87	-46	-51	-45	-50	0	0	-817	-908
CPT	4	-318	-3,043	-109	-1,045	0	0	-279	-2,671	-19	-180	-1,775	-16,987
CPT	5	0	0	-2	-3	0	0	0	0	0	0	-48	-98
CPT	6	0	0	0	0	0	0	0	0	0	0	0	0
CPT	7	0	0	0	0	0	0	0	0	0	0	0	0
CPT	8	13,587	3,141	7,473	1,728	216	50	19,577	4,526	197	46	100,250	23,176
CPT	9	0	0	0	0	0	0	0	0	0	0	-351	171
CPT	10	265	243	142	130	7	7	540	495	0	0	2,947	2,702
CPT	11	-5	5	-56	58	0	0	-156	162	-71	73	-2,318	2,393
CPT	12	2,915	1,616	1,061	588	821	455	1,691	938	589	327	21,350	11,840
CPT	13	52,933	5,581	53,260	5,615	0	0	102,074	10,761	2,024	213	575,069	60,628
CPT	14	8,672	-4,040	3,333	-1,553	0	0	5,890	-2,744	178	-83	33,258	-15,493
CPT	15	28	27	31	33	2	2	2	2	1	2	350	375
CPT	16	0	0	0	0	0	0	0	0	0	0	0	0
CPT	17	4	15	0	0	2	8	0	0	0	0	57	211
CPT	18	0	0	-1	-12	0	0	0	0	0	0	-8	-121
CPT	19	29,189	-22,785	11,082	-8,651	5,207	-4,064	10,588	-8,265	321	-251	141,031	-110,090
CPT	20	7,193	-14,729	1,856	-3,800	596	-1,221	2,066	-4,230	91	-187	30,340	-62,128
CPT	21	12	-26	14	-30	0	0	0	0	0	0	115	-252
MLP	4 - 9.5	50	45	62	56	70	63	371	334	84	76	6,063	5,461
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	3,276	1,135	810	281	0	0	1,152	399	0	0	9,436	3,270
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	0	0	0	0	-3	-22	-20	-160	0	0	-98	-783
Totals =		117,769	-32,846	78,878	-6,692	6,873	-4,773	143,450	-503	3,397	34	914,851	-96,632
CoM (ft.ft) =		55	-15	70	-6	49	-34	72	0	55	1	66	-7



# 1/94 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft^2)	TOC (ft)	BOC (ft)	Depth (ft)	(ft^3)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)	Mass (g)
CPT	1	-8.4	-80.6	1,491	97.4	6.71	2.94	4,370	0	0	0	0	0	1
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	2,238	97.2	6.91	2.96	6,560	0	0	0	0	0	1
CPT	4	-4.5	-42.8	1,345	97.9	7.32	2.82	3,943	12	2	0	7	47	222
CPT	5	-36.3	-74.6	2,152	97.1	6.65	3.17	6,308	4	1	0	3	0	16
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2		96.9	6.75	0.24	0	0	0	0	0	0	0
CPT	8	59.4	13.7	1,697	99.6	8.86	2.23	4,974	324	46	0	560	79	2,592
CPT	9	-51.3	24.9	3,411	97.1	7.33	1.25	9,998	0	1	2	2	0	34
CPT	10	63.4	58.1	1,622	98.2	7.58	3.03	4,753	0	0	0	0	0	2
CPT	11	-16.0	16.5	1,452	97.4	6.65	3.00	4,255	3	2	0	46	1	278
CPT	12	64.7	35.9	1,037	99.0	8.24	3.26	3,040	12	13	0	9	52	334
CPT	13	108.7	11.5	2,492	99.7	9.30	2.35	7,303	898	232	0	1,053	177	6,345
CPT	14	19.0	-8.9	1,195	98.5	7.68	2.25	3,501	468	27	0	31	2	994
CPT	15	14.3	15.4	761	98.1	7.12	3.29	2,232	0	1	0	0	0	5
CPT	16	26.2	-35.4		98.6			0	0	0	0	0	0	0
CPT	17	9.1	33.8	2,430	97.7	6.80	3.20	7,123	0	0	0	0	0	0
CPT	18	-4.3	-61.9	699	97.7	7.00	4.03	2,048	0	0	0	0	0	7
CPT	19	52.0	-40.6	3,540	99.5	8.94	2.95	10,376	1,086	90	0	452	5	4,620
CPT	20	28.5	-58.4	1,024	98.4	7.85	1.72	3,000	19	125	0	476	92	3,059
CPT	21	37.8	-82.8	4,504	98.8	8.20	2.60	13,201	8	0	0	0	0	12
MLP	4 - 9.5	30.5	27.4		98.5	7.24		0	0	0	0	0	0	0
MLP	4 - 9.0	31.2	28.1		98.5	7.00		0	0	0	0	0	0	0
MLP	4 - 7.5	30.0	28.0		98.4	6.90		0	0	0	0	0	0	0
MLP	5 - 9.5	-7.3	-14.3		97.7	7.21		0	0	0	0	0	0	0
MLP	5 - 9.0	-7.3	-14.3		97.8	7.15		0	0	0	0	0	0	0
MLP	5 - 7.5	-7.2	-15.4		97.8	7.13		0	0	0	0	0	0	0
MLP	6 - 9.0	-59.9	-3.2		96.7	6.18		0	0	0	0	0	0	0
MLP	6 - 8.5	-59.9	-4.2		96.8	2.34		0	0	0	0	0	0	0
MLP	6 - 7.5	-59.8	-5.3		96.8	6.80		0	0	0	0	0	0	0
MW	1	103.0	35.7	2,043	99.7	8.49	7.75	5,989	25	0	0	0	0	38
MW	3	0.0	0.0	914	97.5	6.70	9.22	2,678	2	8	7	7	0	107
MW	4	-17.2	-137.5	4,086	96.2	5.89	9.77	11,976	2	1	0	1	0	21
Max Depth =							9.77	Totals =	2,864	551	9	2,648	455	18,689

# 1/94 Ground-Water Data (continued)

Location Designation	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		X (g-ft)	Y (g-ft)	X (g-ft)	Y (g-ft)	X (g-ft)	Y (g-ft)	X (g-ft)	Y (g-ft)	X (g-ft)	Y (g-ft)	X (g-ft)	Y (g-ft)
CPI	1	-1	-8	-3	-32	0	0	0	-3	0	0	-9	-84
CPI	2	0	0	0	0	0	0	0	0	0	0	0	0
CPI	3	-6	-7	0	0	0	0	0	0	0	0	-28	-31
CPI	4	-52	-50	-8	-79	0	0	-33	-315	-208	-1,993	-993	-9,507
CPI	5	-163	-334	-27	-55	0	0	-126	-259	0	0	-589	-1,209
CPI	6	0	0	0	0	0	0	0	0	0	0	0	0
CPI	7	0	0	0	0	0	0	0	0	0	0	0	0
CPI	8	19,254	4,451	2,758	638	0	0	33,281	7,694	4,670	1,080	154,071	35,619
CPI	9	-25	12	-73	36	-99	48	-107	52	0	0	-1,764	858
CPI	10	26	24	0	0	0	0	4	4	0	0	113	104
CPI	11	-45	47	-28	29	0	0	-738	763	-20	21	-4,443	4,592
CPI	12	785	436	832	473	0	0	590	327	3,392	1,881	21,594	11,976
CPI	13	97,626	10,292	25,215	2,658	0	0	114,458	12,067	19,237	2,028	689,739	72,718
CPI	14	8,914	-4,153	519	-242	0	0	585	-273	32	-15	18,931	-8,819
CPI	15	5	5	21	22	0	0	0	0	0	0	77	82
CPI	16	0	0	0	0	0	0	0	0	0	0	0	0
CPI	17	0	0	0	0	0	0	0	0	0	0	0	0
CPI	18	0	0	-1	-16	-1	-11	-1	-11	0	0	-31	-452
CPI	19	56,484	-44,092	4,692	-3,662	0	0	23,505	-18,348	283	-221	240,349	-187,618
CPI	20	528	-1,082	3,564	-7,299	0	0	13,569	-27,787	2,619	-5,364	87,246	-178,658
CPI	21	312	-684	0	0	0	0	0	0	0	0	460	-1,009
MLP	4 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	2,619	908	17	6	0	0	13	4	0	0	3,877	1,343
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	-26	-210	-15	-121	0	0	-23	-182	0	0	-356	-2,846
Totals =		186,235	-34,895	37,483	-7,644	-99	37	184,978	-26,265	30,005	-2,582	1,208,243	-262,940
CoM (II,II) =		65	-12	68	-14	-11	4	70	-10	66	-6	65	-14

## 2/95 Ground-Water Data

Location		X Coord.	Y Coord.	Area	Elevation	Elevation	Water Col	Volume	Benzene	Toluene	Ethylbenzene	p-Xylene	Naphthalene	Total
Designation	Site	(ft)	(ft)	(ft^2)	TOC (ft)	BOC (ft)	Depth (ft)	(ft^3)	Mass	Mass	Mass	Mass	Mass	Mass
CPT	1	-8.4	-80.6	1,490	97.4	6.71	4.24	4,967	0	0	0	0	0	3
CPT	2	54.6	-122.4					0	0	0	0	0	0	0
CPT	3	-47.5	-52.8	1,767	97.2	6.91	3.95	5,889	0	1	0	0	1	15
CPT	4	-4.5	-42.8	1,272	97.9	7.32	3.90	4,240	116	1	6	3	18	584
CPT	5	-36.3	-74.6	2,152	97.1	6.65	4.27	7,173	0	0	0	1	1	13
CPT	6	108.7	55.4		98.9	plugged		0	0	0	0	0	0	0
CPT	7	-41.9	-2.2	1,745	96.9	6.75	1.17	5,818	0	1	0	0	0	19
CPT	8	59.4	13.7	1,737	99.6	8.86	3.19	5,791	400	151	150	874	94	8,850
CPT	9	-51.3	24.9	2,669	97.1	7.33	2.77	8,895	0	0	0	0	0	441
CPT	10	63.4	58.1	1,600	98.2	7.58	3.70	5,333	0	0	0	0	0	6
CPT	11	-16.0	16.5	1,108	97.4	6.65	3.80	3,693	0	13	1	0	63	4,202
CPT	12	64.7	35.9	1,008	99.0	8.24	4.02	3,360	7	4	0	4	10	389
CPT	13	108.7	11.5	2,492	99.7	9.30	3.25	8,304	1,021	754	55	880	62	11,915
CPT	14	19.0	-8.9	1,207	98.5	7.68	3.32	4,023	8	0	0	1	0	572
CPT	15	14.3	15.4	763	98.1	7.12	4.23	2,543	29	11	39	112	38	2,467
CPT	16	26.2	-35.4		98.6	-		0	0	0	0	0	0	0
CPT	17	9.1	33.8	2,479	97.7	6.80	3.90	8,261	0	23	1	1	16	14,984
CPT	18	-4.3	-61.9	693	97.7	7.00	5.23	2,311	0	0	0	1	1	30
CPT	19	52.0	-40.6	3,540	99.5	8.94	3.96	11,799	1,393	219	408	1,699	141	22,804
CPT	20	28.5	-58.4	1,046	98.4	7.85	2.80	3,485	483	261	189	625	78	8,495
CPT	21	37.8	-82.8	5,384	98.8	8.20	3.75	17,944	1	1	0	1	0	15
MLP	4-9.5	30.5	27.4		98.5	7.24	1.26	0	0	0	0	0	0	0
MLP	4-9.0	31.2	28.1		98.5	7.00	1.00	0	0	0	0	0	0	0
MLP	4-7.5	30.0	28.0		98.4	6.90	0.35	0	0	0	0	0	0	0
MLP	5-9.5	-7.3	-14.3		97.7	7.21	0.99	0	0	0	0	0	0	0
MLP	5-9.0	-7.3	-14.3		97.8	7.15	1.35	0	0	0	0	0	0	0
MLP	5-7.5	-7.2	-15.4		97.8	7.13	0.32	0	0	0	0	0	0	0
MLP	6-9.0	-59.9	-3.2		96.7	6.18	2.33	0	0	0	0	0	0	0
MLP	6-8.5	-59.9	-4.2		96.8	2.34	4.79	0	0	0	0	0	0	0
MLP	6-7.5	-59.8	-5.3		96.8	6.80	0.20	0	0	0	0	0	0	0
MW	1	103.0	35.7	2,043	99.7	8.49	8.51	6,810	236	114	18	169	8	2,240
MW	3	0.0	0.0	791	97.5	6.70	10.30	2,637	0	1	0	0	1	129
MW	4	-17.2	-137.5	4,086	96.2	5.89	11.11	13,618	0	0	1	2	0	20
						Max Depth =	11.11	Totals =	3,696	1,556	868	4,371	532	78,194

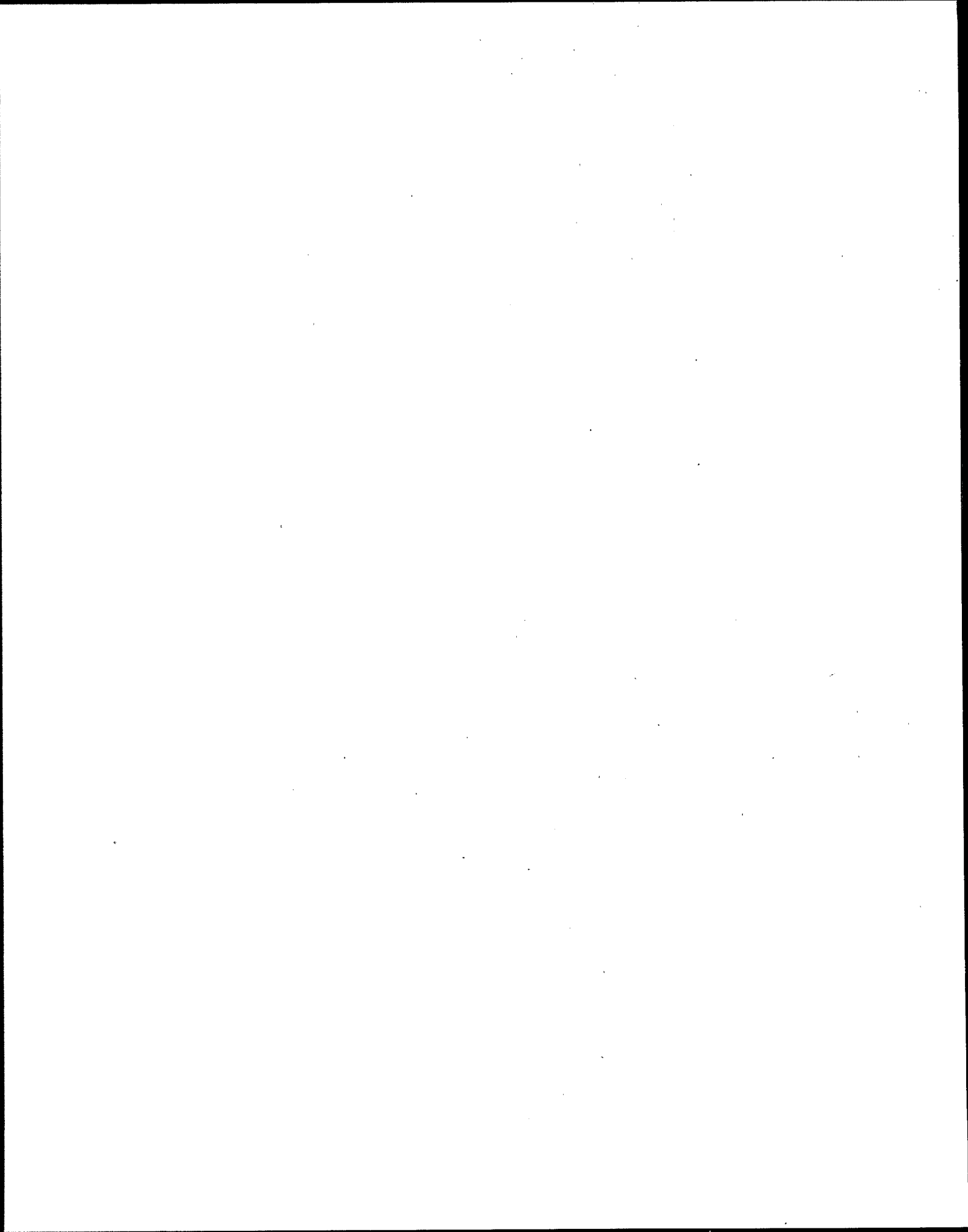
# 2/95 Ground-Water Data (continued)

Location	Site	Benzene		Toluene		Ethylbenzene		p-Xylene		Naphthalene		Total	
		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass		Center of Mass	
		x	y	x	y	x	y	x	y	x	y	x	y
Designation		(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)	(g-ft)
CPT	1	0	0	0	0	0	0	0	0	0	0	-22	-215
CPT	2	0	0	0	0	0	0	0	0	0	0	0	0
CPT	3	0	0	-32	-35	-8	-9	0	0	-32	-35	-712	-792
CPT	4	-518	-4,954	-6	-62	-26	-246	-11	-108	-82	-786	-2,610	-24,977
CPT	5	-7	-15	-7	-15	-7	-15	-37	-76	-52	-106	-480	-985
CPT	6	0	0	0	0	0	0	0	0	0	0	0	0
CPT	7	0	0	-55	-3	0	0	-7	0	-14	-1	-815	-43
CPT	8	23,794	5,501	8,984	2,077	8,915	2,061	51,953	12,011	5,564	1,286	525,970	121,596
CPT	9	0	0	-13	6	0	0	0	0	0	0	-22,602	10,998
CPT	10	0	0	10	9	0	0	10	9	0	0	354	325
CPT	11	0	0	-209	216	-12	12	-2	2	-1,012	1,046	-67,210	69,453
CPT	12	431	239	228	126	6	3	234	130	622	345	25,184	13,967
CPT	13	111,016	11,704	81,958	8,641	5,929	625	95,631	10,082	6,772	714	1,295,207	136,551
CPT	14	154	-72	9	-4	4	-2	15	-7	0	0	10,894	-5,075
CPT	15	419	449	153	164	558	598	1,601	1,717	540	579	35,328	37,893
CPT	16	0	0	0	0	0	0	0	0	0	0	0	0
CPT	17	4	16	208	775	6	24	6	24	146	546	135,757	506,617
CPT	18	-1	-8	-1	-8	-2	-28	-2	-32	-3	-36	-130	-1,878
CPT	19	72,469	-56,570	11,383	-8,886	21,219	-16,564	88,370	-68,982	7,316	-5,711	1,186,402	-926,114
CPT	20	13,772	-28,202	7,451	-15,257	5,390	-11,038	17,823	-36,496	2,235	-4,576	242,318	-496,206
CPT	21	19	-42	19	-42	0	0	38	-84	0	0	557	-1,220
MLP	4 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	4 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	5 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 9.0	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 8.5	0	0	0	0	0	0	0	0	0	0	0	0
MLP	6 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0
MW	1	24,345	8,437	11,756	4,074	1,886	654	17,395	6,028	834	289	230,683	79,941
MW	3	0	0	0	0	0	0	0	0	0	0	0	0
MW	4	-7	-53	-7	-53	-13	-106	-40	-318	0	0	-352	-2,810
Totals =		245,890	-63,571	121,827	-8,277	43,847	-24,031	272,977	-76,102	22,836	-6,447	3,593,721	-482,976
CoM (ft.ft) =		67	-17	78	-5	51	-28	62	-17	43	-12	46	-6

## Appendix K

### Dissolved Oxygen Concentrations Measured in Ground-Water Monitoring Wells and Sampling Points During the Study at the Layton Site

Well Type	Well Number	GW DO (mg/L) 4/92	GW DO (mg/L) 3/93	GW DO (mg/L) 6/93	GW DO (mg/L) 9/93	GW DO (mg/L) 1/94
CPT	1		0.9	0.2		1.7
CPT	2					
CPT	3		0.8	0.2	0.2	1.7
CPT	4		0.8	0.3	0.5	1.6
CPT	5		0.9	0.2	1.7	3.3
CPT	6		7.5			
CPT	7		0.6			
CPT	8		0.6	0.3	0.6	2.8
CPT	9		0.9	0.2	0.5	2.0
CPT	10		0.7	0.2	0.6	1.2
CPT	11		1.7	0.2	0.4	1.6
CPT	12		0.8	0.3	0.8	1.0
CPT	13		2.1	0.3	1.0	1.1
CPT	14		0.6	0.2	0.3	
CPT	15		0.6	0.2	0.3	1.0
CPT	16					3.2
CPT	17		0.6	0.2	0.5	2.1
CPT	18		1.6	0.3	0.3	1.0
CPT	19		0.8	0.3	0.5	1.7
CPT	20		0.8	0.2	0.4	0.7
CPT	21		5.4	0.2	0.4	2.1
MLP	4 - 9.5		0.6	0.3	0.1	
MLP	4 - 9.0		0.6	0.3	0.1	
MLP	4 - 7.5		0.7	0.3	0.2	
MLP	5 - 9.5		1.3	0.3	0.2	
MLP	5 - 9.0		1.6	0.2	0.8	
MLP	5 - 7.5		0.6	0.3	0.2	
MLP	6 - 9.0			0.2	0.2	
MLP	6 - 8.5			0.2		
MLP	6 - 7.5		0.8	1.0		
MW	1	0.9	0.7	2.5	1.0	1.0
MW	3	0.8	0.7	1.4	0.5	0.3
MW	4	1.2	7.5	1.3	0.9	1.5



## Appendix L

### Laboratory Nitrate, Sulfate, Iron, and Manganese Data for Ground-Water Samples Collected from the Hill and Layton Field Sites

#### Hill Site 4/92 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
M W	1	0.7	11.9		
M W	2	7.1	69.5		
M W	3	2.4	18.3		
M W	4	6.3	69.7		
M W	5	7.5	61.4		
M W	6	5.4	64.8		
Trip	Blank	0.0	0.0		
Equipment	Blank	0.0	0.0		

# Hill Site 7/92 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	2	5.5	70.6	0.12	0.02
MW	3	0.4	23.1	0.13	0.02
MW	4	5.6	69.0	0.14	0.02
MW	5	7.5	64.7	0.14	0.07
MW	6	5.6	69.3	0.14	0.02
CPT	3	8.4	57.0		
CPT	4	8.0	59.0		
CPT	5	0.0	23.7		
CPT	6	0.0	21.0		
CPT	8	0.4	23.8		
CPT	9	2.4	65.7		
CPT	10	3.9	45.6		
CPT	11	2.5	26.5		
CPT	12	0.3	54.6		
CPT	13	4.5	59.7		
CPT	14	0.5	67.7		
CPT	15	1.2	53.9		
CPT	16	2.9	49.8		
CPT	17	2.8	56.9		
CPT	18	0.7	70.8		
CPT	20	3.3	60.4		
CPT	21	0.8	44.1		
CPT	25	7.3	136.0		
CPT	26	7.8	115.8		
CPT	27	0.3	65.0		
CPT	28	6.6	107.8		
CPT	29	0.8	121.5		
CPT	30	3.5			
MLP	35d	5.5			
MLP	36s	4.6	41.4		
MLP	37d	1.9	57.4		
MLP	39s	2.1	28.5		
MLP	40m	0.4	92.4		
MLP	41m	0.4	55.0		
Equipment	Blank			0.08	0.01



# Hill Site 2/93 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	2			0.03	0.00
MW	3			0.09	0.35
MW	4			0.02	0.00
MW	5			0.00	0.01
MW	6			0.03	0.00
CPT	4			0.07	0.00
CPT	5			0.30	0.48
CPT	6			0.30	0.62
CPT	8			0.00	0.20
CPT	9			0.02	0.39
CPT	10			0.04	0.22
CPT	11			0.00	0.21
CPT	12			0.10	0.80
CPT	13			0.03	0.24
CPT	14			0.01	0.27
CPT	16			0.03	0.00
CPT	17			0.00	0.00
CPT	18			0.03	0.33
CPT	20			0.60	0.36
CPT	21			0.00	0.00
CPT	25			0.03	0.36
CPT	26			0.00	0.00
CPT	27			0.04	0.73
CPT	28			0.00	0.01
CPT	29			0.03	0.68
CPT	30			0.03	0.00
CPT	31			0.03	0.03
CPT	32			0.01	0.03
CPT	33			0.01	0.37
CPT	34			0.03	0.00
MLP	35s			0.00	0.00
MLP	35d			0.00	0.01
MLP	36s			0.00	0.01
MLP	36m			0.00	0.01
MLP	36d			0.02	0.30
MLP	37s			0.00	0.00
MLP	37m			0.03	0.02
MLP	37d			0.02	0.02
MLP	38s			0.05	0.01
MLP	38d			0.04	0.54
MLP	39s			0.01	0.00
MLP	39m			0.12	0.01
MLP	39d			0.16	0.01
MLP	40s			0.91	0.70
MLP	40m			0.80	1.03
MLP	41s			0.00	0.02
MLP	41m			0.02	0.13
MLP	41d			0.40	1.40
CPT	42			0.03	0.16
MLP	44s			0.00	0.04
MLP	44m			0.00	0.03
MLP	44d			0.02	0.05
Equipment	Blank			0.00	0.00

# Hill Site 6/93 Data

Sample ID		NO3 (mg/L)	SO4 (mg/L)	Fe (mg/L)	Mn (mg/L)
MW	2	7.6	53.2	0.00	0.00
MW	3	4.1	17.2	0.08	0.09
MW	4	8.6	66.7	0.00	0.48
MW	5	9.3	63.8	0.00	0.00
MW	6	5.0	75.3	0.02	0.00
CPT	2	16.0	64.4	0.00	0.01
CPT	3	21.0	50.0	0.24	0.00
CPT	4	11.0	54.4	0.01	0.60
CPT	5	9.9	25.1	0.00	0.24
CPT	6	1.5	11.7	0.00	0.00
CPT	8	0.0	13.6		
CPT	9	7.7	40.6	0.00	0.18
CPT	10	15.3	27.4	0.78	0.03
CPT	11	11.9	29.6	0.00	0.03
CPT	12	0.0	48.4	0.19	0.55
CPT	13	4.2	72.2	0.00	0.39
CPT	14	6.5	20.0	0.00	0.29
CPT	15	2.2	59.5	0.01	0.48
CPT	16	11.3	36.1	0.35	0.01
CPT	17	>34.6	52.9	0.01	0.01
CPT	18	21.1	37.2	0.00	0.02
CPT	20	4.5	62.0	0.97	0.77
CPT	21	1.8	59.7	0.03	0.41
CPT	24			0.02	0.39
CPT	25	7.7	65.3	0.00	0.00
CPT	26	11.7	57.0	0.07	0.00
CPT	27	0.0	27.9	0.00	0.51
CPT	28	32.0	45.9	0.12	0.09
CPT	29	0.9	52.2		
CPT	30	5.0	62.6	0.00	0.74
CPT	31	10.8	53.4	0.00	0.00
CPT	32	5.0	70.4	0.00	0.98
CPT	33	5.3	63.7	0.00	0.25
CPT	34	13.0	52.8		
CPT	35s	3.2	10.6	0.27	0.01
CPT	35m	10.8	29.2		
MLP	35d	2.9	43.6	0.03	0.00
MLP	36s	19.7	31.5	0.00	0.01
MLP	36m	13.2	17.9	0.00	0.08
MLP	36d	19.7	31.5	0.01	0.26
MLP	37s	18.9	29.1	0.20	0.05
MLP	37m	16.4	68.9	0.08	0.10
MLP	37d	4.2	50.2	0.05	0.01
MLP	38s	15.8	51.8	0.00	0.00
MLP	38m	8.0	34.1	0.00	0.16
MLP	38d	2.1	26.3	0.00	0.00
MLP	39s	24.5	47.7	0.00	0.01
MLP	39m	18.5	40.7	0.00	0.11
MLP	39d	2.0	36.1	0.00	0.00
MLP	40s	0.0	65.3	0.00	0.00
MLP	40m	0.0	44.0	0.28	0.62
MLP	40d	12.6	67.5		
MLP	41s	0.0	41.0	0.08	0.14
MLP	41m	0.0	66.5	0.00	0.88
MLP	41d	0.0	64.2	0.07	0.96
CPT	42	6.0	71.3	0.00	0.00
CPT	43	8.3	58.8	0.01	0.00
Trip	Blank	0.0	0.0	0.00	0.00

# Hill Site 9/93 Data

Sample ID		NO3 (mg/L)	SO4 (mg/L)	Fe (mg/L)	Mn (mg/L)
MW	1				
MW	2			0.00	0.00
MW	3			0.64	0.42
MW	4			0.00	0.00
MW	5			0.00	0.00
MW	6			0.00	0.01
CPT	2			0.00	0.00
CPT	3			0.00	0.00
CPT	4			0.00	0.00
CPT	5			0.19	0.53
CPT	6			0.06	0.71
CPT	11			0.02	0.18
CPT	12			0.03	0.53
CPT	14			0.02	0.93
CPT	16			0.04	0.05
CPT	18			0.00	0.32
CPT	20			0.00	0.03
CPT	21			0.04	0.45
CPT	25			0.01	0.01
CPT	26			0.00	0.02
CPT	27			0.04	1.17
CPT	28			0.00	0.00
CPT	29			0.08	0.55
CPT	30			0.10	0.05
CPT	31			0.02	0.01
CPT	33			0.54	0.38
CPT	34			0.04	0.00
MLP	35d			0.00	0.36
CPT	42			0.00	0.12
CPT	43			0.01	7.00

# Hill Site 1/94 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	2	5.8	71.4	0.18	0.00
MW	3	0.8	39.0	0.46	0.38
MW	4	7.9	76.9	0.00	0.00
MW	5	9.2	73.7	0.06	0.00
CPT	2	8.8	76.5	0.27	0.02
CPT	3	9.6	73.2	0.04	0.02
CPT	5	0.6	9.0	2.28	0.45
CPT	6	8.5	63.1	0.15	0.00
CPT	8	3.8	45.6	0.22	0.58
CPT	9	3.1	47.6	0.29	0.54
CPT	10	7.1	57.4	0.03	0.67
CPT	11	4.7	40.7	0.18	0.07
CPT	12	0.3	65.8	0.45	0.43
CPT	13	6.2	72.4	0.06	0.08
CPT	14	0.8	26.2	0.04	0.45
CPT	15	1.7	64.4	0.03	0.17
CPT	16	4.1	59.0	0.03	0.22
CPT	18	0.4	65.2	1.61	0.45
CPT	20	7.4	69.1	0.03	0.02
CPT	21	2.3	71.1	0.05	0.29
CPT	25	8.4	75.7	0.02	0.00
CPT	26	11.1	67.7	0.04	0.00
CPT	28	0.5	5.5	1.01	0.60
CPT	29	1.9	75.1	0.09	0.60
CPT	30	8.7	78.4	0.03	0.00
CPT	31	>25.76	73.8	0.09	0.09
CPT	33	0.2	73.1	0.06	0.33
CPT	34	10.4	62.6	0.20	0.00
CPT	43	8.3	74.5	0.04	0.00
Equipment	Blank	0.0	0.0	0.05	0.00

### Layton Site 4/92 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
M W	1	1.2	41.7		
M W	3	0.4	0.0		
M W	4	9.9	57.0		
Trip	Blank	0.0	0.0		
Equipment	Blank	0.0	0.0		

### Layton Site 7/92 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
M W	1	1.2	41.7	2.76	0.98
M W	3	0.4	0.0	2.72	0.76
M W	4	9.9	57.0	0.15	0.13
CPT	1	1.1	45.5		
CPT	2	>21.1	148.5		
CPT	3	0.0	0.0		
CPT	4	0.0	0.0		
CPT	6	0.4	83.4		
CPT	7	0.3	0.0		
CPT	9	0.0	0.0		
CPT	10	0.0	46.8		
CPT	11	0.0	0.0		
CPT	12	0.3	0.0		
CPT	15	0.3	0.0		
CPT	16	0.3	0.0		
CPT	17	0.0	0.0		
CPT	19	0.3	0.0		
CPT	20	0.3	0.0		
Equipment	Blank	0.0	0.0		

# Layton Site 3/93 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	1	1.1	4.6	5.27	1.01
MW	3	0.8	7.3	1.69	0.28
MW	4	0.5	8.7	0.00	0.00
CPT	1	2.1	21.8	0.00	0.11
CPT	2				
CPT	3	6.4	16.8	0.00	0.36
CPT	4	1.0	3.4	0.00	0.11
CPT	5	>9.0	41.7	0.00	0.00
CPT	6	2.8	>117	0.00	0.57
CPT	7	0.5	4.8	0.29	0.10
CPT	8	0.3	3.9	1.06	0.37
CPT	9	0.6	4.8	0.00	0.35
CPT	10	7.7	>118	0.13	0.61
CPT	11	0.0	3.4	0.17	0.06
CPT	12	0.5	4.3	3.73	0.30
CPT	13	0.6	2.6	0.00	0.28
CPT	14	0.4	3.6	0.00	0.48
CPT	15	0.6	3.4	0.19	0.04
CPT	16	1.4	5.8	0.00	0.23
CPT	17	0.6	32.3	0.81	0.19
CPT	18	0.9	5.0	0.38	0.37
CPT	19	0.9	6.6	0.00	0.13
CPT	20	3.5	16.5	0.82	0.07
CPT	21	>16.2	>91.2	0.00	0.00
MLP	4 - 9.5	0.7	15.4		
Trip	Blank	6.8	22.8	0.00	0.00
Equipment	Blank	0.6	2.6	0.00	0.00

### Layton Site 6/93 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	1	0.6	9.8	0.03	0.09
MW	3	0.0	4.3	1.46	0.63
MW	4	0.0	4.6	0.07	0.04
CPT	1	2.5	9.1	0.27	0.35
CPT	3	1.1	21.6	0.01	0.46
CPT	4	1.4	4.6		
CPT	5	3.5	29.1		
CPT	8	1.1	3.2	0.83	0.23
CPT	9	-	2.3	0.00	0.35
CPT	10	1.1	>103	0.18	0.64
CPT	11	-	2.5	0.00	0.07
CPT	12	0.6	-	0.37	0.35
CPT	13	0.5	2.4	0.00	0.27
CPT	14	2.5	8.9	0.11	0.52
CPT	15	4.6	16.1	0.42	0.19
CPT	16	0.7	4.1		
CPT	17	-	34.0	1.46	0.22
CPT	18	0.5	3.3	1.23	0.50
CPT	19	-	4.1	0.00	0.02
CPT	20	0.5	-	0.15	0.21
CPT	21	>16.9	>89.2	1.46	

### Layton Site 9/93 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	1			1.04	1.61
MW	3			2.46	0.58
MW	4			0.56	1.88
CPT	3			0.02	0.48
CPT	4			0.23	0.10
CPT	5			0.06	0.41
CPT	8			2.25	0.32
CPT	9			0.03	0.29
CPT	10			0.14	0.72
CPT	13			0.97	0.34
CPT	14			0.04	0.13
CPT	15			0.04	0.18
CPT	17			0.00	0.09
CPT	18			0.06	0.26
CPT	19			0.00	0.07
CPT	21			0.00	0.05
MLP	4 - 9.5			0.26	0.09

# Layton Site 1/94 Data

		NO3	SO4	Fe	Mn
Sample ID		(mg/L)	(mg/L)	(mg/L)	(mg/L)
MW	1	0.7	37.9	0.98	1.45
MW	3	<0.50	5.7	2.19	0.45
MW	4	2.8	62.9	0.15	1.35
CPT	1	<0.50	17.3	0.68	0.38
CPT	3	0.0	5.3	0.52	0.48
CPT	4	<.5	<5	8.46	0.11
CPT	5	0.3	30.4	0.00	0.14
CPT	8	0.0	0.0	2.09	0.27
CPT	9	<0.50	<5.0	0.22	0.34
CPT	10	0.0	135.3	0.07	0.60
CPT	12	0.2	<5	3.99	0.23
CPT	13	0.2	<5	6.50	0.22
CPT	14	0.4	2.3	1.75	0.43
CPT	15	<0.50	<5.0	2.00	0.08
CPT	16	2.1	32.2	0.16	0.16
CPT	17	0.2	6.8	0.55	0.13
CPT	18	0.4	2.3	0.28	0.37
CPT	19	0.5	0.0	0.24	0.12
CPT	20	<0.50	<5.0	5.03	0.15
CPT	21	11.7	65.1	0.22	0.03
Equipment	Blank	<0.50	<5.0	0.00	0.00